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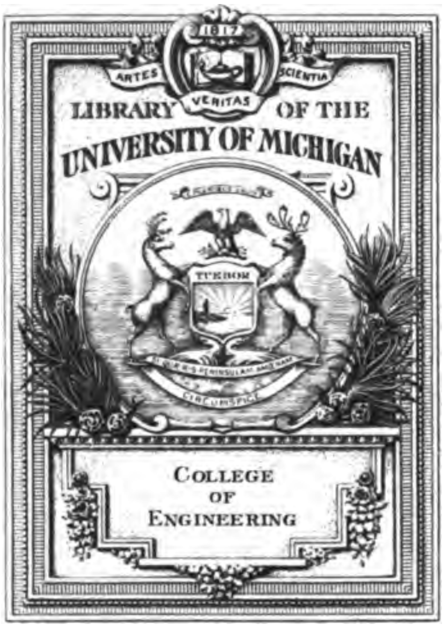
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Bennett, T. J.
Blackmore, Edward
Blanco, Major R., Argentine Navy
Blundstone, Samuel R.
Boaz, William
Boys, Henry, Admiral
Bowden-Smith, Rear-Admiral N., R.N.
Bramwell, Sir Frederick, Bart., D.C.L., F.R.S. (Vice-President)
Brand, J. Arthur
Brassey, The Right Hon. Lord, K.C.B. (President)
Brassey, The Hon. Thomas A.
Brereton, C. A.
Brereton, Robert P.
Broughton-Thompson, R. H.
Brown, A. H.
Brunel, H. Marc
Bryant, Henry
Burnet, Lindsay

Campbell-Thompson, J.
Canter, William James, R.N.
Carttar, Edward Arundel
Cay, Matthew
Chapman, Henry
Chapman, Walter
Chatfield, Alfred J., Admiral, C.B.
Chubb, Richard
Churchill, James D.
Clark, John
Clark, John A.
Cleghorn, Alexander
Cleveland, Rear-Admiral Henry F.
Cobb, George H.
Cohan, E. A.
Cohen, Arthur, Q.C.
Cohn, A.
Collin, D.
Colomb, P. H., Rear-Admiral, R.N.
Commerell, Admiral of the Fleet Sir J. E., G.C.B., V.C.
Cookes, T. S.
Cooper, J. H., Colonel
Corry, John (Assoc. Mem. Council)
Cotterill, Professor J. H., M.A., F.R.S. (Assoc. Mem. Council)
Cowles, W. Sheffield, Lieut.-Com., U.S. Naval Attaché
Crease, John Frederick, Maj.-Gen., R.M.A., C.B.
Crofton, Edward
Cross, William
Crowder, T. W., Capt.
Custance, Reginald, Capt. R.N.

Da Costa, S. J.
Darling, John
De Cuverville, J. De Cavelier, Le Vice-Amiral, French Navy
De Gelder, W. H. M., U.S.N.
De Horsey, Algernon F.R., Admiral
Dempster, John
Denny, John McA.
Dickinson, C. F.
Dixon, James
Donaldson, William A.
Donkin, Richard Sims, M.P.
Dryhurst, A. G.
Dunell, George R.

Eckart, William R., C.E.
Eidlitz, Leopold, jun.
Ellis, W. H. M.
Ellis, Chas. Ed.
Emory, W. H., Captain, U.S.N.
Evans, David
Evans, Frederick R.
Evans, R. D., Commander, United States Navy

Fairbrass, Herbert W.
Fairfax, Joseph S.
Fanshawe, Sir Edward Gennys, G.C.B., Admiral
Fassella, Cavaliere Felice
Fenwick, Fenwick J.
Fenwick, W.
Fitzgerald, D. W.
FitzGerald, C. C. P., Captain, R.N.
Flemmich, G. F.
Fowler, Sir John, K.C.M.G., F.R.S., Bart.
Fox, Samson
Fradgley, J. B.
Fraissinet, Alfred
Frear, Hugo P.
Fremantle, Rear-Admiral The Hon. E. R., K.C.B., C.M.G.
Froud, A. G.
Froude, R.E. (Assoc. Mem. Council)

Garcia, Manuel José, Lieut.-Com., Argentine Navy
Gervais, A., Admiral, French Navy
Gilchrist, Percy C.
Goodridge, Capt. John J. L.
Gough, Kedgwin E. K.
Grainger, Thomas L.
Graves, W. T.
Green, R. H.
Grenet, F. E., Captain, Italian Navy
Gross, Felix

Hadfield, R. A.
Hamilton, The Right Hon. Lord George, M.P. (Vice-President)
Hamilton, Sir R. Vesey, Admiral, K.C.B.
Hamilton, W. Des Vœux, Captain, R.N.
Harfield, William Horatio
Harris, John Henry
Hartmann, August
Hartmann, Wilhelm
Hay, James M.
Hay, The Right Hon. Lord John, G.C.B., Admiral of the Fleet (Vice-President)
Hay, The Right Hon. Sir John Dalrymple, Bart., K.C.B., D.C.L., F.R.S., Admiral (Vice-President)
Healey, Edward C.
Henderson, George T.
Henderson, Thomas
Hibbs, F. W.
Hick, Thomas
Hill, Arnold F.
Hill, E. J.
Hill, Sir E. S., Colonel, K.C.B., M.P.
Hodges, Petronius
Hodgkinson, George
Hodd, Thos. Hy.
Hogarth, A. P.
Holland, Arthur, M.A.
Holland, S. C., Captain, R.N.
Holt, H. F.
Holzapfel, A. C. A.
Holzapfel, Max
Hopkins, Sir John Ommaney, Vice-Admiral, K.C.B.
Houldsworth, William
Hovgaard, Lieut. G. W. (Royal Danish Navy)
Howard, J. William
Howell, J. Bennett
Huddart, James
Hurndall, W. F.
Hutchinson, Walter E.

Ihlen, Nils, Admiral, Royal Norwegian Navy
Ismay, Thomas H. (Assoc. Mem. Council)
Ivanoff, N., Lieut.-Col., Imperial Russian Navy

Jack, Thomas
Jackson, J. E.
Jacobsen, Waldemar
Jamieson, John D.
Jaques, Capt. W. H., late United States Navy
Jarman, Stephen, R.N.R.
Johnson, Arthur
Johnstone, Lieut. George, R.N.R.
Jones, Sir Lewis T., G.C.B., Admiral

Kemp, Dixon
King, Percy Liston
Kirkaldy, John
Kirkaldy, Thomas
Knott, James
Knudson, Gunnar
Korshicoff, Nicolas, General, Imperial Russian Navy

Lagerwall, J. M., Captain, Royal Swedish Navy
Laidley, R. W.
Latorre, Juan José, Rear-Admiral Chilian Navy
Laws, George A.
Le Clerc, F., Capt., Naval Attaché to French Embassy
Le Doux, Richard
Lee, John D.
Lewes, Professor Vivian B., F.I.C., F.C.S. (Assoc. Mem. Council)
Likhatchof, J., Vice-Admiral, Imperial Russian Navy
Lilburn, James
Linley, Joseph A.
Linnard, Joseph Hamilton
Lister, W. N., Lieut., R.N.R.
Little, George H.
Little, Henry W.
Littleboy, C. W.
Long, A. E.
Lund, William
Lyster, G. Fosbery
Lloyd, Capt. E. H., R.N.

MacDonnell, Alexander
MacDougall, Dugald
MacIlwraith, A.
Mackay, Sir J. L., K.C.I.E.
Marr, James
Marshall, Frank T.
Marshall, Robert
Martin, Sir Wm. F., Bart., G.C.B., Admiral
Martin, W. Tyson
Massey, W. A.
McGregor, J.
McGregor, Allan Gow
Mechan, H.
Medhurst, J. D.
Meyer, John
Milburn, J. D.
Miller, Gordon
Milne, Sir Alexander, Bart., G.C.B., Admiral of the Fleet (Vice-President)
Moore, W. J. P.
Morant, George Digby, Rear Admiral (Assoc. Mem. Council)
Morrison, James
Mullan, F. C.

Napier, James
Neal, William George
Neilson, John
Neilson, Colonel Walter M.
Newey, Capt. Samuel C.
Newman, A. R.

Nicolson, Sir Frederick W. E., Bart., C.B., Admiral (Vice-President)
Noad, Lewis.
Noel, G. H., Captain, R.N. (Assoc. Mem. Council)
Northbrook, The Right Hon. the Earl, G.C.S.I. (Vice-President)

Panton, Charles E.
Parker, J. Henry
Parsons, P. R.
Pascoe, J. R.
Perkins, James
Pearce, E. A. J.
Persico, Capt. Alberto, Royal Italian Naval Attaché
Petersen, Otto L.
Petersen, William
Pharo, Jacob C.
Pilcher, Percy S.
Pile, Charles H.
Pinheiro, C. José de Aranjo, Imperial Brazilian Navy
Plater, H. R. F.
Potter, John
Pover, W. T.
Price, Arthur, R.N.
Preston, F. G. Panizzi

Ramsden, Sir James (Vice-President)
Ratliffe, G.
Rawson, Robert, Hon. Mem. Manchester Literary and Philosophical Society
Reincke, Roderich L.
Rendel, Hamilton Owen
Rennie, Keith T.
Ridley, John H.
Riley, James (Assoc. Mem. Council)
Robinson, Capt. John C.
Robson, George
Rock, G. H.
Rogestvensky, Capt. Z., Imperial Russian Naval Attaché
Rogerson, John
Ropner, R., jun.
Rothe, H. P., Commodore, Danish Royal Navy
Rowan, David
Rowley, Charles J., Rear-Admiral
Rugg, C. H.
Ruhm, T. F.

Samuelson, Sir Bernhard, Bart., M.P., F.R.S.
Saunders, James Ebenezer
Saxe-Coburg and Gotha, H.R.H. the Duke of, K.G., K.T., K.P., G.C.B., G.C.S.I., G.C.M.G., G.C.I.E., Admiral of the Fleet (Vice-President)
Schüler, F.
Scott, Colin W.
Scott, Ernest
Scott, George J.
Seaman, Charles J.
Serena, Arthur
Seymour, Edward Hobart, Rear-Admiral, C.B.
Spencer, Right Hon. Earl, K.G. (Vice-President)
Spencer, John W.
Starnes, J. S.
Stewart, Andrew
Stewart, Walter J. L.
Stumore, Frederick
Suart, Alfred

Tagg, George John
Tapscott, G. L.
Taylor, D. W., U.S.N.
Taylor, George W.
Temperley, Joseph
Terry, Stephen H.
Thomasson, Lucas
Thompson, Stephen
Thomson, Andrew
Thubron, E. Blakelock
Thurston, Robert H., Professor
Tindall, William H. (Vice-President)

Urtubey, Clodomiro, Rear-Admiral, Argentine Navy

Van Raalte, J.
Vavasseur, Josiah
Vogelsang, Alexander

Waddilove, Charles L. D., Admiral
Wait, A. McL.
Watson, H. Burnett
Watson, Henry James
Watson, W.
Watson, William
Watt, John
Watts, Edmund H.
Westmacott, A.
Westmacott, Percy G. B.
Wharton, William J. L., Captain, R.N., F.R.S.
White, Robert
Willes, Sir George O., Admiral, K.C.B.
Williams, Samuel
Williamson, J.
Williamson. R. H.
Wilmot, S. Eardley, Captain, R.N.
Wingfield, G. T., Com., R.N.
Wise, William Lloyd
Woodall, J. W.
Woodward, Joseph J.

Younger, Robert L.
Younghusband, Frank C.

Ziffer, J. H.

OBJECTS OF THE INSTITUTION.

The objects of the Institution of Naval Architects—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads:—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our Navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other inquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. The Institution of Naval Architects shall consist of four classes, viz., Members, Associates, Honorary Members, and Honorary Associates.

2. *Members.*—The class of Members shall consist exclusively of Naval Architects, and Marine Engineers conversant with Naval Architecture.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons who are eligible as Members, and upon whom the Council may see fit to confer an honorary distinction.

5. *Honorary Associates.*—The Class of Honorary Associates shall consist of persons who have contributed to the improvement of ships or their equipment, and upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

6. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council), a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

7. A General Meeting of the Members and Associates of the Institution shall be held annually before Easter in each year; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

8. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the election of Associate Members of Council, the Treasurer, and the Auditors.

9. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

10. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

11. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present to preside.

12. The Chairman at any Meeting of the Council of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

13. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

14. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members lasts, be entitled to sit and vote with the Members of Council.

15. *Members of Council.*—Members only shall be eligible for election as Members of Council at the Annual General Meeting.

16. *Associate Members of Council.*—Associates only shall be eligible for election as Associate Members of Council at the Annual General Meeting.

17. The Direction and Management of the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

18. The Council shall meet as often as the business of the Institution requires, and at every Meeting five Members of the Council shall form a *quorum.*

19. The Council may appoint Committees to report to them upon special subjects.

20. All questions shall be decided in the Council by vote; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding meeting of the Council.

21. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and, after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

22. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

23. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide for properly conducting its business in all cases of emergency, such as the death or resignation of Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution.

24. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council and are still Members of the Institution, shall be eligible for election as Treasurer.

25. *Trustees.*—There shall be four Trustees, two of whom shall be the President and Treasurer of the Institution for the time being. The remaining two shall be appointed by, and hold office at the pleasure of the Council. In the names of these trustees, under the direction of the Council of the Institution, all securities shall be taken and investments made, the whole of such property being notwithstanding subject to the disposition of the Council, and the order of the Council in writing, signed by the Chairman of the Meeting and countersigned by the Secretary, shall be obligatory upon and full authority for the Trustees.

26. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

27. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

28. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

29. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

30. In each year six Ordinary and two Associate Members of Council shall retire, unless before the date of drawing up the Balloting Lists for the election of the Council any Members of the Council shall have died or resigned, in which case only so many members shall retire as shall be necessary in order to make up the number to six Ordinary and two Associate Members of Council, subject always to the provisions of Rule 36. The Members who shall retire in each year shall be those who have served longest on the Council from the date of the last election, and in the event of there being several Members who have served an equal time on the Council, the order of retirement amongst these shall be alphabetical. The retiring Members shall be eligible for re-election.

31. In January of each year the Council shall meet and prepare Lists for the election of the Council for the ensuing year. These Lists shall be as follow, namely :—

1st. A List of the names of the President, Vice-Presidents, and Treasurer for the ensuing year to be submitted at the Annual General Meeting, for their election in a body.

2nd. A list of candidates to fill any vacancies in the list of Vice-Presidents that it may be intended to fill up from among the professional Members of the Institution.

3rd. Lists for the election of the Ordinary Members and Associate Members of Council.

32. No addition shall be made to the list of Vice-Presidents until, by death or resignation, their number shall have been reduced to below twenty-four, after which their numbers shall be raised to and preserved at twenty-four. The vacancies are to be filled up in such a manner that not less than one-half nor more than two-thirds of the total list of Vice-Presidents shall be professional Members of the Institution. Provided

always that the Council shall be at liberty, should special circumstances arise before the numbers shall have been reduced below twenty-four, to provide for the election of one Member and one Associate of the Institution as Vice-Presidents.

33. When any vacancy occurs in the list of Vice-Presidents which it is intended to fill by the election of a professional Member of the Institution, the election shall be by voting papers issued to all Members of the Institution. The candidates to fill the vacancy shall be selected by the Council in the month of January from among the existing or past Members of Council. The number of candidates shall not be less than two for each vacancy, but shall not otherwise be limited. The voting papers shall be issued to the members at the same time as the voting papers for the election of Members of Council, and shall be subject to the same regulations and scrutiny as these latter, as provided for by Rules 37, 38, 39, 40.

34. After having been once elected by voting papers, the Vice-Presidents will be subject to re-election every year in a body at the Annual Meetings.

35. When any vacancy occurs in the list of Vice-Presidents which it is intended to fill by the election of an Associate of the Institution, the nomination to fill the vacancy shall be made by the Council, and the candidate nominated shall be included in the list of Vice-Presidents submitted at the Annual Meetings for election in a body.

36. No addition shall be made to the total number of Ordinary Members of the Council until, by death or resignation, their numbers shall have been reduced below twenty-four, after which their numbers shall be raised to and preserved at twenty-four. And no addition shall be made to the Associate Members of Council until, by death or resignation, their numbers shall have been reduced below eight, after which their numbers shall be raised to and preserved at eight, always exclusive of the President, Vice-Presidents, and Treasurer.

37. At the date of issuing the Syllabus of the Annual General Meetings in each year, the Lists proposed by the Council for the election of Members to fill the vacancies in the Ordinary Council for the ensuing year shall be printed, and sent to all Members to serve as Balloting Lists. These Lists shall contain, first, the names of the retiring Ordinary Members of Council at the time of the preparation of the Balloting List, together with as many new names of Members of the Institution as shall be needed to bring the number up to twice the number of vacancies, and the whole of these names shall be printed in alphabetical order. Secondly, the names of the retiring Associate Members of Council at the time of the preparation of the Balloting List, together with as many new names of Associates of the Institution as shall be needed to bring the number up to twice the number of vacancies, and these names also shall be printed in alphabetical order. From these Lists the vacancies in the Council shall be filled up. Every Member shall be at liberty to vote for as many names on each of the Lists as there are vacancies to be filled, but not for more.

38. A similar Balloting List (in which, however, the names of the Ordinary Members of Council proposed for election shall not be included) shall be printed and sent to all Associates of the Institution, to serve as a Balloting List for Associates, from which the voting for Associate Members of Council shall be taken. Every Associate shall be at liberty to vote for as many names on that List as there are vacancies to be filled, but not for more.

39. The Balloting Lists may be sent by post or otherwise to the Secretary, so as to reach him before the day and hour named for the Annual General Meeting, or they may be personally presented by the Members and Associates at the opening of the Annual General Meeting.

40. At the opening of the Annual General Meeting the order of business shall be :—

(1) To read and consider the Reports of the Council and Treasurer.

(2) To read the List of Officers and Nomination for Council for the ensuing year, proposed by the Council.

(3) The Chairman shall next put to the Meeting the List containing the names of the President, Vice-Presidents, and Treasurer for election for the ensuing year.

(4) The Chairman shall then nominate two Scrutineers (of whom one only shall be a Member of the existing or proposed Council), and shall hand to them the Ballot Boxes containing the Voting Papers for the Ordinary Members of Council and Associate Members of Council ; and

(5) The Scrutineers shall receive all Ballot Papers which may have reached the Secretary, and all others which may be presented by Members or Associates at the Meeting. The Scrutineers shall then retire and verify the Lists, and count the votes ; and shall, not later than the following day, report to the Chairman the names which have obtained the greatest number of votes, subject to the conditions of the Ballot. The Chairman shall then read the List presented by the Scrutineers, and shall declare the gentlemen named in the List to be duly elected, provided always that the List does not contain more names than there are vacancies to be filled. If, in consequence of two or more of the candidates receiving an equal number of votes, the List shall contain more names than there are vacancies, the Council shall, at their next meeting, decide which of these candidates shall be elected.

(6) After the Ballot shall have been taken, and the Scrutineers have retired, the Meeting will proceed to the other business before it.

41. The new Council and Officers shall take office immediately after the close of the Annual General Meeting.

DESIGNATION OF MEMBERS AND ASSOCIATES.

42. Any Member, Associate, Honorary Member, or Honorary Associate, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, viz., M.I.N.A. ; Assoc. I.N.A. ; Hon. Mem. I.N.A. ; Hon. Assoc. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

43. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following regulations :—

He shall submit to the Council a statement showing that he has been professionally engaged in shipbuilding or marine engineering for at least seven years in some public or private shipbuilding establishment, or marine engine works, and setting forth the grounds upon which he bases his claims to be considered a professional Naval Architect, or Marine Engineer conversant with Naval Architecture, and to be admitted as such to the Membership of the Institution. This shall be signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement ; or, in the case of persons not British born, the signatures of three Members shall be required, in confirmation of their personal knowledge of the Candidate's scientific reputation.

44. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect, or Marine Engineer conversant with Naval Architecture. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, his proposal for admission shall be submitted to the Members of the Institution (who shall have access to the applicant's statement), at an Ordinary Meeting of the Institution, for them to vote upon, the voting to be by ballot, should a ballot be demanded.

45. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon, the voting to be by ballot, should a ballot be demanded.

46. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

47. Each Member and Associate shall pay an Entrance Fee of two guineas, and an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future ones on the 1st day of January of each year. Any Member or Associate withdrawing from the Institution after that date is still liable for the amount of Subscription due on that day.

48. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

49. No person's name shall be entered on the Roll as Member or Associate of the Institution nor possess the privileges of Membership (except it be on the honorary list) until he shall have paid his first subscription or the life composition, and if the payment be delayed for more than twelve months from the date of his election, the same shall be void unless the Council otherwise direct.

50. The Secretary shall at the close of every year notify to all Members and Associates whose subscription for that year shall not have been paid, that it will be his duty to report accordingly to the Council, and he shall at the same time furnish the person whose subscription is in arrear with copies of this and the two following Rules.

51. The Secretary shall before Easter in every year lay before the Council a list of all Members and Associates whose subscriptions for the two previous years shall be still unpaid, and unless the Council shall otherwise direct, the names of those in arrear shall be expunged from the Roll of Members and Associates, and shall not be replaced without re-election in due form. Provided always that the Council shall at any time within two years therefrom have power to dispense with such re-election, and to restore the name to the Roll upon payment of all subscriptions then due, and upon cause being shown to the satisfaction of the Council why such subscriptions were not previously paid.

52. Nothing herein contained shall prejudice the right of the Institution to the legal recovering of all arrears of subscriptions up to the date of striking the name off the Roll.

53. In case the Council shall be of opinion that any Member, who has been long distinguished in his professional career, from ill-health, advanced age, or other sufficient causes, should not be called upon to continue his annual subscription, they may remit it. Also they may remit any arrears which are due from an individual, or may accept a collection of books, or drawings, or models, or other such contribution as, in their

opinion, under the circumstances of the case, may entitle the person to be enrolled as a Life Subscriber, or to enable him to resume his former rank in the Institution which may have been in abeyance from any particular causes. These cases must be considered and reported upon by a Sub-Committee named for the purpose.

54. In case the expulsion of any individual shall be judged expedient by ten or more Members, and they think fit to draw up and sign a proposal requiring such expulsion, the same being delivered to the Secretary shall be by him laid before the Council. If the Council, after due inquiry, do not find reason to concur in the proposal, no entry thereof shall be made in any Minutes, nor shall any public discussion thereon be permitted; but if the Council do find good reason for the proposed expulsion they shall direct the Secretary to address a letter to the person proposed to be expelled, advising him to withdraw from the Institution. If that advice be followed, no entry on the Minutes nor any public discussion on the subject shall be permitted; but if that advice be not followed, nor a satisfactory explanation given, the Council shall call a Special General Meeting of Members and Associates, for the purpose of deciding on the question of expulsion; and if two-thirds of the persons present at such Special General Meeting, providing the number so present be not less than thirty, vote that such individual be expelled, the Chairman of that Meeting shall declare such expulsion accordingly, and the Secretary shall communicate the same to the individual.

MEETINGS.

55. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

56. The *Transactions* of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

57. A copy of each Volume of *Transactions* shall be sent free to every Member and Associate.

58. The Secretary, under the direction of the Council, may dispose of the surplus stock of *Transactions* which have been published more than three years, at a price of not less than One Guinea a volume, provided a sufficient number remain on hand to supply the probable demand of New Members and Associates to complete their sets by the purchase of the back Volumes.

CHANGE OF ADDRESS.

59. Members and Associates are particularly requested to communicate to the Secretary any change of address.

PROCEEDINGS IN CARDIFF.

SUMMER MEETINGS OF THE THIRTY-FOURTH SESSION

OF THE

INSTITUTION OF NAVAL ARCHITECTS.

JULY 11, 12, AND 13, 1893.

INTRODUCTORY PROCEEDINGS.

RECEPTION BY THE MAYOR OF CARDIFF AND THE PRESIDENTS OF THE CHAMBER OF COMMERCE AND SHIPOWNERS' ASSOCIATION IN THE COUNCIL CHAMBER OF THE TOWN HALL, CARDIFF, TUESDAY, JULY 11, 1893.

Mr. C. A. **Heywood** (Chairman of the Executive Committee of the Reception Committee): Mr. Mayor, Mr. Wood, Mr. Cory, and Gentlemen of the Reception Committee, I have pleasure in introducing to you Sir Nathaniel Barnaby, the senior Vice-President present of the Institution of Naval Architects; Mr. Martell, the Chief Surveyor of Lloyd's Registry; Mr. White, the Director of Naval Construction; Sir James Ramsden, Admiral Boys, Dr. Elgar, and all these gentlemen around you, Members of the Institution of Naval Architects, who have done us the honour of accepting our invitation to visit this town. I have to regret, Mr. Mayor and Gentlemen, that Lord Brassey, the President, who started to come round in his yacht, the *Sunbeam*, has had to run back to Torbay through stress of weather, but his lordship has telegraphed that he will come as speedily as possible by train. With these few remarks I introduce these gentlemen to you.

Councillor W. E. **Vaughan** (the Mayor of Cardiff and Chairman of the Reception Committee): Gentlemen of the Institution of Naval Architects, in the name of the Town and Corporation which I represent, I accord you a hearty welcome to the town. We are very pleased that your Institution decided upon visiting Cardiff. You are not the first body of gentlemen of culture connected with the sciences which has visited the town. Year after year we get visits from gentlemen who are trying to do their best for the country in which they live, and who, I doubt not, find things of great interest during their visit here. I must say if there are any here—and there may be a few—who have not visited the ports on this side of the Bristol Channel for many years, they will be not a little surprised to see the great enterprise that has been manifested, and the great improvements that have taken place on this side of the Channel. When you visit our docks, and the great engineering works in the immediate neighbourhood, in which you are all interested, I think you will find that there has been, in the past few years, great improvement made in this the chief port of South Wales. Cardiff has been looked upon by many strangers merely as a little fishing village, but when you see the accommodation for ships, and the great facilities for loading and unloading vessels, the great ship-repairing yards, and the ever-increasing works connected with shipping, I am sure some of those who have little knowledge of Cardiff now will go away greatly surprised. I am pleased that the Local Committee have prepared such a fine programme. They believe that all work and no play will make even you gentlemen dull boys. I see by looking at the programme that there are adjournments from labour to refreshments, and from refreshments to labour; and, with the efforts of Mr. Heywood, the Chairman of the local Reception Committee, and Mr. Lewellen Wood, Chairman of the Chamber of Commerce, if you do not fully enjoy all the entertainments that they have provided for you, it will not be their fault. They have been most active in their labours in trying to do the best they can to entertain the Institution of Naval Architects, and it will be no fault of theirs, and through no lack of energy or enterprise on their part, if they do not succeed. I trust, gentlemen, that the inhabitants of this town will afford a hearty welcome to you, and do the best for your entertainment during the week. (Cheers.)

Mr. LEWELLEN WOOD (President of the Incorporated Chamber of Commerce, Cardiff): Gentlemen, it is my privilege to echo, and, if I may on the part of the commercial community of Cardiff, to emphasise the appropriate words of welcome spoken by our worthy Mayor. Gentlemen, there is but one feeling, and that is of self-congratulation, throughout the town upon your visit here—a feeling which is all the stronger because the names of many of your members are "familiar in our mouths as household words." I would venture to particularise one in his absence—that of Sir Edward Reed. Some of us do not quite see eye to eye with him in political affairs, but we are all alike glad that on the occasion of your visit to Cardiff the borough should be represented in Parliament by a gentleman who not only takes a high place in the annals of Naval Architecture, but shares in the distinguished honour of having laid the foundations of your valuable Society. Gentlemen, in the intervals of your graver occupation it will be our pleasurable task to make you acquainted with some of the more interesting features and more distinctive activities of our town and neighbourhood. The Mayor—very properly for a Mayor—has only enlarged upon its achievements; but we have not yet attained to that unqualified self-approbation which has, perhaps, rightly been described as the summit of earthly bliss. We are conscious that even Cardiff has its deficiencies, and one of these the members of the Institution of Naval Architects are peculiarly qualified to supply. Some of us think the conditions at Cardiff eminently favourable to the formation and growth of a great shipbuilding industry, and we welcome an opportunity of bringing those conditions under the personal notice of your members. More as to this may, perhaps, be said later on; but I have already detained you too long on this occasion. Gentlemen, although no rite of hospitality shall knowingly be omitted during your stay in Cardiff, I will not dare to say, "We'll teach you to drink deep ere you depart"; but I do predict that, when you leave us, "You shall much better know the love and duty that we bear towards you."

Sir NATHANIEL BARNABY, K.C.B. (Vice-President): Mr. Mayor and Gentlemen of the Reception Committee, we are deeply sensible of the kindness with which last year you were prepared to meet us if we had been able to come here. We are deeply sensible also of the great kindness with which you have arranged for the visit we are making here to-day. Those of us who know the gentlemen who are present feel that the Institution has sent to Cardiff, and we are very glad to be able to say so, extremely distinguished men, some as Naval Architects and Shipbuilders, and others as Marine Engineers. When you get to know their names you will find that you have present amongst you some of the foremost men in this great country, the centre of the shipbuilding industry of the world. We regret extremely that, although the Members and Associates are present in so great a force, our President is, unhappily, unable to be with us to-day. No one regrets it more than Lord Brassey himself, I am quite sure, and we all know from him what has caused his absence. We hope that he will be with us very shortly. Reference has been made to Sir Edward Reed, who, if he had been here, would have occupied the position I occupy; but he was fighting in your interests in the House of Commons last night, and that, I presume, has prevented him from getting here. I trust you will be very grateful to him for the services he rendered you last night. Mr. Mayor and gentlemen, it is, I am sure, the wish of all who are here present that I should convey to you our heartfelt thanks for the cordial reception you have been good enough to give us to-day. (Cheers.)

MEETING OF THE MEMBERS AND ASSOCIATES OF THE INSTITUTION IN THE NISI PRIUS COURT, TOWN HALL, CARDIFF, ON TUESDAY, JULY 11, 1893.

The CHAIRMAN (Sir Nathaniel Barnaby, Vice-President, K.C.B.): Gentlemen, will you allow me to say again, on behalf of the Council, how very pleased we are to see such an excellent representative gathering of the Members and Associates of our Institution present. We are, of course, all of us, disappointed at not having our President here with us. I do not propose to make any such remarks as he would doubtless have been pleased to address to us if he had been here, because we hope he will come to one of our meetings, perhaps to-morrow, and we trust he may be able to give an address to us which will satisfy our expectations. I am sure we also very much regret that Sir Edward Reed has been prevented from coming, but I hope he will be present at our dinner. My duty is to introduce to you this morning the gentlemen who are going to read the papers, and I first beg to introduce to you Mr. Martell, who will read a paper on "Points of Interest in the Construction and Repair of Vessels carrying Oil in Bulk."

ON POINTS OF INTEREST IN THE CONSTRUCTION AND REPAIR OF VESSELS CARRYING OIL IN BULK.

By B. **Martell**, Esq., Chief Surveyor to Lloyd's Registry of Shipping, Vice-President.

[Read at the Summer Meeting of the Thirty-fourth Session of the Institution of Naval Architects, July 11th, 1893; Sir Nathaniel Barnaby, K.C.B., Vice-President, in the Chair.]

Having been requested to prepare a paper to be read at these meetings, it occurred to me that—in view of the extensive repairs which have been executed in this locality on steamers engaged in carrying oil in bulk—this subject might be of interest, and could be dealt with to advantage to many professional men in this district.

The great development in this trade, and the rapid increase in the number of vessels engaged in it since 1886, when I had the honour to read the first paper at Liverpool on this important branch of commerce, may be seen by reference to the appended list of vessels classed in Lloyd's Register alone, engaged at the present time for the special conveyance of oil in bulk on oversea voyages, and may be felt to be a further excuse for my occupying your attention for a short time on a subject which is exercising the minds of many who are personally interested.

The questions which are forced upon us, in view of the serious damage which is so often occurring to many of these vessels, and the great cost to underwriters attending their repair, are as to the general sufficiency of scantlings and arrangement of details in their construction, and the points which should occupy special attention when they come under repair.

The general efficiency, or otherwise, of bulk oil carrying vessels to satisfactorily do the work required of them, has to a great extent been a question worked out by actual practical experience, and a large number of vessels engaged in this trade have now been sufficiently long in existence to enable us to speak somewhat definitely on this point.

With the knowledge now before us, we are better able to form an opinion of the comparative extent to which it may be assumed that the constant repairs found to be necessary to many of these vessels have been due to deficient scantlings, faulty modes of arrangement of materials, bad workmanship, or last, but not least, a want of proper care or knowledge in the management or the navigation of vessels carrying oil or water ballast in large quantities in bulk.

As regards the general scantlings of framing and plating, experience has shown that the scantlings adopted for ordinary cargo vessels are suitable for petroleum vessels. It is mainly in matters of detail that special precautions have to be taken to render these vessels efficient, and the first point to which I would direct your attention is to the rivets and riveting. The case of a vessel carrying a liquid cargo in bulk out to the outer skin differs from one carrying ordinary cargo, inasmuch as that in the first case the cargo is carried directly on the outside plating of the vessel instead of on the floors and framing, and the main strains are therefore brought on the riveting connecting the plating to the frames. Further, in pitching and rolling the pressure due to the inertia of the cargo is very considerably increased, even when the tanks are quite full.

In the early instances of the construction of these vessels, they were comparatively small in size, or built with double skins, and it is possible that, when the inner skin was dispensed with, the increased strains which would be brought upon the riveting of single shell plating had not been fully appreciated until it was forced upon us by actual experience.

Here, then, is one of the principal considerations in the efficient construction and repairs of oil-carrying vessels, viz., the size, form, and spacing of the rivets. General opinion exists that the sizes of the rivets as given in the Rules of Lloyd's Register are sufficient for the various thicknesses of plates prescribed. As regards the *form* of rivet, however, there can be no doubt that many of the failures which have occurred have arisen from the inefficient heads given to the rivets. An opinion existed amongst some builders, which I am glad to say has been to a considerable extent abandoned, that the best form of rivet for producing oil or water-tight work was the plug-headed rivet, as shown in Fig. 1, Plate I. This all our experience shows to be a mistake, and the best form of rivet for ensuring oil-tightness is the pan-headed rivet with swollen neck under the head, shown in Fig. 2, Plate I. Such rivets ensure more thoroughly the filling the holes; they can be more satisfactorily laid up, and their soundness better tested when completed, whilst their holding power is greater, ensuring more strength in the structure, and preserving to a greater extent oil-tightness than any other form of rivet adopted.

If, however, plug-headed rivets are adopted, exceptional workmanship is required. It is highly essential with these rivets that, in hammering up, the conical head should come into close contact with the plate in the hole. In order that this may be the case, the holes should be countersunk and the heads of the rivets well heated. When this is done, and a sufficiently large head is left outside the surface of the plate, these rivets may produce sound work, but careless workmanship will undoubtedly intensify the effect of inefficient work when this form of rivet is adopted.

It has been found that, in some instances where plug-headed rivets have been used, the head has not been sufficiently large to admit of the rivet being properly laid up, as shown in Fig. 3, Plate I., and the consequence has been that the head has had comparatively little hold on the plating, and, when excessive strains have occurred, the head has given way, leading to the adjoining rivets failing in the same manner, and incipient rupture has resulted. This has been more particularly observed in such rivets when used in the gunwale angles connecting the stringer and sheer strake. The relatively lesser thickness of angles has not provided sufficient holding power for such a form of rivet head, and failure has resulted. The rivets at this part especially, to be thoroughly efficient for their purpose, should either be pan-headed or project considerably within the angle bar, similarly to boiler work, as illustrated in Fig. 4, Plate I.

Whichever form of rivet be adopted, the points should be left sufficiently full or convex, and in cases where rivets are found on testing to be unsatisfactory, they should be renewed and not caulked, as is sometimes done.

Great care is also necessary in these vessels to ensure fairness of holes, as without absolutely sound work at the seams and butts, vessels carrying oil in bulk are sure to give trouble and necessitate costly repairs. Holes that are found to be not quite fair should be rimed and not drifted, and rivets specially prepared should be used in such cases, where necessary. And here it may be remarked that sound workmanship throughout is essential and of primary importance in these vessels; as, however satisfactory the general arrangements may be, unless the very best workmanship be executed, failure is certain to ensue.

From considerations of the increased strain on the rivets in oil-carrying vessels, and on account of the penetrating character of petroleum, it has been found necessary to more closely space the rivets in the seams and butts of the outside plating, and also the frame riveting, than in ordinary cargo-carrying vessels. The spacing which has been found suitable for the seams and butts of outside plating is *three* diameters from centre to centre, requiring one additional rivet in each row between the frames. This spacing should also be adopted in bulkheads, where both seams and butts should be double riveted, while the rivets through the frames and outside plating should not exceed six diameters from centre to centre, both the landing rivets passing through the frame.

The best form of butt connection to the outside plating in way of the tanks is a matter on which authorities differ. The ordinary single strap flush butt Fig. 5, Plate II., has been found from experience to be unfit for this work, and in cases where it has been tried, even on alternate strakes, the remainder being lap-butted, failure has ensued, necessitating expensive repairs in the subsequent fitting of double buttstraps. There can be no question that the most efficient connection at the butts is by double buttstraps Fig. 6, Plate II.; but, as this method is heavier and more costly than lapping the butts, I am of opinion that overlapped butts Fig. 7, Plate II., will be found generally satisfactory and efficient for the purpose. An outside strap should, however, always be fitted to the butts of the strake of plating in way of the deck forming the top of the oil tanks.

The maximum length of oil tanks that can safely be adopted in these vessels is a matter of great importance. There is a tendency on the part of some owners to make the tanks as long as possible, thus reducing the cost of construction and rendering the vessel more fit to carry varying cargoes other than oil in bulk, but there can be little doubt that the straining increases very rapidly with increase in the length of the tanks and the consequent greater weight of oil or water carried.

The fact cannot be too clearly appreciated that, when these vessels are rolling and pitching at sea, the motion is communicated to the oil through the medium of the outside skin or plating and the bounding bulkheads.

The stresses therefore on the bulkheads due to the motion of the vessel vary with the weight of oil in any tank, while the support the bulkheads afford to the side of the vessel is an important factor in the efficiency of the vessel. Widely spaced bulkheads, therefore, by admitting of larger quantities of oil acting on any particular bulkhead, and by affording less support to the sides, are very undesirable, and experience has shown that a maximum length of tank of about 24 ft. cannot safely be exceeded without special precautions being taken to additionally strengthen the sides and the bounding bulkheads of compartments of greater length.

As hold beams in this class of vessel are generally dispensed with, the disposition of the web frames in the hold requires special attention. A little consideration will show, as already stated, that the load on the framing is of a different character to that in vessels with ordinary cargoes. As a vessel laden with oil in bulk rolls, the weight of the cargo is brought on directly from the plating to the side framing, whereas in a vessel with a solid cargo the weight is borne *mainly* by the floors.

Experience has shown the necessity of meeting the extra stresses thus set up by a closer spacing of the web frames.

In vessels with tanks 24 ft. long, as suggested, not less than two web frames of the ordinary size should be fitted in each oil compartment, with the usual number of side stringers. The stringers should be connected to the shell plating by double angles for three frame spaces at each end of the oil compartments, and to the bulkheads by bracket plates 6 ft. by 4 ft. of the same thickness as the stringer plates Fig. 8, Plate III.

These brackets should be attached to the stringer plates by a double row of rivets, and to the bulkhead by double angles, or by a large single angle wide enough to take double riveting, as shown in Fig. 9, Plate III.

Instead of butting the stringer plates at each bulkhead, which has been the general practice, in recent cases the stringers have been made continuous throughout the length of the vessel, and oil-tightness ensured at the bulkheads by fitting angle collars around the stringer plates.

Fig. 10, Plate IV., shows the plan which has been adopted in the fitting of the stringers, and which, it may be stated, has proved satisfactory.

Where wide-spaced hold beams are fitted in the tanks, it is highly necessary that the connection of these beams to the sides of the vessel should be of a most efficient character. Straining is certain to occur if this is not the case, and can only be prevented by fitting exceptionally large gusset plates—say, 6 ft. by 3 ft.—on the ends of the beams connecting with the stringer plates, and by fitting most efficient and well-riveted beam knees (see Fig. 11, Plate V.).

A radical point of difference in the construction of oil vessels and vessels fitted to carry ordinary cargoes exists in the arrangement of keelsons, &c., at the bulkheads. In ordinary vessels, in order to preserve continuity of strength, all keelsons pass through the bulkheads, and water-tightness is obtained by fitting angle collars round them on the bulkheads. This arrangement, however, is not adopted in oil vessels, it being felt that any disposition of material which necessitates three-ply riveting should, as far as possible, be avoided.

To maintain the strength of the keelsons and side stringers—which is all the more necessary in these vessels, as, when carrying water ballast, the load carried is necessarily localised—brackets are fitted against the bulkheads; and it is highly important that they should be of sufficient size to admit of a rivet connection, approximately, at least, equal to the strength of the keelsons and side stringers. Double angles, or a large single angle double riveted against the bulkhead, will be required to provide the rivet power requisite for the purpose. The size of the bracket will consequently depend on the stringer; but, in general, brackets about 4 ft. by 4 ft. are found to be necessary. Where these brackets have not been made sufficiently large, and the riveting has consequently been of much less strength than required, very serious straining has been set up at the bulkheads, involving subsequently considerable additional strengthening.

As the main part of the stress on the rivets to these brackets through the bulkhead will be in the direction of the length of the rivet, it is essential for good work that the points and heads be full; so that, in addition to the countersink, the rivets should have a good bearing on the plates. Pan heads with full hammered points, as in boiler work, are found to be the most efficient for this purpose.

The brackets, as before stated, should be large, say, 4 ft. by 4 ft., and, in order to keep them well to their work, it is desirable that they should be stiffened on the edge away from the bulkhead (Figs. 12, 13, Plate VI., and Fig. 14, Plate VII.).

The construction of the bulkheads and the brackets at the ends of the bulkhead stiffeners, in order to develop their full strength, has demanded the attention of those overlooking the construction of these vessels. These bulkheads being continuously under strain, any inherent weakness is quickly developed, and experience soon points out the proper remedy. It has been found most satisfactory, instead of fitting these bulkheads between double angles at the ship's side, to use one large angle with double riveting, Fig. 15, Plate VIII. The vertical stiffeners to bulkheads should be secured at the heels by bracket plates of the thickness of the bulkheads, fitted between double angles on top of the floor plates, with a staple knee fitted between the two floor plates. The upper ends of the stiffeners should be attached to the deck plating by bracket knees of the depth of the main deck beam knees, as shown in Fig. 16, Plate IX.

In addition to the vertical stiffening, it has been found desirable to fit horizontal stiffeners in a line with those on the transverse bulkheads. Fig. 17 shows the method adopted of connecting the horizontal stiffeners at the corners of the tank.

In some of the earlier vessels the tops of the stiffeners to the middle-line bulkhead were left unbracketed at the ends. A comparatively weak line was thereby caused at the tops of the stiffeners immediately below the beams. The effect of this faulty arrangement was soon apparent. A repetition of pressures, alternately on one side and then on the other, set up a motion of the bulkheads about this weak line, along which the plating fractured. As indicating the excessive strain brought to bear on these bulkheads, it may be mentioned that in one case the working had proceeded to such an extent that the bulkhead was bodily torn out of place, and was found at the end of the voyage lying on the floors of the vessel.

In dealing with these brackets at the ends of the stiffeners, it is well to remember that, in order that they may be effective, the stiffener should be held by them absolutely rigidly, and when this is the case, the bending moment at the bracket is greater than at any point of the stiffener. Small brackets will not be sufficient to withstand this stress, and straining will occur at these parts if the strength and rivet connection of the bracket does not bear a proper proportion to the strength of the stiffener to which it is attached.

So many failures have occurred owing to brackets being either too small, or not being fitted at all, or inefficiently riveted, that I feel it to be necessary to strongly draw attention to this matter.

The necessity of fitting cofferdams to divide the oil tanks from the engine space and other parts of these vessels appears to be generally recognised. Where the machinery is fitted aft, a cofferdam should be fitted at each end of the space devoted to oil cargo, and carried to the extreme height of the upper deck; and where the machinery is fitted amidships, cofferdams are required at each end of the vessel, and before and abaft the machinery space. These spaces should extend to the top height of the vessel, and should not be pierced by doorways in the 'tween decks, unless the bottom of the doorway be at least 18 in. above the 'tween decks. In such cases hinged doors should be fitted, to be screwed up oil-tight when the vessel is filled with oil.

To obtain immunity from danger from this cause, these cofferdams should be filled with water. By this means the cargo holds are completely separated from the machinery space, and from the storerooms at the fore end. A much-discussed case of explosion on an oil steamer was caused by oil leaking from the foremost oil tank into a water tank from which no efficient means of ventilation existed. As a result an explosive mixture accumulated in the tank, which ultimately exploded. It is considered that no line of oil pipes should be connected with pipes in communication with water-ballast tanks.

In a more recent case, oil presumably leaking from the trunk in the 'tween decks, from greater expansion than provided for, or from other causes, found its way through the doorway in the bulkheads into a coal bunker, and caused the destruction of the vessel by fire. A cofferdam filled with water, and extending to the upper deck the full width of the vessel, would have prevented these disasters, as any oil escaping into the cofferdam from the oil tanks would have floated to the top, from where it could have been drawn off, or, if it evaporated, the gas would have escaped into the open air.

The bulkheads forming the cofferdams should be stiffened by angles, and the two bulkheads tied together by a series of plates attached to the stiffeners, with a space equal to the breadth of the plates between consecutive plates ; a series of these plates to be fitted in way of the middle-line bulkhead and the side and bilge keelsons. The side stringers also should be extended through the cofferdams by plates of the same thickness extending to the inner edge of the bracket plates connecting the stringers to the bulkheads (Figs. 18 and 19, Plate XI.).

In some instances where the engines were placed amidships, thereby requiring a shaft tunnel to be fitted, the tunnel was made double—the inner one being made gas-tight—and an external one being formed, having a space between the two of about 18 in., this space being ventilated by ordinary cowl ventilators.

Considerable risk was found to exist when this arrangement was adopted, as the inside tunnel was open to the machinery space, thereby allowing the escape of any oil or gas which might find its way from broken or leaky rivets, or other causes, into the intermediate space, and subsequently through the inner tunnel into the engine-room.

It was also found that great difficulty and danger existed in entering the confined space between the tunnels when necessary for repairs, where an accumulation of oil and gas might exist, if a leak had taken place in the outer or oil-tight tunnel, as has been the case.

These circumstances led to the abandonment of this practice, and the later vessels, where the engines are placed amidships, are constructed with a single tunnel, which is completely shut off by a " cofferdam " from the engine and boiler space.

The single tunnel, the best form of which is circular, is substantially constructed with thicker plating and made oil-tight, and an oil-tight trunk extending to the upper deck is fitted at each end to afford means of readily entering and leaving the same.

The tunnel is efficiently ventilated by large cowl ventilators placed on the trunks referred to, and a provision is also made for artificial ventilation by fitting a large perforated pipe along the bottom of the tunnel and carried to the upper deck, in communication with a fan. A steam jet is also arranged for use in the event of the fan from any cause being unworkable (Fig. 20, Plate XII., and Fig. 21, Plate XIII.).

It is highly desirable that, before oil steamers are handed over by the builders, the compartments should be crucially tested to ascertain whether they are capable of withstanding the stresses which are brought upon them when the vessel is loaded. Should any leakage take place from a loaded compartment, especially when the vessel is in water ballast, and some of the compartments are empty, the result may be very serious, as, the surface falling below the deck, violent motion is set up in the water, inducing stresses, in some cases, that no ordinary vessel could be expected to withstand.

But, even where no leakage occurs, the stresses due to the rolling and pitching motion of a vessel at sea, are much in excess of the still-water stresses. This being the case, the minimum test which it is considered desirable to require is that due to a height of water not less than 12 ft. above the maximum height of the oil or water that is likely to be carried in the compartment, or, in other words, 12 ft. above the top of the oil tank. This rule has been adopted by Lloyd's Register for some time past, and has been found to give satisfactory results.

As in the lifetime of any vessel it is almost a certainty that repairs on a greater or less scale will require to be carried out, it is desirable in the design of an oil vessel that provision should be made to render the work as safe and simple as possible. As several terrible disasters have occurred through the presence of oil or oil vapour in tanks in which repairs were being executed, it is a point of great importance that the internal arrangements should be such that clearing the tanks from gas can be readily effected. To absolutely clear the tanks of petroleum will probably be impossible, as small quantities must inevitably find their way at the backs of the frames, laps, and butts of plating, &c. To minimise this as far as possible, the framing should be of a simple character, anything of the nature of cellular construction being avoided.

It is worthy also of consideration whether it would not be advisable to cut a manhole in way of each tank in the bottoms of these vessels for the purpose of clearing and exhausting explosive gases. I see no objection to this plan being adopted, if great care is taken in securing the manhole covers to make them perfectly oil or watertight, to ensure which there is no practical difficulty.

Where, as is often the case, the oil tanks are below the main deck, and trunks for oil are constructed at the middle line in the 'tween decks, it is usual to cut the frames and reversed frames at the main deck to secure oil-tight work. To preserve the transverse strength at this part, the frames in the 'tween decks should be connected to the main deck stringer plate by bracket knees fitted to every frame. The main deck stringer plate should be connected to the outside plating by an angle of the same size as fitted at the gunwale, and double riveted on each flange, as shown in Fig. 22, Plate XIV.

Where a continuous expansion trunk is fitted in the 'tween decks for carrying oil, it is very necessary that it should be strongly constructed, as there will be increased stresses at this part, due to the movement of the oil, which will not usually extend to the top of the trunk. The flat sides and angles at the decks consequently require to be considerably strengthened, or leakage will probably occur at these parts.

The knees to the deck beams forming the crown of the oil tank should also be of increased size—say, three times the depth of the beam, and the spacing of the rivets connecting the knees to the frames should not exceed five diameters from centre to centre.

To further secure the efficiency of the oil tanks, it has been found necessary to fit quarter pillars, or ties of channel or other section, bracketed to the floor plates and deck beams.

In the foregoing remarks I have indicated the salient points which experience has shown it is desirable should receive most careful attention in the construction of the description of vessel referred to. At the same time, after producing such vessels in all respects sufficiently strong and efficient to do the work required of them, failures will still occur, unless they are intelligently loaded and navigated. It is not an uncommon practice, due to the necessity of proper trim, when these vessels are loaded with water ballast, instead of filling consecutive compartments, so that the stresses would be uniformly distributed, to leave empty one or more compartments near the middle of the vessel. The unnecessary local strains thus brought on the structure might be avoided if such vessels were properly designed, so that they would be in the required trim when the consecutive tanks were filled. Or this might be obviated if the owners were not, in some instances, anxious to carry as little water ballast as possible, in order to reduce the expense attending the filling and emptying, and to ensure a faster passage with a vessel drawing a less draught of water. Again, it has been often urged that much of the damage these vessels have sustained has been owing to the very objectionable practice of running up an empty tank when a vessel was at sea encountering rough weather. The enormous strains occasioned by a heavy body of moving water, under the circumstances referred to, has been vividly placed before those navigating such vessels, but it is well known that in many instances the practice is still maintained. The prospect of making a quick passage with a comparatively light vessel may be thought by some to be worth the risk of being compelled, on account of deficient stability, or to alter the trim, to run up an additional tank, when the vessel is at sea; but it is thought that the large sums likely to be involved in having to repair damages resulting from such heedlessness will not eventually be to the benefit of the owners of those oil-carrying vessels. In view of the manner in which they are constructed, with a large number of divisional bulkheads, the risk should be reduced to a minimum.

Whilst, however, underwriters are called upon for large sums to repair these vessels, occasioned, in many instances, by the recklessness referred to, it is to be feared the outlook is not very promising that underwriters will be enabled to see their way to reduce the premiums on vessels engaged in this trade, whilst such a practice of running up large tanks at sea is continued.

It has often been said that, in view of these vessels being divided to such an extent by transverse and longitudinal bulkheads, the risks of foundering must be considerably diminished, and that, therefore, the premiums of insurance should be less.

This, doubtless, is the case as regards total loss from collision or similar causes, but the heavy claims which have been made on underwriters in consequence of repairs necessary through faulty construction, and exceptional strains brought on them by moving water or oil, do not warrant underwriters in accepting a discriminating lesser premium; and, until the unnecessary risks of damage referred to are obviated, or provided for, it is thought that the exceptional premiums now asked will be continued.

Under these circumstances, it is gratifying to be able to say that the experience now gained, and the desire of the owners and builders of vessels engaged in this trade to ensure efficiency, have reduced such additional risks, as regards construction, to a minimum, and it only remains that such vessels should be intelligently managed and navigated to dissipate any fears that unnecessary risks are incurred.

The question of the best position for placing the engines in oil-carrying vessels has recently received considerable attention, and a few words on this point in conclusion may not be out of place. When vessels were first built for carrying oil in bulk, it was thought that danger would arise from the probability of gases given forth coming into contact with the sparks or flame from the funnel, if the engines were placed amidships, as in ordinary cargo vessels. This led to the engines being placed in the after end of the vessel, as was formerly done in coasting coal-carrying vessels. Several cargo vessels having the engines amidships, as usual, were subsequently converted into oil-carrying vessels, and have now been running sufficiently long to enable a comparison to be made of the relative merits of the two plans.

It may be pointed out that this problem, as regards vessels carrying oil in bulk, is different, in some respects, to that of vessels carrying ordinary cargo. It has already been shown before this Institution that the large quantity of coal necessary in the earlier steam vessels, wherein the consumption reached 4 lbs. per I.H.P. per hour, made the trimming of vessels with engines placed aft a most difficult subject, owing to the great varying weight aft, caused by this large consumption. This difficulty, in fact, led to the almost entire abandonment of the system, and the general practice of placing the engines amidships.

The objections to the latter arrangement are as follow, viz. :—

(1) Increase of first cost.

(2) Increase of weight, and a corresponding decrease in cargo-carrying capacity.

(3) Increase of labour in maintenance, due to the greater number of bearings requiring lubrication.

(4) Owing to the weight of engines and boilers, &c., being considerably less than the displacement of the vessel over the length between the machinery space bulkheads, and consequently the weight in the holds being greater than the corresponding displacement, it has been alleged that there is a permanent hogging moment, in still water, in vessels wherein this arrangement is adopted.

As regards vessels carrying petroleum, however, the last objection has no weight, for, where the engines are placed aft, the weight of the midship portion of the vessel, when the tanks are full, is greater than the corresponding displacement, and consequently these vessels are subjected to a constant sagging moment in still water. For purposes of comparison, therefore, the question of straining need not be considered, and it is only necessary to consider whether the additional first cost, and less cargo-carrying capacity of the vessels with engines amidships, are compensated for by the facility in trimming the vessel which this type possesses.

Considering the case of a vessel designed by Mr. D. J. Dunlop, who has had considerable experience in dealing with tank steamers, it appears that in a vessel carrying 4,200 tons of oil, if the engines were placed aft, from 160 to 180 tons of water ballast would be required, on her arrival at port of discharge, to bring the vessel to an even keel; while, if the machinery were placed amidships, in the usual relative position, 40 tons only would be required for this purpose. When the vessel returns in ballast, this water aft must be pumped out to restore the vessel's trim, and therefore the additional cost of working such a vessel with engines placed aft is that of pumping out some 130 tons of water ballast per voyage, which is far more than balanced by the freight of cargo (viz., about 70 additional tons) carried.

At the same time, in making the return voyage in water ballast, such a vessel with engines *amidships* has a decided advantage, as she can be brought to a seaworthy trim with a less weight of water ballast, and with less liability to strain, owing to the more even distribution of the ballast required.

Structurally, therefore, it appears that the vessel with the engines amidships is the better vessel, whilst the advantages as regards trim, in cases where vessels are required to discharge portions of the cargo at different ports, are found to be very great. At the same time, it is a question whether the commercial advantages of placing the engines aft in vessels trading alone from one port to another will not be found to be too great to be given up by owners, especially as experience has, we think, enabled us to now construct these vessels so as to be capable of satisfactorily withstanding the increased structural strains to which vessels so arranged are subjected.

It may be mentioned that a shipowner who owns several of these vessels, portions of the cargo of which have to be discharged at different ports, finds, from actual experience of their management, the arrangement of having the engines amidships much more advantageous.

Having, therefore, indicated some of the advantages and disadvantages attending the adoption of the two systems, it is felt that it must be left to the shipowner to select, from his practical experience, whichever arrangement is most suitable for the particular trade intended, viz., the ports—if more than one—at which cargo has to be discharged.

LIST OF VESSELS CONSTRUCTED FOR "CARRYING PETROLEUM IN BULK," AND CLASSED IN LLOYD'S REGISTER OF BRITISH AND FOREIGN SHIPPING.

Name.	Gross Tonnage.	When Built.	Class.	Position of Machinery.
Steel SS. Allegheny	2,914	1890	100 A1	Aft
,, American	3,897	1892	100 A1	Aft
,, Apscheron (ex Era)	1,851	1887	100 A1	Aft
,, Aras	3,210	1893	100 A1	Aft
,, Astral	2,249	1889	100 A1	Aft
,, Attila	2,141	1889	100 A1	Aft
Iron SS. Bakuin	1,669	1886	100 A1	Aft
Steel SS. Baku Standard	3,708	1893	100 A1	Aft
,, Bayonne	3,294	1889	100 A1	Aft
,, Bremerhaven	3,393	1890	100 A1	Aft
,, Broadmayne (ex Oka)	3,095	1888	100 A1	Aft
,, Charlois	2,744	1888	100 A1	Aft
,, Chester	2,834	1888	100 A1	Aft
Iron SS. Chigwell	1,824	1883	100 A1	Amidships
Steel SS. Ciudad de Reus	1,899	1893	100 A1	Aft
,, Clam	3,552	1893	100 A1	Aft
,, Conch	3,555	1892	100 A1	Aft
,, Delaware	3,855	1893	100 A1	Aft
,, Elax	4,100	1893	100 A1	Aft
,, Etelka	2,373	1892	100 A1	Aft
,, Henri Rieth	2,265	1893	100 A1	Aft
,, James Brand	3,907	1893	100 A1	Aft
,, Kura	2,372	1889	100 A1	Aft
Steel Bkn. La Viguesa	666	1893	100 A1	Sailing vessel

Name.	Gross Tonnage.	When Built.	Class.	Position of Machinery.
Iron SS. L'Oriflamme	3,328	1892	100 A1	Amidships
Steel SS. Looch	1,446	1886	100 A1	Aft
Iron and steel SS. Luciline	3,319	1893	100 A1	Amidships
Steel SS. Manhattan	3,300	1889	100 A1	Aft
Iron SS. Marquis Scicluna	1,599	1883	A1 *1	Amidships
Mineral (ex Charles Howard)...	1,304	1866	90 A1	Amidships
Steel SS. Murex	3,564	1892	100 A1	Aft
,, Northern Light...	3,893	1893	100 A1	Aft
,, Ocean	2,835	1888	100 A1	Aft
Iron SS. Petriana...	1,672	1879	100 A1	Amidships
Steel SS. Prudentia	2,730	1889	100 A1	Aft
,, Rion	2,186	1889	100 A1	Aft
,, Rock Light	3,225	1889	100 A1	Aft
Iron SS. Robert Dickinson	2,100	1881	100 A1	Amidships
Steel SS. Spondilus	4,129	1893	100 A1	Aft
,, Suram	3,803	1893	100 A1	Aft
Iron SS. Titian (ex Colbert)	1,249	1870	A1, 1	Amidships
,, Tancarville	2,336	1889	100 A1	Aft
Steel SS. Trocas	4,129	1893	100 A1	Aft
,, Turbo	4,134	1892	100 A1	Aft
Iron SS. Vindobala	1,865	1879	100 A1	Amidships
Steel SS. Wild Flower	2,657	1889	100 A1	Aft
,, Willkommen	3,126	1887	100 A1	Aft

Total number of vessels built 47

Vessels under construction to class 100 A1 in Lloyd's Register of British and Foreign Shipping, in addition to the above list 17

Grand Total 64

DISCUSSION.

Mr. J. H. Heck (Member): Sir, what struck me most in listening to Mr. Martell was the confession that the early steamers which had been constructed to carry oil in bulk were not adequate for the work they have had to do; and in view of this fact, even with the additions to strength which have been made, it is a question, unless great care is taken, whether some of the more recent vessels will carry oil in bulk across the Atlantic during all seasons without showing some signs of straining. In talking to a captain who had been engaged for some years in carrying oil, he said, It is all very well for you to say do not fill tanks at sea, and do not this nor that; at sea things are different to what they are on shore. Conditions are sure to arise when a tank may be partly emptied or partly filled, and if ships are not strong enough to stand this they should be made stronger. I believe the best way of reducing straining is to make the oil tanks smaller. It has been asserted at a recent discussion in Newcastle that the longitudinal bulkhead is of little use, and not necessary to ensure adequate stability. Outside of the question of stability, however, the longitudinal bulkhead plays an important part in reducing the strain that is set up to balance the acceleration and retardation of motion that takes place when a vessel is rolling heavily, and its effect can be very simply illustrated. If a tank 35 ft. long and 1 ft. square is taken and filled with sea water, the weight of the water in the tank would be 1 ton and the pressure on the ends when the tank is still only 32 lbs. To put this tank in motion and to give it the acceleration due to gravity would cause a pressure of 1 ton on the end in place of 32 lbs.; again, when in motion, to cause a retardation of motion similar to that of gravity would cause a pressure to be set up of 1 ton on the other end. In other words, while the pressure on the ends of the tank when still is only 32 lbs., when having the acceleration or retardation assumed the pressure on the ends would be 1 ton, or seventy times greater. Again, if the tank had been divided by bulkheads into ten spaces, the pressure on the ends, with similar conditions of motion of acceleration and retardation, instead of being of 1 ton would only be $\frac{1}{10}$th of a ton. This is, of course, a very simple case; the inference drawn from it, however, is applicable in all cases, no matter what may be the law governing the rate of acceleration or retardation of motion. The reactions and strains that are set up when a vessel is in heavy weather at sea are evidently very great, and I think that, in order to reduce the straining, the best, simplest, and easiest way would be to make the tanks smaller by fitting more longitudinal and transverse bulkheads. Mr. Martell always puts both sides of a question; but I must say I do not like the machinery placed amidships, and for the following reasons. Reference has been made to an accident which happened because the machinery space was not properly isolated from the oil tanks. Even in a vessel with the machinery placed aft and the cofferdam carried up to the upper deck, the cofferdam through a collision might get damaged and allow the oil to flow into the boiler-room and so cause an accident. With the machinery placed amidships this risk is doubled. Again with the machinery placed amidships a tunnel is required for the screw shafting, and as this tunnel is enveloped with oil and has to be entered frequently, it is against the fundamental rule which many urge and experience has proved sound, viz., that no confined spaces enveloped by oil should exist in any well-designed petroleum steamer. In conclusion, I have to express the pleasure which reading this most interesting and valuable paper has afforded to me.

Mr. H. H. West (Member of Council): Mr. Chairman and Gentlemen, I have followed this paper of Mr. Martell, as he read it to us, with very great interest. It deals with a subject that I have been brought into contact with from the underwriter's point of view. Mr. Martell says there is hope, and I agree with him, that premiums on this class of vessel may be brought to more manageable proportions; but it must be borne in mind that the premium paid to underwriters on these vessels is not only a premium for the loss of, or damage to, the ship from ordinary sea perils, but also from another peril, the risk of explosion, which, although it certainly is being reduced, is still a very important factor. We have been told that going to sea is a pastime that involves the probability of being drowned, with the chance of being burnt. This class of vessel is subject to both these dangers in a very marked degree. There is one point in connection with this matter of riveting that I am very much struck with. Some few years ago I read before the Institution of Naval Architects a paper urging the increase of the number of rivets in a butt connection considerably above what was then the ordinary practice; and I am very much struck by the urgency with which Mr. Martell presses upon us a still further increase in the number of rivets, where we have such special conditions as we have in petroleum steamers. In this I thoroughly agree with Mr. Martell, and the evident necessity of increased riveting in petroleum steamers convinces me of the accuracy of the line of argument which I followed in the paper referred to. Mr. Martell gives his preference for the pan-headed rivet. In that also I agree with him. The conical-headed rivet, I believe, is an advantage when the hole in the plate is carefully countersunk, so as to correspond accurately with the taper in the head of the rivet. It is an advantage in making tight work of the rivet itself. The rivet better fills the hole; but in the very essential quality of drawing the plates together, and keeping them together, my experience is that the conical-headed rivet is vastly inferior to the pan-head rivet. Mr. Martell said something about the use of these steamers. A point that has often struck me in connection with the use of these steamers is that, in going out in water ballast, one tank is filled, the next is empty, the next is filled, and so on. I cannot imagine a state of things more likely to lead to structural trouble if the vessel falls in with bad weather when so loaded, which she is pretty sure to do at some time or another. It has occurred to me that this might, in a measure, be got over, if, instead of having the tank the whole depth, from the bottom plating to the oil tank deck, another flat was introduced lower down, which could be so fitted with hatches as to be ignored when the vessel was in laden trim, yet closed up and used as water ballast when the vessel was in water ballast trim; so that she would have the necessary amount of water ballast, and yet carry it as a practically continuous body of water. I do not know that I have any other remarks to make upon the subject. I have read the paper with great interest, and I am struck with the amount of thought and care with which it has been compiled.

Mr. H. F. Swan (Member): Mr. Chairman and Gentlemen, I need not say that I have read this paper with very great pleasure, and I can very well endorse all that Mr. Martell has said, and for the simple reason that Mr. Martell, in his official position, has brought before him all the latest points and all the latest data in connection with the construction of oil vessels, so that he is able to focus up to date the very best methods that experience has shown are advisable with regard to these very difficult ships. Tank steamers, we all know, require very exceptional care, both in designing and building; and more particularly we have to deal with this difficulty—that owners, and more especially captains who have to navigate these ships, treat them quite differently from the ordinary cargo ship with which they have been accustomed to deal. They put these vessels to tests such as they were never intended to bear, and with the natural result that many vessels have been found unable to stand them. Take, for instance, the case of docking a ship. Who would think of treating an ordinary vessel as a tank steamer is treated, which, without hesitation, is placed in a dry dock with perhaps a thousand tons of water ballast concentrated at the fore end to trim her, and where she would be left unsupported excepting on the keel blocks, with the result of having the enormous sagging strain of a thousand tons bearing down on each side of the blocks. It is necessary to have a certain amount of water for trimming, but that can be dealt with by lowering the amount of water in the tank as the water is pumped out of the dock. Most of the loading ports for petroleum are shallow water ports, and these vessels are put aground sometimes on a stony bottom, and they are subjected to the very severe local effect of such grounding. Another thing in the treatment of them is the absolute indifference with which captains look upon the question of filling and emptying the tanks at sea. I know a case of a vessel recently, where in crossing the Atlantic in winter it was found, after a voyage or two, that she was a good deal strained. On making inquiry it was found that every compartment of that ship—not only every oil compartment, but even the water ballast compartments forward—every place, in fact, where water could be got, had been pumped up at the same moment, with the result that she had two thousand tons more than she was intended to have, and the spar deck bore the same relation to the water as the main deck ought to have done. The captain, on being spoken to, did not seem to think he had done anything wrong. Every compartment of that ship had been twice emptied and filled on her voyage across the Atlantic. As I have already said, these ships are subjected to strains they were never intended to bear. The great difficulty in dealing with them, however, is to get to the bottom of these things. We have had vessels running for several years that have not had half a dozen rivets put into them, whereas sister ships have required a good deal of strengthening; but, on coming to inquire into the matter, we find the difference has always arisen from the way the ships have been treated. Experience has shown it is desirable to make the vessels to-day stronger than they were originally built, to withstand in a measure the exceptional treatment to which they are subjected. In speaking of riveting, a good deal of confusion has been made between the *form* of the rivet and the *treatment* it has received. Owing to the strains brought upon the ships themselves rivets have become slack, and have had to be taken out. A distorted rivet handed to you in a rough condition conveys with it an impression that it is necessarily bad. I do not wish to appear specially as the champion of the "plug"-headed rivet as against the "pan"-headed; but I must say I cannot agree with the speakers on that point. I look upon a pan-headed rivet as nothing more than a plug rivet with a head to it, because in the pan-headed rivet you have a thick neck to fill the hole. The diagrams given in the paper all show the plug-headed rivet with a vacancy in the counter sinks, but show the pan-headed rivet as filling the hole, but we do not find this in practice. On the contrary, we are able to lay up the head of the plug, provided the head is made big enough; and this has been the difficulty in many cases, where it has been made too small; so much so, in fact, that when laid up the head has gone under the surface of the plate. Again, in testing plug heads, there are many places where, if you put the water in from the one side it is tight, and if you put it in from the other it leaks. It is, moreover, necessary in some cases to caulk a rivet. You cannot caulk a pan-headed rivet, but a plug-headed one you can, especially is this so in some cases where the rivets are very close together. In the earlier ships we went too much on the principle of dividing one compartment from the other, in trying to make each compartment self-contained, and the result was that at the bulkheads we had a very rigid point, and the strains were not carried off in a sufficiently gradual manner. In the ships built during the last year or two we are making the side stringers continuous, and this will, I think, get over a good deal of the difficulty that has been found in dealing with these ships. Speaking now of the way in which the ships are handled—only a few months ago we had a case where they had pumped out a ballast compartment at sea without taking the trouble to open the air cock, with the result that they brought down the upper deck three inches, caused by the vacuum underneath. If ships have to bear such treatment as this, you must expect ships that are built to bear anything. As regards placing engines amidship or aft, I think the advantages of placing engines aft are so apparent that it is unnecessary to go into them in detail. You get the fires away from the cargo, you get your oil compartments completely isolated, and, leaving the continuous trunk combined with the hinged hatch covers, you can examine every part of the hold, and you have no confined places in which gas can lodge. In the case of a vessel which was destroyed after discharging her oil cargo, and which was taking in her water ballast, all that was necessary to do was to shut down the hatches and let the gas escape up the masts, which were arranged for the purpose. Instead of doing so, in this case the engineer had gone to see how high the water was, and with this object lowered a lamp into the open hatch, with the result that the ship was lost, and himself too, poor fellow. I do not know that there is any other point that occurs to me at this moment. Mr. West spoke of making vessels with a lower deck. We recently built two large vessels with that arrangement, and there is no doubt it has an advantage in the direction indicated, but there is this drawback that it involves considerable additional weight, and it makes what we always strive to avoid, a complicated space for the lodgment of gases. The lower holds, no matter whether you put in large hatchways or not, cannot be got at, and the skin of the ship examined with the same facility as with the ordinary plan. There is also a great disadvantage, now that such ships are coming into vogue for carrying dry cargoes through the Suez Canal, and that is, that even if the deck were good in itself, it would be very objectionable from the point of view of cargo-carrying ships, interfering as it would with stowage, and making them much more difficult to clean out after carrying an oil cargo.

Mr. B. Martell (Vice-President): Sir Nathaniel Barnaby and Gentlemen, I will not occupy your time long, whilst making a few remarks on what has been said. In reference to the remarks of Mr. Heck, we know he is a very intelligent and assiduous man, and he has had a great deal of experience in reference to the repairs of oil ships; but I hope and trust and beg of him when he is sitting in a saloon on the next occasion, and when he is talking quietly to the captain, that he will not be satisfied with being taught by the captain, but that he will endeavour to teach him. To be told by a captain that you cannot help running up water when a ship is at sea! Why, if you continue that practice, as Mr. Swan has very properly illustrated, there is no ship that you can build that will stand it. Even an ironclad could not be constructed that would bear such stresses without serious injury. Do not, I beg of you, take it quietly when a captain says this, but do your utmost to endeavour to convince him that he is decidedly wrong. I cannot conceive, if a certain number of tanks are properly filled when vessels start on their voyage in water ballast, what necessity there can be for running up tanks at sea. The only necessity that would arise would be in consequence of the tanks leaking somewhat, but these tanks are so efficiently devised and tested, that they do not leak, and therefore, I see no necessity for running tanks up at sea. Whenever a captain tells you this, do not you believe him; that is my advice to you. With Mr. West I perfectly agree, and there is no doubt (I mentioned it myself in one paper) that these oil vessels can be arranged where the consecutive tanks could be run up without putting the vessel unduly out of trim. Probably the transverse bulkheads may be put a little closer together at the end, and you might trim the vessels in that way so as to have the compartments full. The tendency is to increase the size of these compartments, and what has been alluded to by Mr. Swan is the fact that it is for the purposes of endeavouring to carry oil one way out, and to carry dry cargo home, and that is facilitated by having the compartments larger. To put your foot down and make a hard and fast rule, such as is advocated by Mr. Heck, is very difficult. We get reproached sometimes for being obstructive, but we wish to be as little so as possible. We want at the same time to make the vessels efficient, but we take care, when we get above 24 ft. in length, that we require those tanks shall be additionally strengthened in order to withstand the greater stress brought upon them from the larger amount of oil contained in them. With regard to this riveting question, I must say this, that the plug-headed riveting as carried out by Mr. Swan, is very different from the plug-headed rivets we have sometimes seen. He does allow a large head inside in addition to the swollen part for filling the hole. That gives room for properly laying up a rivet of that kind, and properly testing it afterwards. When a rivet is nearly level with the plating, it is difficult to test it with a testing hammer to find out whether it is sound or not. I recommend Mr. Swan, if I may, to lay down a rule, and say, "You are not to caulk any rivets; if a rivet wants caulking, it is unsound, cut it out and put in a new one." Unsound rivets should not be dodged by caulking. They may be made watertight for a short time, but we know in the end it is extremely unsatisfactory. Mr. Swan will excuse me for making that remark. I will only mention one case. This is only within the last week or two. An oil vessel in a foreign port had 3,000 rivets renewed. It struck me with amazement at first, but not so when I found out that plug-headed rivets had been used. The builder of this vessel has used for the last half-dozen ships he has built pan-headed rivets, and he would not use any other kind now on any account. I am exceedingly obliged to you for the kind reception you have given this paper, and I regret that it does not contain something of more interest to you.

The Chairman (Sir Nathaniel Barnaby, K.C.B., Vice-President): I am sure we are much obliged to Mr. Martell and the gentlemen who have assisted in this discussion.

FAST OCEAN STEAMSHIPS.

By Francis Elgar, Esq., LL.D., F.R.S.E., Vice-President.

[Read at the Summer Meeting of the Thirty-fourth Session of the Institution of Naval Architects, July 11th, 1893; Sir Nathaniel Barnaby, K.C.B., Vice-President, in the Chair.]

When the present meeting was arranged for I was asked to read a paper upon the above subject, with special reference to vessels of the largest type—such as the new Cunard steamships *Campania* and *Lucania*, for which I am the consulting naval architect. The Secretary informed me that the subject was considered very suitable to the occasion, especially as no paper upon it has been contributed to our Transactions since the late Mr. William John—one of the ablest and most valued members this Institution has had during the third of a century it has existed—read one upon "Atlantic Steamers," in 1886.

Our present knowledge and experience of many of the conditions that limit or influence speed at sea, and of their separate or combined effects, are by no means exact or exhaustive. In considering the general question of the proportions, power, and detailed arrangements requisite for a ship in order to absolutely ensure that the highest possible average speed shall be obtained, and kept up over an indefinite number of long ocean voyages, under the restrictions imposed by the existing conditions of ship, engine, and boiler construction, harbour and dock accommodation, &c.—a question which would be a mere matter of calculation if all the circumstances affecting it were fully and accurately known—we find that the answer depends ultimately, to a great extent, upon personal judgment, and is open to be materially affected by hopefulness or imagination. It would be unprofitable to attempt to enter upon such a speculation here, and I resist the temptation to do so. It might, perhaps, be more useful and appropriate to call attention to a few of the principal points that affect speed at sea, and some of the directions in which theory and experience show the way to continued improvement.

The *Great Eastern* is the most wonderful instance the world has seen of attempts to obtain high speed over long distances at sea. She was designed forty years ago, and her name is probably associated in the minds of most people only with errors and disaster. Our Transactions contain but little about her, although her constructor, Mr. J. Scott Russell, was one of the founders of this Institution, and was for over twenty years one of its most prominent members. It is universally known that she was remarkable for her enormous size; but it is often forgotten that there was anything else about her worthy of notice or admiration. Every new ship that is built of greater dimensions than her predecessors is naturally compared in size with the *Great Eastern.* The *Great Eastern* was remarkable, however, not only for the vastness of her proportions, but also for the thought, care, and skill employed in her design and construction, and for the extent to which problems relating to high speed upon the longest ocean voyages, some of which are, at times, thought to be peculiarly modern, were understood and worked out by her designer. I have thought it might be interesting to compare the latest large steamships with the *Great Eastern* more in detail than is usually done, and to bring into the comparison not merely size, but some of the leading details of design and construction.

In the latter part of 1851 Mr. Brunel began to work out his idea of a great ship for the Indian and Australian trade. He spent two years in inquiries, investigations, and calculations relating to the numerous problems—many of them quite novel then, though more familiar now—that were raised by such a tremendous stride in advance of all former experience and ideas. The magnitude of the stride was as great as would now be involved by the construction of a ship 1,200 ft. long and 30 to 35 knots speed.

The following is a comparative statement of particulars of the *Great Eastern* and *Campania* :—

Particulars.		Great Eastern.	Campania.
		Ft. in.	Ft. in.
Length over all		692 0	622 0
Length between perpendiculars ...		680 0	600 0
Breadth moulded		82 2	65 0
Depth moulded to upper deck... ...		58 0	41 6
		Tons.	Tons.
Register tonnage ...	Gross ...	18,915	12,950
	Under deck	18,837	10,267
		Ft. in.	Ft. in.
Load draught		30 0	27 0
Passenger accommodation	1st class	800	600
	2nd ,,	2,000	300
	3rd ,,	1,200	700
Indicated horse power of engines ...		about 8,000	about 30,000
Speed at sea in knots at full power ...		14 to 14½	22 to 23

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The *Great Eastern* had two separate sets of propelling machinery; one driving a screw propeller, and the other a pair of paddle-wheels. The screw engines were the most powerful, and could indicate up to 4,500 H.P. at sea. The paddle engines indicated 3,500; so that the maximum I.H.P. was about 8,000. This power gave a speed of 14 to 14½ knots at sea, with a coal consumption of about 400 tons per day. There were four cylinders to each set of engines; those of the screw engines being 7 ft. in diameter, with a stroke of 4 ft.; and those of the paddle engines 6 ft. 2 in. in diameter, with a stroke of 14 ft. The screw was four-bladed, and had a diameter of 24 ft. with 44 ft. pitch. The paddle-wheels were 56 ft. in diameter. The working steam pressure appears to have been about 20 lbs., and steam was cut off in the cylinders at one-third of the stroke. The boilers were tubular, and of the square box type, and they were double-ended. There were ten boilers in all, 18 ft. long, 17 ft. 6 in. wide, and 14 ft. high, with 112 furnaces.

The *Campania* has also two separate sets of propelling machinery, but in her case they drive twin screws. The propelling power is fully three and a half times that of the *Great Eastern*, and the speed more than 50 per cent. greater. This increase in power and speed is obtained with a daily coal consumption that is but little in excess of the *Great Eastern's*. There are five cylinders to each set of the *Campania's* engines, and they work three cranks. There are two high-pressure and two low-pressure cylinders, and the high-pressure cylinders are placed upon the low pressure. The cylinders are 37 in., 79 in., and 98 in. in diameter respectively, with 69 in. stroke. The screw propellers are smaller than that of the *Great Eastern*. The boilers are thirteen in number, twelve being double-ended, and one single-ended, with 100 furnaces—or 12 furnaces less than in the *Great Eastern*.

Figs. 1 to 4, Plates XVI. and XVII., show the main structural features of the *Great Eastern* and the *Campania*. One of the chief differences is that the main structure of the hull is much deeper in the former vessel than in the latter. The *Great Eastern* was a flush-decked ship, with no erections on deck, except a few small houses at the middle line, shown by dotted lines; and the moulded depth from this deck was 58 ft., making the vessel 11·7 depths in length. The *Campania* carries upon her upper deck—in conformity with the type of vessels that has been developed for the accommodation of the largest number of passengers—two tiers of decks. The first, or promenade, deck consists of forecastle, poop, and midship deck for passengers, nearly 400 ft. long. This deck is practically continuous: the midship part being separated from the forecastle and poop only by a small break at each end. Upon the promenade deck a large amount of first-class passenger accommodation is provided, which includes library, drawing and music rooms, smoking-room, twenty state-rooms, &c. The second, or shade deck, is carried right across the promenade deck as a shelter to the passengers, and it extends fore and aft over the whole length of that deck. Upon it are carried the boats, cabin accommodation for the captain and officers, chart-room, wheel-house, &c.

The moulded depth from the upper deck of the *Campania* is 41 ft. 6 in., making 14½ depths in length. The moulded depth from the shade deck is 59½ ft, which is only 1½ ft. more than the moulded depth of the *Great Eastern* from the upper deck.

Apart from this difference in moulded depth, the main features of the structural design of the hull are very similar in the two cases. There are several complete iron or steel decks—the upper one being of great extra strength*; a bottom made very strong by means of inner bottom plating and longitudinals, and a very similar amount and arrangement of internal subdivision of the hull by watertight bulkheads.

The framing of the hull was entirely longitudinal in the *Great Eastern*, and the inner bottom was carried up as shown in Fig. 3. The longitudinals were 2 ft. 10 in. deep, and ½ in. thick. They were about 2 ft. 6 in. apart on the flat of the bottom, and 5 ft. apart from the bottom to a height of 36 ft. The scantlings of the hull seem to have been arranged upon a simple principle, for Mr. Scott Russell says, in his work on "Naval Architecture," page 394, "there is one thickness of plates, ¾ in., for skin, outer and inner; one thickness for internal work, ½ in.; one size of rivet, ⅞ in.; one pitch, 3 in.; and one size of angle iron, 4 in. by 4 in. by ⅝ in.

The shell plates, which were ¾ in. thick, were only 10 ft. long and 2 ft. 9 in. wide; being, it may be presumed, the largest obtainable at that time. The weight of one of these plates would be under 7½ cwts. The bulkhead plates, which were ½ in. thick, were about 9 ft. long and 3 ft. wide. The progress since made in the manufacture of ship plates is shown by the fact that the shell plates of the main portion of the hull of the *Campania*, which are ⅞ in. thick, average over 26 ft. in length, 5 ft. 3 in. in breath, and 45 cwts. in weight. Mr. Scott Russell says, "The *Great Eastern* was entirely built with single riveting, the double riveting being at the butts mostly." We have since learned that much can be done to increase the strength, and prevent the undue straining, of such a structure as a ship's hull by extra riveting. In the *Campania*, three of the edges of the bilge strakes and the top edges of the upper strakes of plating on each side are treble riveted, and the remainder are double riveted; and all the butts, which are lapped, as in the *Teutonic* and *Majestic*, are quadruple riveted—except at the extreme ends, where they are treble riveted.

Mr. Brunel communicated his views respecting a great steamer for the Indian trade to the directors of the Eastern Steam Navigation Company, after discussing them with Mr. Scott Russell and others. This Company was formed in 1851, to convey

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* In the *Great Eastern* this deck is cellular in construction, and consists of longitudinal girders plated at the top and bottom with ½ in. plates.

mails, passengers, &c., by the overland route between England and India and China, with a branch to Australia. The Government, however, gave the contract for the whole service to the Peninsular and Oriental Company in March, 1852; and the Eastern Steam Navigation Company found itself in the position of being unable to carry out the objects for which it had been incorporated.

They then turned their attention to the main oversea route followed by British commerce round the Cape towards India, China, and Australia, which was nearly the same as far as Ceylon. "On the fact of this great pathway of commerce they grounded, and not without plausible reasons, their scheme for the profitable employment of various vessels of gigantic size between England and Ceylon, from which place smaller vessels were to diverge to the other parts of India, as well as to China, Japan, and Australia: the intention, however, being to despatch their first great vessel, when ready, direct to Calcutta, Sydney, and Melbourne."*

Mr. Brunel reported as follows, in March, 1853, to a committee appointed by the directors to confer with him upon the design of the great ship: "The dimensions arrived at by calculation for this ship would be, in round numbers, 670 ft. long, 80 ft. beam. This sized vessel would combine most of the advantages which we seek to obtain. It would carry coal to Diamond Harbour (in the Hooghly), and back to Trincomalee; it would afford room for about 800 separate cabins, larger than those now fitted up in packet ships, with large saloons capable of accommodating 1,000 or 1,500 first and second-class passengers, and would carry 3,000 tons weight of cargo, without making any allowance for that increase of speed proportionate to the mere increase of size, of which we see every day fresh proof; the average speed of the ship, with the proposed power of engine and calculated consumption of coal, would be 14 knots at the average, making the passage out in 34½ days, say 36; but with that increased speed which has been shown to take place with increased dimensions, we may speculate upon the voyage being performed in 30 days.

"This same vessel, fitted up for the Australian voyage, and loaded deeper, would carry coals to Australia and back; would take out 3,000 passengers easily, and a small amount of cargo only, but could bring back any amount that could be conveniently collected; or if provision were made for taking in 3,000 or 4,000 tons of coal in Australia, that additional amount of cargo might be taken on the passage out. The passage out to Port Philip should be made easily in 36 days, and home by Cape Horn in the same time."

Mr. Brunel was authorised to continue his communications with shipbuilders and engineers, and to invite tenders. The contracts for building the vessel, as slightly

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* History of Merchant Shipping and Ancient Commerce, vol. iv. page 488. (W. S. Lindsay.)

enlarged to 680 ft. by 82 ft., were signed at the end of 1853. The hull and paddle engines were given to Messrs. Scott Russell & Co., of London, and the screw engines to Messrs. James Watt & Co., Soho Works, near Birmingham. Mr. Scott Russell wrote as follows to *The Times* on April 20, 1857:—"My share of the merit and responsibility is that of builder of the ship for the Eastern Steam Navigation Company. I designed her lines, and constructed the iron hull of the ship, and am responsible for her merits or defects as a piece of naval architecture. I am equally responsible for the paddle-wheel engines. . . . It is to the Company's engineer, Mr. I. K. Brunel, that the original conception is due of building a steamship large enough to carry coals sufficient for full steaming on the longest voyage. He, at the outset, and long before it had assumed a mercantile form, communicated his views to me, and I have participated in the contrivance of the best means to carry them into practical effect."

Sufficient capital was raised to build the ship, which the directors stated could be completed in eighteen months, and "which would, undoubtedly, according to all existing experience, pass through the water at a velocity of 15 knots an hour, with a smaller power in proportion to tonnage than ordinary vessels now require to make 10 knots." The first plates of the flat portion of the bottom were laid on May 1, 1854; but it was not till November 3, 1857, that she was ready for launching. The launching operation was, as is well known, a disastrous failure, and the vessel was not got into the water till January 31, 1858. The cost of the launch is said to have amounted to £120,000; and the Company's funds became exhausted. The vessel lay in the Thames for more than a year with all work stopped upon her, when she passed into the hands of a new company called the "Great Ship Company." She made her first steam trial in September, 1859; and as the trade for which she was originally intended could only be worked, if at all, by a number of such ships making voyages at regular, and not too long, intervals; with smaller vessels in the Indian Ocean to distribute the freight and passengers among the Eastern ports, this idea had to be given up. She was accordingly put into the Atlantic trade, and made nine Transatlantic voyages between 1860 and 1863. Upon the fourth voyage, with 400 passengers on board, the rudder head was twisted off and the paddlewheels damaged in a heavy gale, and the vessel was obliged to put back to Queenstown. On another voyage outwards to New York, she passed over a reef of rocks off Long Island Sound, which tore the bottom plating open in ten places, and made one hole 80 ft. long and 10 ft. wide. Her very complete subdivision protected her against anything more than local damage, and most of the passengers landed in ignorance of an accident which would probably have proved fatal to any other existing vessel.

The *Great Eastern's* speed upon the Atlantic sometimes reached 14½ to 15 knots average during one day, with a draught of water on leaving port of about 28 ft. Upon one voyage her speed averaged 13¾ knots outwards, and 14 knots homewards. The highest average speeds upon the Atlantic in 1852, when the *Great Eastern* was designed, were about 10 knots. It will thus be seen that the anticipations with regard to her speed were not without justification.

Owing to the impossibility of working upon the Atlantic at a profit, the ship passed into other hands, and was afterwards occupied chiefly in cable-laying. After the demand for her employment in this work fell off, she lay many years, uncared for, in Milford Haven, and was at last sold and broken up.

Mr. W. S. Lindsay says: "Though far from realising the expectations once entertained with regard to speed* and small consumption of fuel, her failure is mainly to be attributed to the fact that, at the time she was constructed, there were no lines of traffic on which a vessel of such huge capacity could procure, with despatch, the amount of freight or passage money necessary to insure a profit."

The *Great Eastern* was a failure commercially; but, from a mechanical point of view, she was in all her main features successful to a degree that was marvellous, when compared with the standard of the time. Mr. Brunel did not know the "law of comparison," taught us by the late Mr. Froude, which shows how the power required to drive a ton of displacement at a given speed in a small ship becomes reduced as the dimensions are increased in similar ships; but he well knew the fact that the proportion of power to displacement becomes less as a ship is increased in size, for the same speed. He acted upon this principle in 1836 in the design of the famous Atlantic steamer *Great Western*, and carried it to an extreme length in the design of the *Great Eastern*.

Mr. Brunel said: "I never embarked in any one thing to which I have so entirely devoted myself, and to which I have devoted so much time, thought, and labour, and on the success of which I have staked so much reputation."† This will be understood when the responsibilities of the designer of such a vast and novel work are considered. Almost everything had to be thought out and arranged for, with but very little help from existing ideas and experience. Mr. Brunel said in one of his memoranda: "Every part has to be considered and designed as if an iron ship had never before been built; indeed, I believe we should get on much quicker if we had no previous habits and prejudices on the subject."

The lines were designed by Mr. Scott Russell upon his wave-line principle. The cellular construction of the hull, and the inner bottom, with the very complete

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* The expectations with regard to speed appear to have been fairly realised, though with a consumption of coals that greatly exceeded Mr. Brunel's estimates.

† "The Life of Isambard Kingdom Brunel, Civil Engineer." By Isambard Brunel. (Longmans, Green & Co. 1870.)

internal subdivision into watertight compartments—an arrangement that would fulfil the most modern and stringent requirements, as laid down in the recent report of the Bulkhead Committee—were due to Mr. Brunel. Investigations upon the rolling of ships, with special application to the design of the *Great Eastern*, were made for Mr. Brunel by his friend, the late Mr. William Froude; and, I think, we probably owe Mr. Froude's important contributions upon the Rolling of Ships to our Transactions to his association with Mr. Brunel in this matter. Mr. Froude employs in his first paper on the Rolling of Ships (Vol. II. of Transactions, pp. 219—221) data obtained from rolling experiments made with a model of the *Great Eastern*. Mr. Brunel also wanted to experiment upon the relative resistances in water of clean copper and painted iron surfaces, with the view, at first, of having the outer shell of the *Great Eastern* of wood, sheathed with copper. He appears to have finally settled upon iron, because of the difficulty of devising any means of dealing exhaustively with the question; and because he doubted whether, with a very long surface, the smoothness would much affect the total resistance.

Having dealt at much greater length with the subject of the *Great Eastern* than I would otherwise have done, because of the want of information in our Transactions respecting the design and performances of the most wonderful piece of naval architecture ever projected, I will pass on to some of the general questions involved by the growing demand for increased speed at sea.

There are already several ships that can cross the Atlantic at an average speed of over 20 knots, or 23 statute miles per hour. The *Campania* crossed from Sandy Hook to Queenstown, on her first voyage in May last, at an average of 21·3 knots, and during one day she averaged 22·3 knots. These speeds are a little over 24½ and 25½ statute miles per hour respectively. It is thus already possible to cross the Atlantic at as great a speed as journeys of the same length could be made on land by all but the fastest railway trains. The Canadian Pacific Railway, for instance, takes 5 days 19 hours between Montreal and Vancouver, a distance of 2,906 miles, giving an average speed of a little less than 21 miles per hour.

There are various standards by which the speeds of ships are judged. We have the trial speeds, which may be determined by a series of runs over a measured mile, or by runs over various distances in smooth water at sea; we have runs for a certain length of time in ordinary weather at sea; and, finally, we have the average speed which a ship can maintain, year after year, over the whole of her voyages in all seas and all weathers.

The last-named is the kind of speed now under consideration. Among the conditions essential to high speed, as thus defined, are:—(1) Great size of ship; (2) a form suitable for driving easily at high speeds over heavy seas without shipping heavy water, or lifting the propellers sufficiently to cause racing; (3) deep draught of water; (4) steadiness in a sea way; (5) great strength of structure and of machinery; (6) a large proportion of boiler power, so as to enable a full supply of steam for the engines to be easily kept; (7) a full and well-regulated supply of air to the furnaces.

Effect of Size of Ship upon Speed.—The well-known effect of size upon speed in still water, which is explained by Froude's "Law of Comparison," is not the only one that gives great size of ship an advantage at sea. There is an additional advantage at sea, in a large ship, due to the waves being smaller in proportion to the dimensions of the ship, and to the pitching motion being less in a heavy sea as a ship is increased in size. The speed of a ship at sea approximates more nearly to that obtained in still water, with the same propulsive power, the larger she is made. No doubt length is the principal element of size in this respect, but depth, or draught of water, is also very important. Whatever might be the speed obtained with a ship on trial in smooth water, the extent to which her average sea speed would afterwards approach this would depend very greatly upon her size. A striking proof of this is seen in the increasing regularity—as distinct from increase of speed—with which steamers make their voyages as their size is increased. The variations in length of voyage from the average become less with increase of size. The effect of size upon speed is the same in sailing ships as in steamers, and is shown by the reduction in the average times of voyages to Australian, and other far-distant ports, to which large sailing ships trade, as size is increased.

Effect of Form upon Speed.—The full effect of form upon average speed at sea, over long voyages and in all weathers, cannot be measured by still-water trials. The form that gives the best results in still-water trials, with any size of ship, does not necessarily give the best results at sea. It is sometimes said as an objection to model experiments, such as Mr. Froude taught us to make, and to still-water trials—which belong to the same category—that they do not tell us what the speed will be at sea, or what is the best form for speed at sea. The reply is that Mr. Froude never said they would. The late Mr. Froude always explained that his experiments merely related to speed in absolutely smooth water; and Mr. R. E. Froude reminded this Institution in 1883 (see Vol. XXIV. of Transactions, page 161) that his father was very particular in pointing out this qualification. He said, in speaking of the comparative resistance of long and short ships: "A diminution of the fulness of the ends, and concentrating the displacement in the middle of the ship, and removing it from the ends, is certainly likely to make the ship pitch, and it is not only objectionable on that ground, but the performance of such a ship in a seaway would, from that reason, be comparatively less favourable than in still water, because the pitching must certainly rather tend to increase the resistance. So that it is probable the gain in the performance which we find in trials to be realised by ships with fine ends in still water is greater than they would evince in practically working at sea."

If it ever be assumed that the best form of ship for a still-water speed trial is the best form for speed at sea, as herein defined, or that the sea speeds will bear a fixed relation to the trial speeds, Mr. Froude must not be blamed for the fallacy. Mr. Froude has given us a wonderfully ready and exact means of determining the resistances of ships in smooth water; but the designer is necessarily left to his own judgment and experience as to the modifying effects of bad weather and heavy seas—which are all-important upon such voyages as Atlantic steamers are designed for. I have crossed the Atlantic seven times, but it has never been my lot to find there a state of sea which even approximately resembled the conditions of a still-water trial. With fine lines forward and aft, such as would be most favourable to trial speeds, the speeds at sea might be considerably reduced; and it would be easy to improve the speed upon trial of some of the fast Atlantic steamers at the expense of their subsequent speeds at sea. The improvement of existing forms in suitability for Atlantic seas must, in my judgment, be looked for more in knowledge and experience of what such a sea requires than in mere still-water experiments. Some of the present steamers maintain an average speed of not more than a knot less than they obtained on trial with the same power, showing that their forms are almost as well adapted for speed in ordinary seas as in smooth water; and it would be easy, as I have said, if speed upon smooth-water trials were the crucial test, to considerably increase the latter at the expense of the former.

One of the chief points in connection with the form best adapted for sea speed is that it should offer resistance to pitching. The fineness of ends that would give the best results in smooth water requires to be corrected by the fulness necessary to prevent undue pitching. It is only the judgment and experience of the naval architect that can decide where the line is to be drawn between the two directions. If he err on the side of fineness, as tempted perhaps by the desire to obtain the highest possible still-water results, he will lose in speed when there is any sea; and if on the side of fulness, he will lose by excess of resistance in smooth water, and perhaps at all times. Mr. R. E. Froude has pointed out in the passage already quoted that pitching tends to increase resistance; but there is, in addition, the further consideration that it practically limits speed in a heavy sea. The engines require to be slowed as soon as a ship pitches so as to take heavy water on board or to lift the propellers sufficiently out of the water to cause racing; and it is the ship that moves easily over the seas without requiring the engines to be slowed on account of pitching that makes the best passages in bad weather. Circumstances which thus influence, and often limit, speed at sea are not taken into account in still-water experiments; and I doubt if it would be possible to arrange to do so, in a way that would be satisfactory, in any experiments with models.

Deep Draught of Water.—This is a most important element of speed at sea, and it is now strictly limited by the depth of water in the ports and docks used by the fast passenger steamers on both sides of the Atlantic. Twenty-seven feet is the extreme limit of depth to which a ship can load on either side. The *Campania* cannot load an inch deeper than the *Umbria*, although she is 100 feet longer. If the underwater dimensions of *Campania* had been increased proportionately to those of *Umbria*, her draught of water would have been 32½ ft. This class of steamers are increasing in length and breadth, but the draught of water has to be kept the same. The result is that it is only a question of time, and not of a very long time, with our present materials of construction and type of propulsive machinery, to find an absolute limit of speed imposed by the restriction of draught of water. The weight of steel in the hulls of this class of steamers varies almost as the cube of the linear dimensions in similar ships. This is a much greater ratio than is found in ships of smaller size, where thicknesses of material are often governed by considerations that are not directly related to the strength necessary to resist longitudinal straining at sea; but in these large ships, where the weight of much of the structural material is regulated mainly by the longitudinal strength required at sea, it is not safe to allow much less than the variation of weight named. This practically agrees, subject to certain qualifications, with the conclusions arrived at by Mr. Froude in his paper on "Useful Displacement as Limited by Weight of Structure and of Propulsive Power," read before this Institution in 1874. Mr. Froude there showed that, in similar ships of equal strength the weight of hull would vary as $\frac{\text{length}^4 \times \text{breadth}}{\text{depth},}$; and that, consequently, the weight of hull would vary as the fourth power of the length, whether the length only were increased, or all three dimensions were increased in the same ratio. This was based upon the assumption that the straining actions are those due to waves whose heights are proportional to their lengths. There is doubtless a small reduction due to the fact that the heights of sea waves do not increase quite in proportion to their lengths; and there is, besides, the important practical qualification that a large portion of the structural materials does not play a great part in resisting longitudinal straining action. The result of my own experience of some of the largest steamers is that, in cases where the strength to resist longitudinal straining action at sea appears to be about the same, the weight of steel varies, or would vary, if corrections for the want of exact similarity were made, about in proportion to the cube of the linear dimensions.

What Mr. Froude really shows is that, those portions of a ship's structure whose strength is relied upon for resisting longitudinal straining action at sea require to vary in weight as the fourth power of the dimensions under the conditions he states.

Much of the structure of a ship, however, does not contribute materially to longitudinal strength, and does not require to be increased in weight, in the same ratio, with increase of dimensions. This, together with the reduction in amount of straining action due to diminution of the ratio of height to length of waves with size, must be taken to account for the fact, that the variation of weight of structural materials found to be sufficient in practice is nearly as the cube instead of as the fourth power of the dimensions. With regard to the woodwork, fittings, and equipment that go to complete the total weight of a ship's hull, their weight does not as a whole vary at such a high rate even as the cube of the dimensions. If a ship's dimensions only are increased, all in the same ratio—keeping the same number and thickness of decks—much of the woodwork, such as the wood decks and the work upon them, would only vary as the square of the dimensions. The final result is that, in similar ships of the largest size, the total weight of hull may be taken to vary as rather less than the cube of the dimensions. No doubt the rate of variation is kept down by the fact that, as ships are increased in size, the details of the structural arrangements and the riveted work are all carried out with greater care and efficiency, and with the result of obtaining more perfect continuity of strength, and consequently greater strength out of the same weight of materials.

While the weight of the whole hull varies approximately as the cube of the dimensions, the displacement can only vary as the square, in similar ships, so long as the draught of water is fixed. Hence, a point would ultimately be reached beyond which increase of displacement would be exceeded by the increase in weight of hull necessary for the requisite strength of structure; and beyond which speed would be limited by inability to carry any more engine power.*

It is not only that the present limited draught of water will finally impose an absolute limit of speed, other conditions remaining the same, but it has already a very prejudicial effect in keeping down speed at the point actually reached. If the draught were not restricted, the form of section could be improved by giving to it more rise of bilge and an easier curvature. The resistance could be reduced by giving the section such a form and proportions as would increase the draught of water. At the load draughts of the present ships, the indicated horse-power required for a given speed does not vary as the displacement with increase or diminution of draught of water. It often varies as about the $\frac{2}{3}$rds power of the displacement. In some cases it may be as low as the square root. In other words, as the displacement is increased by increase of draught, the power required to drive a ton of displacement at a given speed becomes reduced. Hence increase of draught does not mean a proportionate increase

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* See "Note sur la Loi de la Variation du Poids de la Charpente des Navires avec les Dimensions, et sur la limitation qui en résulte dans la grandeur absolue," by M. Augustin Normand, member of this Institution, and see also my own remarks on the same in the Bulletin de l'Association Technique Maritime, No. 3, 1893.

of engine power, even when such increase is obtained merely by extra immersion, without any improvement of form such as would otherwise be possible.

The advantages of increased draught would be felt still more in a seaway than in smooth water, as the lower part of the hull would be less affected by the wave surface, and better and more constant immersion could be given to the propellers.

Steadiness in a Seaway.—Steadiness is important, not only as a very desirable element of comfort to passengers, but also as contributing to speed. When a vessel is rolling heavily from side to side her resistance must be increased. This is shown by the fact that whereas bilge keels have an appreciable effect upon speed on a smooth water trial, they cause no reduction in speed upon sea voyages—at any rate, that is my own experience. The advantages of bilge keels are well known in the Royal Navy, but they are not generally understood in the Mercantile Marine. They are often objected to on the ground of the increased frictional resistance they offer. This increase of resistance is, however, fully compensated for at sea by the reduction of resistance due to diminished rolling. The following is a typical case. I was consulted several years ago about the design of one of the largest and fastest passenger steamers, and recommended that she should be fitted with bilge keels. This was opposed by all who had to do with her, and they were not fitted. One of the managing owners informed me afterwards that the ship rolled very badly, and asked my advice. I recommended him again to try bilge keels, and they were fitted for about one-third of the length of the ship, their depth being 2 ft. 3 in. She has now been running four years with the bilge keels, and the result is that she is reported not to roll to more than one-half the extent she did before, and not to show any difference that can be detected in speed or coal consumption. The success has been so marked in this instance that the other ships of the line have since been similarly fitted.

It would add greatly to the comfort of passengers if rolling could be reduced in these large steamers; and bilge keels furnish a ready and certain way of doing it, when they are properly fitted and are of appropriate size. The objection in some of the largest ships is that the docks they have to use do not admit of it. None of the fast Atlantic steamers are so fitted. Rolling chambers, containing water free to move from side to side, have been tried in some ships; but, I understand, they have sometimes failed in their action under the worst conditions of the heaviest rolling. The *New York* and *Paris* were fitted originally with rolling chambers; but I am not aware that they were ever used.

Strength of Structure and Machinery.—This is a matter of the greatest importance in all steamers that require to make quick passages in bad weather, as must be self-evident, and I need not say much upon it. A good margin of weight pays in the long run, both in hull and machinery, by reducing the amount necessary to be expended annually upon up-keep and repairs, and preventing the taking a costly vessel off her station, and losing her earnings, occasionally for the purpose of repairs. It also contributes materially to the maintenance of a high average speed by preventing temporary breakdown or stoppage of machinery at sea. It is a question, however, whether the limit of length has not now been reached with the present structural arrangements; and whether the promenade deck, shown in the *Campania's* section, Fig. 4, Plate XVII., should not, as a next step, be made the structural upper deck of the ship. This would be approaching more nearly to the proportions of the *Great Eastern.* It would necessitate some modification of the arrangements under the present promenade deck; but this is a step which now appears to be called for, and it would certainly be necessary, with any further increase of length, to increase the depth of the main structure of the ship in this manner. If this be not done the vibration is likely to be excessive, especially when the revolutions of the engines approach to synchronism with the period of vibration of the hull.

A Large Proportion of Boiler Power.—The necessity for this is also well known. The best results upon short trials are obtained with large engines and small boilers; but the best results at sea are obtained with smaller engines and large boilers. This is also an instance in which short trials fail as a standard of what can be done upon a long voyage at sea.

Twin screws are now becoming usual in the largest class of passenger steamers. They were a necessity in the latest Atlantic liners, if only because of the necessity of keeping down the size of the machinery by dividing it into two sets. The immunity thus given against total breakdown of the propelling machinery is now appreciated, and no single-screw ship is likely to be built again for the Atlantic passenger trade. The number of propellers is more likely to be increased in the future than diminished. The two engine rooms are usually divided by a middle line bulkhead; but it is necessary to have watertight doors in this bulkhead to admit of free communication between the two engine rooms. In the event of accident these doors would be closed. The objection often made to a middle line bulkhead, that water upon one side would list the ship, is met by the arrangements for admitting water ballast upon one side of the double bottom, which would counteract any such list.

The improvements that would have the greatest effect in promoting the increase of speed at sea are: increase of depth of water in harbours and docks, such as would admit of much greater draughts of water being obtained; and improvements in boilers, by which greater steam power could be developed out of the same space and weight. Mr. Milton is to read a paper upon Water-tube Boilers, a type of boiler to which many are looking with hope for the future. In the matter of boilers, however, it is necessary to move very cautiously, and, above all, to run no serious risks. Stronger qualities of steel may also be obtained; but the tensile strength of steel used is not a measure of its efficiency for all the purposes of a ship's structure. The present steel is 40 or 50 per cent. stronger than the iron that was formerly used; but it cannot be reduced in thickness so as to save more than 12 to 15 per cent. in weight. In any improved material that may be introduced, the rate of elongation with tension, or, speaking more generally, the relation of strain to stress may be more important than the mere tensile strength, as a ship's hull requires to be very rigid, and to be practically free from movements due to stretching or compression of materials.

The Atlantic trade is increasing at such a rapid rate that larger and swifter ships are certain to be soon called for. The depth of water has lately been somewhat increased at Liverpool; but much deeper harbours and docks will be required if further great increases of speed at sea are to be obtained without excessive difficulty and cost.

I have taken out of this paper some remarks upon the very important questions of the internal subdivision of the hulls of the largest class of steamers, the precautions necessary to make it effective in an emergency, and the degree of safety that should thus be insured in the event of accident by collision or other cause of damage. With the news of the dreadful catastrophe to H.M.S. *Victoria* still ringing in our ears, and the circumstances connected with it not yet fully brought to light, I have considered it undesirable to attempt to deal with a section of the subject of the paper which cannot at present be thought of apart from its possible bearing upon this great national disaster. I would only add, in view of Sir Edward Harland's remarks, at the last spring meeting, upon the manner in which the Report of the Bulkhead Committee has been received by those for whose benefit it was framed, that when the design of the *Campania* was first referred to me I had the question of internal subdivision looked into and carefully compared with the recommendations of the Bulkhead Committee: and it was finally arranged so as to carry out those recommendations in the most complete manner, and to rather exceed the requirements laid down in the Report.

DISCUSSION.

The **CHAIRMAN** (Sir N. Barnaby, K.C.B., Vice-President): We have, Gentlemen, with us to-day the designer and builder of the *Teutonic* and the *Majestic*, Sir Edward Harland. If he will favour us with a few remarks, I am sure we shall be very much indebted to him.

Sir **EDWARD HARLAND**, Bart., M.P. (Member of Council): Mr. Chairman and Gentlemen, you pay me a very great compliment by suggesting that I should enter upon a discussion of this most valuable paper that we have just heard read. I had not had an opportunity of seeing it before I came into the room, but I think that the views contained in it are completely in accord with my own. Perhaps Dr. Elgar will permit me to compliment him, as far as I have any right to do so, upon producing one of the most interesting papers that I have heard read. I think he takes a most practical view in many respects, in addition to which he brings us down to the present day. He dwells as a matter of comparison on the difference between the magnitude of the *Campania* and the *Great Eastern*. I must say I fail to share with him his admiration for the *Great Eastern;* but the circumstance that the builders, and even the ship herself, are now no more, makes me very reluctant to offer a word of criticism. I must confess during the building of that ship I was very much struck with the boldness of the designers; in fact, I envied their possession of such a mass of matter to turn into the great structure which they had the power to do. I then only wished that I had the same material of which to build two ships instead of that one, for I think they should have built two ships; that experience had hardly warranted their embarking on such an undertaking, and that they took a much more gigantic stride than was warranted in turning that material into one ship. Unfortunately for the owners, she proved a lamentable failure, not even surviving the period of her condition as a steamer, though so many of our ocean steamers were, after their day, turned into very fine and useful sailing ships. With reference to her in other respects, I will only say in passing, referring to her construction, that the machinery and the propelling power in her were, to my mind, simply two masses of very miserable failures. In the first place, as to her screw propeller, the power was applied to one screw; but even to-day there are single-screw steamers crossing the Atlantic with great success, yet with far more power applied than in the *Great Eastern* to the paddles and the screw combined. If the stroke had been a little shorter, the engines would hardly have been able to do more than turn themselves round. One of the greatest strides that we have had in marine engines has been the increase of stroke, which was so very deficient in the *Great Eastern.* Paddles should not have been applied to such an immense hull capable of rolling to such angles, and making it almost certain that one paddle was bound frequently to be out of the water. You must bear in mind that if she left in fair trim with the paddles she had, she was bound to arrive at the end of her voyage quite out of trim. I think we must pass the *Great Eastern* as a melancholy illustration of great ambition but great ignorance. Now, with regard to the launch, I was over here before it, and I must confess I would have ensured a successful launch. I am convinced, if Mr. Brunel had given the order to let her go, she would have been safely afloat in the course of a couple of minutes; but he was afraid that one end might arrive so much earlier in the water than the other that he adopted a scheme, very ingenious, but very risky, for stopping her speed when being launched. She was checked when going down the ways, which otherwise were very admirably constructed for the passing over of a weight that was only to rest for a moment, and the result was that the ways were not able longer to support the ship in that position, whereas, if the order had been to let her go, she would have been afloat in the course of a moment or two. In reference to the *Campania,* as she is the last and most magnificent type of the Mercantile Marine that we have, I should have been glad if Dr. Elgar had favoured us with a comparison between the *Campania,* the *New York,* and the *Paris,* or the *Teutonic* and *Majestic* ships, more near her size and more near her age. The comparison with the *Great Eastern* is artistic, but it has no practical advantage to us whatever, and I am quite sure that in the next paper with which Dr. Elgar favours us he will kindly compare this last splendid specimen with her more recent predecessors whose names I have given. In that case it would be a still more valuable paper. We have now arrived, I think, at almost the highest position in ocean steaming, taking the Atlantic as being the great ferry for the last and finest specimens, and, perhaps, for the two reasons which Dr. Elgar gives. The first being the draught of water, we must be pleased to find, not only in Liverpool but in New York, that this has been very much increased; and, if I mistake not, the *Campania* is able to leave those ports more nearly at 29 ft. draught of water than the draught given. It is so much in excess of what I should have dreamed of some few years ago as to encourage owners and builders to go in for vessels so large as the *Campania*. So essential is this draught of water in order to gain strength of structure in our ships, that the more it is increased the more you can increase their magnitude. If you increase your length you must of course have more depth. We are now able to increase dimensions on account of the magnificent material of which we build our ships, the steel of the present day being somewhat like copper in its ductility. Dr. Elgar has said that it is perhaps wise to put another deck on. There are advantages and disadvantages in this, and, in the view that everything you put on has a tendency to put the ship deeper down in the water, you will see at once, that the poor owner will have but little left, wherewith to earn a profit, if you build the ship so heavy that she will require too much of the draught of water available. That is a point of economy which has to be carefully considered. For we must remember that, unless the builders and designers of ships can produce vessels that will pay the owner, we must give up, because to the owner we are indebted for his orders; and unless we take a commercial view in building these ships neither party will gain his object. With reference to other points, I must thank Dr. Elgar for referring to the matter of subdivision of ships by the Bulkhead Committee. I have the pleasure of the friendship of Mr. Laing, one of my associates upon that Committee, and I can bear testimony to the very great care and labour which was devoted to it. If after our labours were finished, so eminent and able a man as Dr. Elgar has thought it worth his while to follow the recommendations of that Committee, as he says in this paper, we cannot but feel it a very great compliment indeed, and no small return to us for the attention that we gave to the subject. I can say no more, as the time is short, otherwise I should like to have made some remarks on some other points. Permit me to congratulate Dr. Elgar for his very excellent paper.

Professor J. H. Biles (Member of Council): Sir Nathaniel Barnaby and Gentlemen, personally I have to thank Dr. Elgar for reading this paper, and for the many suggestive points he has thrown out in it. The comparison of the *Great Eastern* is very interesting, and recalls one of the finest specimens of ship's structure that we have ever seen. That is the opinion I have formed of it, and that opinion has been formed by others better able to form an opinion than I am. In looking through the sections of the *Great Eastern*, I notice one striking difference between it and the *Campania*, and that is that the double bottom of the cellular structure is carried up to the lower deck. That must have afforded in that ship an element of stiffness the absence of which in our later ships is in no way made up for. In the case of the *Paris* and the *New York*, which were rather earlier than the *Campania*, the double bottom was carried up to the height of the first keelson. That is shown in the *Campania* section, above the double bottom, and from that point up to the lower deck, a system of very wide web frames was carried, somewhat similar to the *Great Eastern*. That was to some extent a substitute for the enormously stiff cellular structure of the *Great Eastern*, but I do not think it was in any way so stiff. I gather from Dr. Elgar's paper that he rather thinks we have reached the limit of length in Atlantic steamers; at any rate, with the present system of structure. I am not quite sure that he is right in that.

Mr. F. Elgar, LL.D., F.R.S.E.: I do not think I say that. I say we shall ultimately reach it.

Professor J. H. Biles: On page 33 I see this sentence:—"It is a question, however, whether the limit of length has not now been reached with the present structural arrangements."

Mr. F. Elgar: That relates merely to the permanent deck. Whether it should be retained as a light deck, or whether it should be the principal deck of the ship.

Professor J. H. **Biles**: I gathered from the general tone of the paper that the structural arrangements in general limited the length of ships, and from the consideration that the weight of the ship varied as the cube of the dimensions. I do not think, as we increase the size of the ship, *that necessarily* follows. If we measure the strains on the ship by the same standard as we have been in the habit of measuring, as we increase the length of the ship that would necessarily follow. We assume that the longitudinal strain is the strain which is brought on a ship when she is supported on a wave of her own length, and of some definite proportion of height to length. There must come a time when that condition does not exist as a testing condition in practice. If we had ships a thousand feet long they would not be so likely to meet waves of a thousand feet in length as a ship 600 ft. long would be to meet a wave 600 ft. in length. Therefore I think that the ships will to some extent, as they grow in size, meet with less proportionate strains than they do at the present size. Further than that, the consideration that the whole of the weight of a ship should be increased to meet the extra longitudinal strains does not, I think, hold. Of course, Dr. Elgar has pointed out that there is a considerable part of the ship which is not subject to longitudinal strains, and which is not consequently necessarily increased with it. On page 34 he gives us something that bears upon that point. He says:—"The present steel is 40 or 50 per cent. stronger than the iron that was formerly used; but it cannot be reduced in thickness so as to save more than 12 to 15 per cent. in weight." Now I think from that we can safely infer that the part that contributes to longitudinal strength is not so great as would involve the cube of the dimensions. The maximum strain that is brought upon a ship exists for a comparatively short length of that ship, and if you trace the strains that are brought upon a ship, even upon a wave of her own length, through the whole of her length, you will find they fall off very rapidly; and if you follow up the principle of producing a ship to resist a strain on a wave of her own length, you would necessarily have to carry the investigation of stresses through the whole ship. You can confine the calculation to the part most severely strained, but it does not therefore necessarily follow that the weight of the structure of a ship should increase at anything like the rate of the cube of the outside dimensions. There is another point which is very interesting, and one which Dr. Elgar has treated in an admirable way, if I may be allowed to say so, and that is the question of the effect of the fineness of the ends on a ship's motion in a seaway. Fineness is rather an indefinite term. Fineness of water-line is one thing, fineness of cross section is another thing. It is possible to have a very fine water-line, and to have a comparatively full cross section. You can have a ship fine-ended on the water-line, and if you carry the floor well forward, she is to all intents and purposes a full-ended ship. I remember once crossing in a ship in which we were in what appeared to be practically smooth water. There was the long ocean swell, and the ship pitched to as violent an extent as she had in the most heavy weather. I took the trouble to count the speed of the wave in relation to the pitching period of the ship, and they coincided within two-tenths of a second. If the period of the waves fitted in with the period of the ship, then the vessel would have pitched just the same. Shear and freeboard forward affect the pitching of fine-ended ships. These matters have to be taken into account in saying whether a form that is good for smooth water is good or not for rough water. The rounding of the section that Dr. Elgar refers to would be an advantage; but I think the reason that sections are not so round as one would like to see them is that one is tempted to get as much displacement in a section as possible. There is one other point to which Dr. Elgar has made reference—the rolling chambers of the *New York* and the *Paris*. These chambers were fitted as the result of a series of experiments that were made on a ship in which a temporary tank was fitted. This temporary tank gave a reduction of rolling from 50 to 60 per cent. They were fitted in the *New York* and in the *Paris*, but the vessels proved themselves to be good sea-boats without the tanks, and the pressing commercial necessity of the owners caused them to fill these tanks with cargo. They filled them up with cargo, and they have continued to fill them up ever since, finding that they got more by cargo than when they were half filled with water. If, however, there was any necessity to reduce the rolling of these ships, these tanks could be made to do it. I wish to thank Dr. Elgar for the very able paper he has given us, and the many suggestive points which are contained in it.

Mr. W. H. White, C.B., LL.D., F.R.S. (Vice-President): Mr. Chairman and Gentlemen, I had not the least intention of joining in this discussion, which deals with matters of great interest, but respecting which I have little personal experience. There are, however, certain points of a general nature to which I should like briefly to refer. I am extremely glad that Dr. Elgar has rescued from old volumes of the Transactions the truth as to what Mr. Froude did and said in relation to the effect of form on speed, and particularly in relation to the influence of fineness at the ends upon speed at sea. I would add a word to that statement. Mr. Froude never said a word against the beneficial influence of increase of length on economy of propulsion. He was dealing always, in his work for the Admiralty, with types of ships where length had necessarily to be limited in connection with protective arrangements. The conditions are altogether different as between ships built for passenger traffic and war-ships built to attain high speeds, to carry armaments and armour defences. That point is often forgotten by critics of Mr. Froude's statements, who have not taken the trouble to go to the fountain head and find what he really did say. In our practice in the Admiralty we have been always most careful to distinguish between sea work and smooth water work. In our model experiments we often find that, with a given length, increase of breadth amidships, with well rounded lines, and extremely fine ends, will give us a more economical propulsion in smooth water. But those forms have, in many instance, been deliberately set aside in favour of forms with less fineness at the ends, and less breadth amidships, although somewhat greater power was needed for propulsion in still water. Taking our experience as to the change of form which came into Admiralty practice in consequence of the experimental inquiries made by Mr. Froude, we can say that, working under our conditions, we have obtained enormous economy by following on the general lines he laid down. If gentlemen will refer to the paper I read in 1886, on "The Speed Trials of Recent War-ships," it will be found that we have absolutely succeeded in driving vessels like the *Collingwood* (which my friend Captain Fitzgerald until recently commanded), 325 ft. long, as economically as the *Warrior*, which was 380 ft. long. In that paper also will be found some facts which have a direct bearing upon Dr. Elgar's remarks on the influence of draught of water upon economical propulsion. The *Collingwood* was tried at a displacement of 8,200 tons, and a sister ship at a displacement of 9,600 tons, this greater displacement being due to an increase of nearly 3 ft. in draught of water. With 9,600 H.P. the *Collingwood* attained a speed of 16·8 knots; and with the same horse power the *Howe*, although of 1,400 tons greater displacement, could be driven about 16⅓ knots. This matter of draught of water available in ports and docks obviously has an important bearing upon possible economies in the future of steam shipping. Experience at sea with fine-ended war-ships, of limited length, has, on the whole, been favourable. They have not proved to be liable to excessive pitching. In war-ships, moreover, the speeds in relation to length are often very high, and merchant ship proportions are impossible. I may refer to one class as an example. In the *Apollo* class we have a length of 300 ft. and a displacement of 3,400 tons. Those ships have been frequently driven at sea at speeds of 18 to 18½ knots an hour, and on the measured mile at 20 knots. It will be admitted that such a performance is a very useful model experiment for guidance in future designs. This high working speed has been obtained in vessels of small size, and which have proved themselves to be excellent sea-boats. Personally I have always favoured increase in length up to the full limit we can afford to go in connection with our conditions of defence, but we are always suffering in war-ship construction by being asked to "put a quart into a pint pot," and to produce vessels of very moderate dimensions. I can only envy gentlemen who can build vessels like the *Campania*, of great length in relation to speed, and who have simply to deal with propulsion under fairly uniform conditions. Commercial considerations come in of course in the design of all merchant ships. But when one analyses the essential features in fast ocean steamships, and compares them with the limitations imposed on the designs of war-ships, I say again the war-ship designer must in many respects envy the private designer his greater freedom. In relation to the utility of bilge keels, I entirely endorse what Dr. Elgar has said. He will agree with me, however, when I say that as the size and inertia of ships increase, so the useful effect of bilge keels must diminish. In some cases, with which I have had to deal, actual experiments have shown that no bilge keel that could be fitted would have produced any sensible effect. That stage must be reached in other than war-ships, although in war-ships with their distribution of weights the inertia is greater. In mercantile steamers the stiffness is less, and the period of oscillation probably about the same that we have to deal with in first-class war-ships. It is unnecessary for me to add more than to say that, in putting before us this historical description of past work and these weighty considerations and suggestions as to future practice, Dr. Elgar has conferred a great benefit upon the Institution.

The Chairman (Sir N. Barnaby, K.C.B., Vice-President): It has been found to be desirable not to take the third paper down for reading this morning, as we should have to limit the time for the discussion of that most valuable paper; and, seeing that there will be another opportunity to take Mr. Hamilton's paper, it has been decided that it shall not be read to-day.

Mr. B. Martell (Vice-President): Mr. Chairman, I merely wish to make one remark on this valuable paper of Dr. Elgar, which has been discussed so ably by those more capable of criticising it than I am. I think it is a most excellent and valuable paper, most suggestive, and deserving all the praise that has been given to it. I wish, however, to draw your attention to one remark on page 33, where Dr. Elgar suggests that in these large ships the main structure of the ship should be continued up to the permanent deck. I cannot, like Sir Edward Harland, go into the commercial disadvantages of that, but I only hope that such can be done, because I am quite certain it would be one of the best means of minimising that excessive vibration which we know many of these ships with such great proportionate length to depth experience. In such enormous ships as we have now we have very little experience of the numerous stresses to which they are subjected. What we know at the present time gives a very imperfect knowledge of the enormous stresses to which some of these ships are subjected, and in increasing the depth, I am quite sure it would add immensely to their longitudinal strength, making them very much more efficient structures, whilst diminishing the vibration experienced by many of them. What can be done in the structural arrangements to meet this, so as not to interfere with the comfort of the passengers and their convenience, I cannot say, but I have no doubt that difficulty will be overcome, and I believe it is essentially necessary; and ultimately, in building these large ships I believe it will be invariably the case, that the depth will be considerably increased. I have only one more remark, and that is with regard to bilge keels. Dr. Elgar, in making his remarks, does not state to what extent these bilge keels are used in merchant ships. They are adopted to a very considerable extent; and, although they may not produce very much effect in large passenger ships, in large cargo ships they are exceedingly useful, and they are very largely fitted. When undue rolling has been found to be the case they have diminished it very considerably. There is only one thing, and that is the danger that is likely to arise by the bilge keel coming into contact with something, and disturbing the rivets. Leakage has taken place owing to this in some cases; but, to obviate this, all the rivets should be tap rivets, so that if the bilge keels were carried away, the hull of the vessel would be left intact.

Mr. F. Elgar, LL.D., F.R.S.E. (Vice-President): I am very gratified by the manner in which this paper has been received, and particularly by the complimentary remarks of Sir Edward Harland. I have only two points to refer to in connection with Sir Edward Harland's remarks. He appears to be under the impression that I proposed an extra deck for this class of ships. What I suggest, however, is not an addition to the present number of decks, but that the present promenade deck, instead of being a light structure that contributes but little to the strength or stiffness of the hull, should be made the upper structural deck of the ship. I would effect this by means of a re-distribution of weight, taking some of the material from the neighbourhood of, and from below the present upper deck, and transferring it to the promenade deck and its connections with the hull. We might thus get a stronger and stiffer ship with the same weight of material as that now employed. I would be very pleased to comply with Sir Edward Harland's suggestion to compare the *Campania* with the *Teutonic* and *Majestic,* and the *New York* and *Paris,* if I could obtain full and authentic particulars of those ships; but this would be impossible without some assistance from Sir Edward Harland himself. If he would kindly furnish me with the necessary information respecting the *Teutonic* and *Majestic,* I would try to obtain it for the *New York* and *Paris,* and would then make the comparison referred to. I am reminded that our time has already been exceeded, and as there appears to be very little more needed in the way of reply, I will only add that the rate of variation of weight of steel, with dimensions I have named, is the actual rate of variation found to exist in ships of 450 ft. long, and over, that are similar in form and construction and appear to be equal in strength. This rate of variation is, however, I consider, confirmed by theory, as explained in the paper. I agree, of course, with Mr. White that the steadying effect of bilge keels theoretically diminishes with size, or moment of inertia of ship; but the transverse moment of inertia has not yet reached the point, in any ship in the Mercantile Marine that I know of, to affect the practical application of my remarks on the subject.

The Chairman (Sir Nathaniel Barnaby, K.C.B., Vice-President): Gentlemen, that this paper has been a most valuable one we all agree. If Dr. Elgar can add the information which has been suggested we shall be very pleased.

PRELIMINARY PROCEEDINGS.

WEDNESDAY, JULY 12, 1893.

The **President** (the Right Hon. Lord Brassey, K.C.B.): Gentlemen, in opening the proceedings of to-day, I have to express my extreme regret that I was not present yesterday. While I feel that sincere regret at what would appear to be a failure of duty on my part, I am confident that, as no man is indispensable, certainly I am not indispensable in order to ensure success for the Summer Meetings of the Institution of Naval Architects. The Council of the Institution is brim full of men far more able to discharge the office of President than I can pretend to be. It is not expected or desired that the President should interpose on this occasion with any lengthened remarks, but I cannot deprive myself of the opportunity of saying that the Members of the Institution of Naval Architects attach great value and importance to their Summer Meetings. Those Meetings afford to the Members of the Institution very valuable opportunities for mutual consultation and conference upon professional topics. They also afford the opportunity of personally visiting the great ports of the kingdom, and among those ports there is none which offers more objects of interest to professional men than this great Port of Cardiff. Its docks, its shipping, its appliances for loading and discharging ships, the great establishments and the metallurgical industries which surround the place are all of the deepest interest to the Members of the Institution of Naval Architects. There are other reasons why we attach value to our Summer Meetings. We feel that if this Institution is to stand on a broad and enduring basis, it must be in touch with every port of the United Kingdom, and we can conceive of no means by which that object can be more successfully accomplished than by holding meetings, from year to year, at the various great centres of our shipping industries. Gentlemen, I must not detain you longer with general remarks. I have to refer to the papers which will be read this morning. We have, first of all, the paper by Mr. Ellis, who deals with the difficult subject of forced draught. Mr. Ellis's claims to be heard on any professional subject are too firmly established to make it necessary that I should make any personal allusion to his distinguished career as a great maker of steel and iron. I do not know any individual to whom the Navy is more indebted than to Mr. Ellis for his great inventions in the construction of armour plates. We have another paper also of great interest by Mr. Blechynden. He deals with the "Transmission of Heat through Boiler Plates." As one of those who, with Admiral Boys (who I am so pleased to see sitting near), are interested in the great shipping works at Barrow, I feel it a duty to pay a personal compliment to Mr. Blechynden. We have the best means of knowing how able he is, and how competent to prepare a paper on this important and interesting subject. My only regret is that Mr. Blechynden is not here personally to read his paper. Before we separate this morning, we shall have a paper by Mr. Hamilton on "Wear and Tear in Ballast Tanks." I believe Mr. Hamilton will be present to read the paper himself. Gentlemen, with these introductory observations I now call on Mr. Ellis to read his paper.

SOME EXPERIMENTS ON THE COMBINATION OF INDUCED DRAUGHT AND HOT AIR, APPLIED TO MARINE BOILERS FITTED WITH "SERVE" TUBES AND RETARDERS.

By J. D. Ellis, Esq., Managing Director Messrs. John Brown & Co., Limited, Sheffield.

[Read at the Summer Meeting of the Thirty-fourth Session of the Institution of Naval Architects, July 12th, 1893; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

In these days of triple and quadruple expansion engines and high speed for ships, I trust some remarks and results of experiments on the economical and efficient production of steam for marine boilers will not be uninteresting to the members of this Institution.

The combined use of strong artificial suction draught, "Serve" tubes, and retarders, and further utilising the heat of the gases when they have left the boiler, seem to me the natural outcome of the requirements of the day.

The engine-power demanded by the present ships has advanced by leaps and bounds, and two of the latest built have reached a power of over 30,000 I.H.P. each. It has therefore become an urgent necessity to obtain more work per cubic foot of boiler than hitherto, not only without loss, but, if possible, with a gain of economy.

The height of smokestacks for natural draught has increased with the increase in the size of the ships, and thus a vacuum of about half an inch of water has been reached, being nearly twice as much as had been obtained only three or four years ago in the great majority of vessels with natural draught. In other vessels the draught has been artificially increased by blowing air into an open or closed stokehold or closed furnace. Mr. Martin has worked in the direction of exhausting the gases by fans in the funnel, instead of forcing the air into the boilers. Jets of steam or compressed air in the funnel have been tried to obtain an increase of draught. Mr. Howden has, in addition to his forced draught, utilised some of the heat of the waste gases by heating the air, making it pass round a nest of short vertical tubes through which the waste gases go from the smokebox to the funnel. In other cases the air has been heated slightly by the heat which would otherwise have been lost by radiation. Retarders have been used by Mr. Howden in plain tubes with forced draught to bring the swiftly passing gases into better contact with the heat-absorbing surface, and have thereby, as well as to some extent by radiation, been a source of economy.

The advent of the "Serve" tubes has marked another important era in the history of boilers. The heat-absorbing surface of the "Serve" tube is much greater than that of a plain tube of the same outside diameter, and a retarder placed in the centre of the "Serve" tubes makes, for a draught of three-quarters of an inch, and over, of water pressure or vacuum, the most efficient and economical combination I know at present.

Having ascertained in ordinary single-ended Scotch marine boilers the value of the "Serve" tube and of the retarder with different rates of draught, with Martin's induced draught with cold air, and Howden's forced draught with heated air, it seemed to me that a considerable improvement was possible over existing practice by combining and extending the best features of the various systems, and the accompanying drawing No. 1 shows this combination as it has been at work in boilers Nos. 7 and 8 for over twelve months at the Atlas Works.

I have preferred artificial "suction" draught to "forced" draught, because it seemed the natural way of increasing the efficiency, being "natural" draught intensified, produced by artificial means, merely because the equivalent height of smokestack cannot be used at sea. Seeing that in any case, whether the draught be suction or forced, a given quantity of air must pass through the boiler at a certain speed to produce a given combustion, and being of opinion that suction draught was less likely to produce trouble in the combustion chamber than forced draught at the high rate of combustion I had in view, the best means applicable at sea of obtaining this kind of draught had to be considered. Steam jets in the funnel could not be entertained because of the loss of the water. Air jets were doubtful. Fans had been tried for exhausting the gases, and the heat had given trouble even when burning at rates far below those intended by me, for to avoid the gases passing into the fans at a high temperature, the tubes had to be made very small in diameter, therefore liable to choke readily, and reducing greatly the amount of coal which could be burnt with a given rate of draught compared with ordinary sized tubes. Besides this the crowded tubes impeded circulation within the boiler. I knew the "Serve" tubes and retarders would reduce the heat of the gases appreciably within the boiler itself; but, as I desired to burn at the rate of 45 lbs. to 60 lbs. per square foot of full-size grate, therefore three or four times the rate of ordinary natural draught, the temperature of the gases escaping from the boiler into the smokebox would still be high, and required to be further absorbed for the double purpose of preventing difficulty with the fans and increasing the efficiency per pound of fuel A nest of short vertical air-heating tubes, as in the Howden system, would do good, but I desired something more, because I wished to burn at a higher rate. Thus I came to horizontal tubes, which are more effective than vertical ones, and which can be used of greater length. The ultimate combination and extension is shown in Plate XVIII., the leading features of the boiler being therefore—

(1) Suction or induced draught.

(2) The utilisation of the waste gases for heating the air before it passes into the furnace.

(3) "Serve" tubes.

(4) Retarders in the tubes.

The principal dimensions of the boilers are as follow:—

BOILER	Diameter of boilers	10 ft. 6 in.
	Length of boilers	10 ft. 6 in.
	"Purves" flues in each boiler	2
	Inside diameter of flue	2 ft. 10½ in.
	Length of furnaces	7 ft. 6½ in.
	Total number of tubes ("Serve")	118
	Outside diameter of tubes	3¼ in.
	Thickness of ordinary tubes	·116 in.
	Number of stay tubes	44
	Thickness of stay tubes	·144 in.
	Pitch of tubes from centre to centre	4¾ in.
	Total heat-absorbing surface of tubes	1303·6 sq. ft.
	Heat-distributing surface of tubes	741 ,,
	,, ,, furnaces	75 ,,
	,, ,, combustion chambers	95 ,,
	Total heat-distributing surface per boiler	911 ,,
	Area of grate surface	32 ,,
	Length of grate	5 ft. 8 in.
	Bars, 3 in. deep, ¾ in. thick, and ⅝ in. air space.	
	Proportion of grate to total heating surface	1 to 28·4
AIR-HEATING BOXES	In the heat-absorbing chambers there are	80 tubes (plain)
	Diameter of tubes outside	3 in.
	Length of tubes	14 ft. 4 in.
	Thickness of tubes	·116 in.
	Total heat-absorbing surface	900 sq. ft.
FANS AND ENGINES	Fan to each boiler	1
	Diameter of fan over tips of blades	5 ft. 6 in.
	Width of fan	1 ft. 9 in.
	Diameter of engine cylinders (two cylinders)	7 in.
	Stroke	5 in.

It will be seen that the boiler itself is an ordinary single-ended Scotch type marine boiler, with "Purves" furnaces and "Serve" tubes. The combustion chamber is fairly large for the size of boiler. The tubes, 3¼ in., outside diameter, are spaced somewhat further apart than is customary now, and good circulation of water and ready escape of steam are thereby facilitated. In selecting so large a diameter of tubes—instead of the usual small diameters—for high rates of combustion, I was not concerned as to the amount of heat-"distributing" surface within the boiler, and this finally came out at the proportion of 28·4 square feet to one square foot of grate surface. Small plain tubes have been necessary previously for the sake of obtaining the utmost heat-absorbing surface; but by using the "Serve" type of tube, I obtained much more heat-absorbing surface with the smaller number of 3¼ in. tubes widely spaced, than could be done with a large number of small diameter plain tubes closely pitched. The advantages are obvious. Increased section for the passage of the gases; increased heat-absorbing surface, and better circulation of the water and escape of steam. Events have proved that in these boilers prolonged evaporation can take place, without trouble, and from cold feed, at unprecedented rates for this class of boiler.

The grate is in two lengths—the bars are ordinary wrought-iron bars, 2 ft. 10 in. long by 3 in. deep, ¾ in. thick at top by ¼ in. at bottom, spaced ⅝ in. apart. The only departure from ordinary practice is that the grate for high rates of combustion, say, over 35 lbs., rises towards the back (2 in. in 5 ft. 8 in. total length), instead of falling about 2 in. as is usual. Up to 35 lbs. per square foot the grate may be horizontal. I did not arrive at this conclusion without considerable experiment. At one time it seemed as if I should require to have recourse to a tubular grate with air or water passing through the same; but, realising the objections to such grates, I persevered, after having repeatedly burnt down in half an hour a new wrought-iron grate composed of bars as above, sloping downwards. The gradual raising of the back end to 2 in. above front end has resulted in our being entirely relieved of all anxiety as to the grate, even when burning at 60 lbs. per square foot.

For convenience of admission of the air in proper quantities above or below the grate, I use the cast-iron mouthpieces introduced by Mr. Howden, and have modified them to my requirements. The Howden mouthpiece has one valve over the fire, and two at the side for the air to pass under the grate. I have added two valves over the fire, as I found the usual practice gave incomplete combustion with certain classes of coal, because it did not admit sufficient air over the grate. In our boilers the three top valves are wide open, and the two side valves shut, for smoky coal, and *vice versâ* for non-smoky coal. A number of small holes in the bottom furnace doors allows a certain quantity of cold air to be drawn in under the grate, and it is only the heated air which is put sometimes over, sometimes under the grate, according to the nature of the coal. Thus we have found every sort of coal can be burnt with economy without smoke.

The accompanying tables of experiments give the results of various classes of coal, moderate and high rates of combustion, short and long trials, and grates cleaned at great and smaller intervals. These results, I trust, are individually and collectively interesting. I have endeavoured to eliminate all circumstances which might make the results doubtful. For experiments, the water is taken from tanks made of cast-iron plates planed to template. The inside dimensions are 4 ft. 5 in. by 4 ft. 4¼ in. by 9 ft. high. One inch depth of water equals ten gallons = 100 lbs. The quantity pumped into the boilers can be read off at any time by the scaled gauge glasses. The coal is weighed out carefully as the trials proceed. Mercury thermometers are used for temperatures to 600° F. Only one indication needs the means of measuring a higher temperature, viz., the smokebox. For this we use now metals of which the melting-point is well known, in preference to any kind of pyrometers. The trials commence with the fires burnt down to a minimum, and finish, as near as possible, with the same height of fire and same condition. The tables show how the temperature of the gases is greatly reduced before they reach the fans, and the heat utilised by the high temperature of the air, and the satisfactory evaporation per pound of coal.

Leaky tube-ends are unknown, and coke-nests have been found to occur only with coal from certain mines. The heat-distributing surfaces evidently do their work well, one square foot of heating surface having evaporated as much as 16·8 lbs. of cold water (70°) per hour (see test No. 4) with Scotch coal for seven hours without cleaning the grate, averaging a combustion of 59·34 lbs. per square foot of grate over the whole period.

In our experiments we have already used South Wales, Newcastle, South Yorkshire, Scotch, Lancashire, Pennsylvanian, and Australian coal, and it is intended to continue the experiments until all the different kinds principally used in our Mercantile Navy have been tried, and the comparative results ascertained.

I am well aware that these experiments have been made on land, and with a comparatively low pressure of steam, but I am unable to see any sufficient reason why similar advantages and results should not be obtained at sea, if the system be adopted, provided care is taken to keep the boilers reasonably free from oil and solid matter. One ship thus fitted is working satisfactorily and several others will be running shortly.

Besides the principal advantages of high evaporation with economy and safety, thereby reducing the number of boilers (consequently the boiler space and weight hitherto required), the following further advantages appear to me not unimportant:—

Cool stokehold or engine-room, if the air supply is taken from the latter instead of the atmosphere.

Clean stokehold, the coal-dust being sucked into the boilers.

Absence of risk of burns to firemen, the flame at all times being sucked away from them.

Convenience to firemen, there being no valves to shut or open, when opening or closing the doors.

Smoke with unskilful firing is greatly reduced, and with careful firing need not occur at all, with any kind of coal.

Great elasticity of power under ready control.

Greatly reduced quantity of clinker and residue.

In making these results of the combination public, I desire to express my indebtedness to the eminent French engineer, Mr. J. Serve, for his valuable suggestions, and to the staff at the Atlas Works.

TABLE I.

Results of Experiments made with "Serve" Tubes and Induced Hot-air Feed on August 23 to 27, 29 to 30, September 1 to 2, 2 to 3, 1892, Atlas Works, Sheffield.

Nos. 7 AND 8 MARINE BOILERS. "SERVE" TUBES WITH RETARDERS AND INDUCED HOT-AIR FEED.

Date.	Duration of trial, in hours.	Total coal burnt, in lbs.	Coal burnt per hour, in lbs.	Fuel used.	Total water evaporated, in lbs.	Water evaporated per hour, in lbs.	Lbs. of water per lb. of coal evaporated at actual temperature of feed.	Lbs. of water evaporated per lb. of coal, from and at 212°.	Lbs. of coal burnt per square foot of grate per hour.	Temperature of air at side valves, Fahrenheit.	Temperature of gases at base of chimney, Fahrenheit.	Temperature of gases in smokebox, Fahrenheit.	Vacuum under grate bars.	Vacuum over fires.	Vacuum at base of chimney, in inches, of water.	Vacuum above outlet of fan.	Speed of air under grate bars, in feet, per minute.	Average temperature of feed water.	Average steam-boiler pressure per square inch.	Revolutions of fan and engine per minute.	Air spaces in grate.	Thickness of bars.	Lbs. of water per square foot of heat-distributing surface per hour.
892.										deg.	deg.	deg.	in.	in.	in.		ft.	deg.	lbs.			in.	
Aug. 23 to 27	96	123,648	1,288	Yorkshire.	1,102,800	11,487·5	8·91	10·29	40·25	263	393	656	—	·43	4·68	—	1,207	87	44	541	$\frac{3}{8}$	$\frac{3}{4}$	12·6
Aug. 29 to 30	24	34,552	1,439·6		303,700	12,654·1	8·78	10·24	44·98	305	386	653	—	·39	3·87	—	451	76	46	463	$\frac{3}{8}$	$\frac{3}{4}$	13·89
Sep. 1 to 2..	24	32,805	1,366·8		295,500	12,312·5	9·00	10·45	42·71	262	386	618	·77	1·16	4·56	—	—	81	45	525	$\frac{3}{8}$	$\frac{3}{4}$	13 51
Sep. 2 to 3..	24	32,928	1,372		297,000	12,375	9·10	10·48	42·87	294	391	692	·65	·72	5·05	—	—	79	45	571	$\frac{3}{8}$	$\frac{3}{4}$	13·58

August 23 to 27.—In this experiment all bars were cleaned and tubes swept before starting; fires were cleaned every twelve hours alternately; the tubes were not swept during the whole of this trial. In this test all hot air was passed above the fires, and cold air underneath, the bottom doors being half open to allow admittance of cold air.

August 29 to 30.—In this experiment new fire bars were put in, and tubes swept before starting; fires were cleaned every four hours; the tubes were not swept during the whole of this trial. In this test all hot air was passed above the fires, and cold air underneath, the bottom doors being half open to allow admittance of cold air.

September 1 to 2.—In this experiment all bars were cleaned and tubes swept before starting; fires were cleaned every six hours; the tubes were not swept during the whole of this trial. In this test the hot-air feed was both top and bottom, but underneath the bars the hot air was diluted with cold air, being admitted through seventy holes in each ashpit door; there was also a second perforated plate behind the ashpit door, for the purpose of mixing the air thoroughly. The temperature of air under grate was an average of about 150° Fahrenheit.

September 2 to 3.—In this experiment all bars were cleaned and tubes swept before starting; fires cleaned every six hours; the tubes were not swept during the whole of this trial. In this test all hot air was passed above the fires, and cold air underneath; the bottom doors being shut, the cold air passed through seventy holes drilled in each door for the purpose; area of these holes, 124 square inches, *i.e.*, 62 square inches in each door; area for passage of air over both fires—220 square inches.

TABLE II.

RESULTS OF EXPERIMENTS MADE WITH "SERVE" TUBES AND INDUCED HOT-AIR FEED ON AUGUST 15, AND NOVEMBER 5, 8, 15, 17, AND 18, 1892, ATLAS WORKS, SHEFFIELD.

NOS. 7 AND 8 MARINE BOILERS. "SERVE" TUBES WITH RETARDERS AND INDUCED HOT-AIR FEED.

Date.	Duration of trial, in hours.	Total coal burnt, in lbs.	Coal burnt per hour, in lbs.	Fuel used.	Total water evaporated, in lbs.	Water evaporated per hour, in lbs.	Lbs. of water evaporated per lb. of coal at actual temperature of feed.	Lbs. of water evaporated per lb. of coal, from and at 212°.	Lbs. of coal burnt per square foot of grate bar per hour.	Temperature of air at side valves, Fahrenheit.	Temperature of gases at base of chimney. Fahrenheit.	Temperature of gases in smokebox, Fahrenheit.	Vacuum under grate bars.	Vacuum over fires.	Vacuum at base of chimney, in inches, of water.	Vacuum above outlet of fan.	Speed of air under grate bars, in feet, per minute.	Speed of air through heating tubes, in feet, per minute.	Temperature of air entering heating tubes, Fahrenheit.	Average temperature of feed water, Fahrenheit.	Average steam-boiler pressure in lbs. per square inch.	Revolutions of fan and engine per minute.	Grate bars.		Lbs. of water per square foot of heat-distributing surface per hour.
																							Air spaces.	Thickness of bars.	
1892.										deg.	deg.		in.	in.	in.	in.		ft.	deg.	deg.				in.	
Nov. 5..	4	4,969	1,242·25	American	47,550	11,887·5	9·56	11·28	38·82	307	380	Melted Lead	—	·5	4·08	·25	1,902	486	85	65	49	505	Front ⅝ in. Back ½ in. in.	¾	13·04
„ 15..	7½	8,018	1,069·06		72,500	9,666·66	9·04	10·63	33·4	246	331	„	·88	1·2	4·35	·36	2,176	1,249	66	66	45	498	½	½	10·61
„ 17..	5	5,632	1,126·4		52,600	10,520	9·33	11·02	35·2	246	336	„	·91	1·27	4·37	·35	2,404	1,220	51	59	4 3	490	½	½	11·54
Aug. 15..	7	7,448	1,063·28	Nixon's Navigation	68,900	9,842·85	9·25	10·83	33·22	200	290	442 deg.	1·07	1·64	2·65	—	—	—	—	72	45	382	⅝	¾	10·8
Nov. 8..	48	67,268	1,401·41		599,700	12,493·75	8·91	10·5	43·79	311	442	Melted Zinc.	—	·62	6·18	·33	1,319	508	64	66	49	634	⅝	¾	13·71
„ 18..	7	10,192	1,456		99,300	14,185·71	9 74	11·44	45·5	265	374	„	·78	1·3	4·87	·36	2,658	1,141	57	67	45	548	½	½	15·57

REMARKS.—In these experiments with Welsh and American coal, the best results were obtained by putting all the hot air under the grate with the ashpit doors closed, the hot air being diluted by the cold air being admitted through the holes in ashpit doors. Fires kept a moderate thickness. During the 48 hours' test the mode of admitting the air was tried in various ways, but the best results were obtained as above stated. This experimenting with the valves accounts for the apparently low evaporation. The fire bars in this test were partly cleaned every eight hours; but in the others they were not cleaned during the whole of the tests. Melting point of lead, 630 degrees Fahrenheit; of zinc, 700 degrees Fahrenheit.

TABLE III.

Results of Experiments made with "Serve" Tubes and Induced Hot-Air Feed on February 24, 27, and March 15, 1893, Atlas Works, Sheffield.

No. 7 MARINE BOILER. "SERVE" TUBES WITH RETARDERS AND INDUCED HOT-AIR FEED.

Date.	Duration of trial, in hours.	Total coal burnt, in lbs.	Coal burnt per hour, in lbs.	Fuel used.	Total water evaporated, in lbs.	Water evaporated per hour, in lbs.	Lbs. of water evaporated per lb. of coal at actual temperature of feed water.	Lbs. of water evaporated per lb. of coal, from and at 212°.	Lbs. of coal burnt per square foot of grate bar per hour.	Temperature of air at side valves, Fahrenheit.	Temperature of gases at base of chimney, Fahrenheit.	Temperature of gases in smokebox, Fahrenheit.	Vacuum under grate bars.	Vacuum over fires.	Vacuum at base of chimney, in inches, of water.	Vacuum above outlet of fan.	Speed of air under grate bars, in feet, per minute.	Speed of air through heating tubes, in feet, per minute.	Temperature of air entering heating tubes, Fahrenheit.	Average temperature of feed water, Fahrenheit.	Average steam-boiler pressure, in lbs. per square inch.	Revolutions of fan and engine.	Grate bars.		Lbs. of water per square foot of heat-distributing surface, per hour.
																							Air space.	Thickness of bars	
1893.										deg.	deg.		in.	in.	in.	in.			deg.	deg.			in.	in.	
Feb. 24..	7	9,632	1,376	Newcastle.	88,100	12,585·71	9·14	10·81	43	279	408	Melted Bismuth.	1·01	1·17	5·06	·375	2,464	1,167	61	61	47	573	5/8	3/4	13·81
„ 27	7	10,304	1,472		96,600	13,800	9·37	11·18	46	281	392	„	·93	1·24	4·62	·375	2,098	1,332	61	50	47	510	5/8	3/4	15·14
Mar. 15..	7	10,192	1,456		92,300	13,185·71	9·05	10·66	45·5	276	390	Melted Lead.	1·25	1·57	5·42	·375	2,586	1,570	65	66	49	567	5/8	3/4	14·47

Remarks.—February 24: In this experiment all the hot air was passed above the fires, and cold air underneath, the bottom doors being shut, the cold air passed through 70 holes drilled in each door for the purpose. February 27 and March 15: In these experiments all the hot air was passed under the fires, but was diluted with cold air, admitted through 70 holes in each ashpit door. In the above experiments the fire bars were cleaned and tubes swept before starting. The fire bars were not cleaned again during the whole of the 7 hours' test. Melting point of bismuth, 493 degrees Fahrenheit; of lead, 680 degrees Fahrenheit.

TABLE IV.

Results of Experiments made with "Serve" Tubes and Induced Hot-air Feed on May 5 and 8, 1893, Atlas Works, Sheffield.

No. 7 MARINE BOILER. "SERVE" TUBES WITH RETARDERS AND INDUCED HOT-AIR FEED.

Date.	Duration of trial, in hours.	Total coal burnt, in lbs.	Coal burnt per hour, in lbs.	Fuel used.	Total water evaporated, in lbs.	Water evaporated per hour, in lbs.	Lbs. of water evaporated per lb. of coal at actual temperature of feed.	Lbs. of water evaporated per lb. of coal, from and at 212°.	Lbs. of coal burnt per square foot of grate bar per hour.	Temperature of air at side valves, Fahrenheit.	Temperature of gases at base of chimney, Fahrenheit.	Temperature of gases in smokebox, Fahrenheit.	Vacuum under grate bars.	Vacuum over fire.	Vacuum at base of chimney, in inches, of water.	Vacuum above outlet of fan.	Speed of air under grate bars, in feet, per minute.	Speed of air through heating tubes, in feet, per minute.	Temperature of air entering heating tubes, Fahrenheit.	Average temperature of feed water, Fahrenheit.	Average steam-boiler pressure, in lbs. per square inch.	Revolutions of fan and engine per minute.	Grate bars.		Lbs. of water per square foot of heat-distributing surface per hour.
																							Air space.	Thickness of bars.	
1893.										deg.	deg.		in.	in.	in.	in.			deg.	deg.			in.	in.	
May 5 ..	7	11,228	1,604	Scotch Coal.	91,600	13,085·71	8·15	9·46	50·12	300	416	Melted Lead	·99	1·22	4·58	·375	2,445	1,150	83	82	46·6	542	5/8	3/4	14·36
„ 8 ..	7	13,293	1,899		107,200	15,314·2	8·06	9·45	59·34	293	434	„	·93	1·26	4·58	·375	1,981	1,448	83	70	46	544	5/8	3/4	16·81

Remarks.—May 5, 1893: In the 7 hours' run the fires were not cleaned for the whole of the seven hours. The fires were kept very thick, and all the hot air put on top of fire, the cold air only being admitted under grate. May 8, 1893: In this test of Scotch coal, the bars were again not cleaned during the whole of the run, but the fires were very thin, and the whole of the air, both heated and cold, was passed under the grate. The results were, it will be seen, much better even than on May 5. Melting point of lead, 680 degrees Fahrenheit

DISCUSSION.

Mr. J. F. Fothergill (Member): My Lord and Gentlemen, I am sure we are all very much indebted to Mr. Ellis for his most valuable paper. This subject is a most important one, as shown by the frequent discussions at our meetings. Extended experience in the use of forced draught leads me to believe its application in some mechanical form will in the future be more general. When the strong prejudice against it is broken down and its general principles are better understood, a great many imaginary difficulties will be swept away, its advantages will be more fully realised, and its application will become a common necessity. My own experience, extending over some nine or ten years, shows the greatest difficulty to be the firemen, and this is more particularly so as you shorten the grate and increase the consumption per square foot of grate, which necessitates constant, regular, and steady firing. The firemen, unless under constant supervision, will not do other than fire most irregularly, throwing on the fire in a heap huge quantities of coal, frequently leaving the corners against the bridge bare. It is needless to say such firing is to be condemned under any condition, but more especially so as the consumption per square foot of grate is increased. Naval and mail steamers, due to better disciplined and trained men, may not experience, to anything like the same extent, this difficulty, which in the cargo steamer has to be borne. The only feasible way to surmount this difficulty is an application of some simple form of mechanical stoker in conjunction with forced draught: although there are difficulties in the way of such a combination to a marine boiler, yet there does not appear to be any exceptional reason why such combination should not in the near future be an accomplished fact. Mr. Ellis touches upon so many features that it is impossible to do more than refer to one or two. Probably the most important feature in the paper is that of heating the air. It has always appeared to me the advocates for heating the air by the waste gases are under some misapprehension as to the value obtained. Every unit of heat obtained from the waste gases and returned to the furnace is a unit gained, but nothing more. If we take averages from the four tables given at the end of the paper, we find the mean temperature in the smoke-box is 611°. The temperature at the base of the chimney is 392°. Therefore the heat absorbed by heating the incoming air and lost by radiation is 219°, but we find from the same tables the mean temperature of the air at the side valves is 279°, and, assuming the temperature of the atmosphere to have been 60°, it follows, the temperature of the incoming air has been increased by 219°, which exactly equals the difference of temperature of the smoke-box and chimney gases, which is a somewhat peculiar coincidence, when we consider the loss that must have taken place by radiation. Then we must also remember the specific heat of moving air is very low, so that one may well be pardoned feeling somewhat sceptical as to the correctness of the temperature of the incoming air as given in the tables. It would appear in taking the temperature of the air at the side valves sufficient consideration cannot have been given to the effect of radiation on the thermometer by the surrounding parts. In some experiments for heating the air which we made on board one of the steamers, we experienced great difficulty in obtaining the air temperature due to radiation from the iron casings through which the air passed, the thermometers registering a temperature much in excess of that at which the air really was. By reference to the Table, page 44, it will be observed for the size of the boiler the number of tubes, 118, having a heating surface of 911 sq. ft., is unusually small. If Mr. Ellis had put more tubes into his boiler and utilised the heat there instead of allowing the heat to escape from the boiler to heat the incoming air, he would in all probability have done equally as well and saved the cost of the expensive additional apparatus; or, to put it in another way, if the cost of the additional apparatus had been expended in increasing the size of the boiler, and adding a sufficient number of tubes, the result would have been altogether more efficient and economical. These opinions are borne out by the very complete and valuable experiments carried out at Mr. F. C. Marshall's works, Newcastle-on-Tyne, by Mr. Spence, and embodied in a paper which was read by Mr. Spence before the North-East Coast Institution of Engineers and Shipbuilders. Special pipes were arranged and heated by coke fires for heating the air. When the air was heated to 261° F.—and in this case there was no difficulty as to false temperature due to radiation—the gain in economy was only ·68 per cent.; that being so, what does Mr. Ellis gain, for the mean temperature of his incoming air is very much below this? I again repeat, as I have frequently done on various occasions, that, except in very exceptional cases, the cost of obtaining the heat of the waste gases by heating the incoming air is not worth the gain. There is also another disadvantage in heating the air. If you increase the temperature of your air by 450° in round figures, you will double the volume, and will thus require double the fan power, and although in one sense this is only a small matter, yet it has considerable bearing on the whole arrangement. Mr. Ellis is certainly to be congratulated on his great achievement in burning about 50 lbs. of coal per square foot of grate. That unquestionably is a great advance in the right direction, and, if he can continue doing this over extended periods without damage, he deserves our warmest expression of appreciation. As an experiment I have burnt 40 lbs. of good coal, but I should feel considerable hesitation in continuing it for any length of time. Not only has Mr. Ellis burnt this large quantity of coal, but the mean evaporation has been 10·41 lbs. of water per lb. of coal. This is a remarkable result when we consider the consumption per square foot of grate. In the case of the steamer *Iona* under my supervision, and fitted with my arrangement of forced draught, the results obtained by a committee of the Institution of Mechanical Engineers under Professor Kennedy were 10·63 lbs. of water evaporated per lb. of coal, when burning 23 lbs. of coal per square foot of grate, and this was with cold air supply and ordinary tubes. I doubt very much if this could have been improved upon by heating the air; at all events, I feel certain no economy, so gained, would pay the cost of fitting apparatus to obtain the waste heat. Will Mr. Ellis kindly explain what is meant by the following in Table, page 44: "Total heat-absorbing surface 1303·6 sq. ft.," and "Total heat-distributing surface 911 sq. ft."? What is the total tube-heating surface calculated in the usual manner? As to the "Serve" tubes, in theory they are unquestionably correct, and in practice will prove economical; but as to what extent that economy may prove to be, I am not at all clear. If Mr. Ellis could arrange to test the value of these tubes under conditions proposed in the following suggestion, it would have a most reassuring effect. Take a steamer fitted with ordinary tubes that has run in one trade, say, to India, for two or three years under ordinary conditions, and where the consumption is really known, and re-tube his steamer with "Serve" tubes, and run her under the same conditions without any other alterations for at least eighteen months, and then you should be able to place before the public data of real value and convincing. In conclusion, may I suggest to Mr. Ellis the value of analysis of the chimney gases. For, after all, the efficiency of combustion is shown by the gases produced and the quantity of air supplied. The anemometer is practically valueless for measuring the air supply under the various conditions necessary, and this I have proved over and over again. The only safe way to obtain the air supply is by analysis of the gases. There are many other subjects one might touch upon; but I feel I have already exceeded the "allotted span," and gladly give place to other speakers. I again beg to thank Mr. Ellis for his most valuable paper.

Mr. F. C. MARSHALL (Member of Council): My Lord and Gentlemen, I am not at all prepared to speak on this paper, only having had it in my hands a few minutes; but I would personally, being somewhat intimate with the subject, add my thanks to Mr. Ellis for the paper and the very valuable information he gives us in it. That forced draught is a thing of the future there cannot be a doubt. George Stephenson saw that many years ago. He introduced it on his first locomotives, and made them a success, and we reap the benefits of it to-day in precisely the same manner as he carried it out at that time. One of the advantages of Mr. Ellis's paper is, that he has followed George Stephenson in the manner of attaining the object he had in view; that is, he has followed George Stephenson in the direction of "induced draught." George Stephenson had his method, viz., the agency of the exhaust steam of the engine. Mr. Ellis used a certain amount of power—we have just heard Mr. Fothergill say he should like to know the amount of it—in blowing the gases up the chimney. There can be no doubt that Mr. Ellis's views are entirely in the right direction. Whether his methods are all that can be desired, or whether they do not add a little complication that may be of difficulty afterwards, remains to be seen. Now, as to the question of the "Serve" tubes. Mr. Fothergill, as a practical and everyday working engineer in vessels running with cargo, is much more able to speak on that subject than I am, and he says there are practical difficulties (and I think we shall find there are) in the general adoption of the "Serve" tubes. Mr. Fothergill mentioned experiments that I had carried out in our works some seven or eight years ago, and I think at that time we could only make out that there was a gain of ·68 per cent. in heating air up to 260°. I am free to confess that at that time we knew very little about the question, and that we had it all to open up. Mr. Howden had introduced his system of forced draught at that time, the efficiency of which largely depends upon the heating of the air, and I was anxious to ascertain how much was to be gained by so doing, and these experiments were carried out for that purpose. The complication that is necessary for heating the air is very great, and Mr. Ellis shows it in the drawings here. He indicates that there is very great difficulty about it. I may say at present we are constructing four boilers—two to Mr. Ellis's order—for the purpose of trying practically the efficiency of the whole system for marine purposes; and, in working out the details of the drawings, I find that the retardation caused by the resistance to the flow of the gases is very great, and will involve a considerable loss of power. I think when Mr. Ellis gets his system more perfected probably these matters will be rectified. The question of the retardation of the gases is a serious one. The power and efficiency of the fans is a very important question, and will need a great deal of consideration. The quantity of coal burned is very satisfactory, as it is found to be so large. In our locomotives we burn from 80 lbs. to 100 lbs. per square foot of grate. Mr. Ellis states he has got this up to 60 lbs. In our ordinary forced-draught vessels for the Admiralty we are working from 40 lbs. to 50 lbs. per square foot of grate. There is a great advantage, I think, in the system in relation to the firemen. The dangers to which the firemen are exposed by our ordinary forced draught would be entirely obviated, if we had an efficient system of induced draught. I think Mr. Ellis is in the right direction in that matter. I have not had an opportunity of going into the question of evaporation of the boiler. I believe Mr. Ellis has thoroughly worked that out in the presence of experts. I have no doubt some members will be able to throw more light on the subject than I can. I again beg to add my tribute of thanks to Mr. Ellis for the patience with which he has worked at this question, and the success which has attended his efforts. I am glad to have the opportunity of testing Mr. Ellis's system in the two vessels we are now about to fit. They will be vessels of 3,000 horse-power each, and that will be a good practical way of testing a system which is, I think, a growing one, and one which we shall all receive with increasing favour as our experience of it extends.

Mr. J. S. Milton (Member of Council): My Lord and Gentlemen, I am unprepared to discuss this paper in a critical manner; for I, equally with Mr. Marshall, only had it in my hand this morning. I should just like, however, to say a few words about it. I had an opportunity of seeing some of the experiments made some months ago at Messrs. Brown's works, and, so far as the words which have fallen from Mr. Fothergill may lead to a wrong impression, when he said he was somewhat sceptical as to the results, I can bear testimony to the great accuracy with which the experiments were made. The figures can be thoroughly relied upon as having been actually obtained at the works The whole question of this system is the economy to be obtained. Mr. Ellis has adopted practically a compound boiler with a view of obtaining economy. If you look at his figures, you find that the total heating surface in the boiler itself is 911 sq. ft. He supplements that with the total heat-absorbing surface in his heating-box of another 900 sq. ft., that is to say, for the sake of getting the last element of heat out of the combustion, he has added another boiler. So far as the surfaces are concerned, whether that extra 900 sq. ft. could not have been more profitably employed by converting water into steam, or by heating the feed-water up to the temperature of evaporation, I think is an open question. There is another question that we must bear fully in mind in this paper. Mr. Ellis's results are, I believe, obtained mainly by the perfect combustion of coal. He tells us that he puts a great deal of air above the fire-grate, and he has to vary this quantity of air in accordance with the quality of the coal. In that lies, I think, the secret of the success he has obtained. He gets more heat of combustion from his coal than is got by an ordinary boiler where all the air goes in under the fire-grate. The experiments alluded to by Mr. Marshall showed the great importance of admitting the air above the grate, when burning North-country coal. When North-country coal is burned with a proper supply of air, you get as good economy, or very nearly so, as in burning Welsh coal. There is one point about the air-heating supply which has not been noted, and I wish Mr. Ellis had given some information upon it. This second boiler may be called a regenerative boiler, its purpose being to absorb the last degrees of heat, and return it to the fire. From the figures, it seems we get part of the air supply raised in temperature about 200°. If that heat of 200° is obtained there, we necessarily get from the combustion of the coal a greater temperature in the fire than would be obtained with cold air supply. It is well known that as soon as the products of combustion leave the fire and enter among the cool surfaces of the boiler, a great deal of the heat is absorbed. There is a critical point below which, if the temperature falls before the combustion is complete, no further combustion takes place. It may be that the 200° of the heated air enables the mixture of the products of combustion and air to remain above this critical temperature for a longer period than it could otherwise do, and so gives us more time to complete the combustion of the coal in the boiler, and consequently enables the combustion to be more complete.

Mr. W. H. WHITE, C.B., LL.D., F.R.S. (Vice-President): My Lord and Gentlemen, I regret to say that through illness, my colleague, Mr. Durston, the Engineer-in-Chief of the Navy, is unable to be present, as he intended. In his absence I would like to say a word or two on this paper. Some months ago Mr. Ellis gave me the opportunity of seeing this apparatus in operation at the "Atlas" Works. No one can witness those experiments without being greatly struck with the beauty of many of the arrangements, and the care that is taken to endeavour to ascertain the facts. It occurred to me that this Institution would be benefited if Mr. Ellis would give us the results of his experiments. I mentioned it to him, but he was disinclined to do it for a reason which does him credit. He feared it would seem like an advertisement of his own goods. I ventured to express to him—what I am sure will be the feeling of all members of the Institution—that we were always glad to have facts, and that one of the purposes of the Institution was to deal with inventions and new processes; so that, if he would put aside his modesty and fear and give us this paper, he would be certain of the favourable reception it has now obtained. In looking at the working of the boilers in the "Atlas" Works, what struck me greatly was the fact that the conditions there were more favourable to the system in many respects than those which hold good on board ship. The supply of air to the boilers was made from the open. The apparatus stood near one of the principal roadways through the works. The work which the fans had to do in supplying air to the furnaces was consequently small, as compared with what would have to be done on board ship, with comparatively limited and tortuous passages for the air supply to stokeholds. All that Mr. Ellis and his staff fully admitted. They said they were making the experiments under these conditions for comparative purposes only, and any adaptations required on board ship could readily be made. In looking through the tables of results obtained at Sheffield, it is necessary to remember their differences in circumstances, and to realise that greater fan power would be needed on board ship. I would ask Mr. Ellis, if he feels at liberty to do so, if he could give us briefly, in his reply, the general conclusions that may have been reached in the applications that have been made of this system on board ship. Trials have been made on a very large scale. He may not be able to give us yet those results, but, if he could, it would add to the value of the paper. The Admiralty has made extensive trials with induced draught on Mr. Martin's system. They were made in strict comparison with forced draught. They were first carried out on a locomotive boiler specially fitted at Portsmouth, and they have more recently been repeated in a torpedo gunboat at Chatham, one stokehold being worked under the ordinary "closed" system with forced draught, and the other under the induced draught system. They are not yet complete, but so far as they have gone, they do not appear to bear out some of the claims made respecting advantages inherent in induced draught as compared with forced draught. There are undoubted advantages in induced draught—such as greater cleanness and comfort in the stokeholds, while the access to the stokehold is the same as with natural draught; and there are equal facilities for escape in case of accident. It has been asserted that with induced draught there will be an absence of risk to the firemen if leaky tubes occur. Perhaps the greater freedom of escape reduces the risk somewhat, but there must be risk in any case, if tube leakages are serious when any form of assisted draught is employed. It has been claimed also that, with induced draught, better results would follow in keeping tube ends clean and reducing the "birds' nests" on the tube ends. There appears to be no very great difference in that respect between induced and forced draught. As regards the production of power, the two systems are apparently nearly on an equality. I do not know whether Mr. Martin is present, and I am not attempting to give in fixed form the results of the trials of his system. But those are the general conclusions, so far as I know them. It is a fact worth noting that in the French service, before forced draught with closed stokeholds was adopted, a trial was made with induced draught obtained by means of air jets in the base of the funnel. M. Bertin (who is a Member of this Institution) was the author of the system then tried, and it answered very well. After considerable trial, the French set it aside in favour of closed stokeholds. Mr. Ellis modestly speaks of his arrangements as a combination of things previously in existence. I take the most important features to be the association of Mr. Martin's fan draught system with arrangements for heating the air and for retarding the gases in the tubes. Mr. Howden has worked out some of these to a great extent. The introduction of the "Serve" tubes in the boilers and in the air heaters is also a novelty. Personally, I venture to hope that Mr. Ellis may succeed in obtaining all the results he has expected, because it must be to the good of all designers and builders of ships and engines that we have rival and alternative systems in operation, each tending by competition to improve the other.

Mr. **Stephen** H. **Terry** (Associate): In common with other members of the Institution of Naval Architects, I feel how much we are all indebted to Mr. Ellis for his valuable paper on an original subject, and for the great care which has been taken in making experiments. I also feel that Sir John Brown & Co. have shown in a remarkable way the courage of their opinions in the large scale on which the experiments have been conducted, involving obviously a great expenditure of money. As one who has for some years taken an active interest in connection with mechanically aided draught, I would like to ask Mr. Ellis one or two questions—not because I am specially interested in one kind more than another, but with the object of elucidating the facts, so as to get to the bottom of the matter, for I feel convinced that mechanically aided draught, in some form or another, will in the course of a few years be universal at sea, not only in mail boats, as at present, but in all classes of steamships, and that its use will extend to land boilers also. I am glad to see several systems being adopted in a tentative way, as progress springs from competition, if competition is conducted on fair and straightforward lines. Mr. Ellis and some who are supporters of induced draught seem to attach great importance to the advantages which they claim for artificially moving air, by means of producing a partial vacuum in the uptake and funnel, rather than by producing a plenum under and above the bars. Personally I am unable to see how there could be any advantage in a vacuum over that obtained by a plenum. The flow of gases is subject to known laws, and the laws which control their speed are differences of pressure. I am, therefore, unable to see that any advantage would accrue to the furnaces, flues, or tubes by producing a partial vacuum instead of producing a slight plenum. I can, however, see many disadvantages attached to this system, the chief of which are the following. The efficiency of a fan is largely affected by the density of the gas or vapour passing through it, and, if this gas be dense, the centrifugal force will be greater at a given peripheral velocity, and the power of the fan will be greater. Air, when heated to the temperature given by Mr. Ellis as that of the waste gases, is more than double, and in some cases treble, in volume of that of the air at ordinary atmospheric temperature, consequently its density will be only one-half or one-third. In this way the efficiency of the fan will be very largely reduced, whilst from the fact that the air is of double or treble the volume, the velocity of the air through the fan has to be greatly increased over that which would be necessary if the same weight of air were passed through the fan at atmospheric temperature; thus simultaneously we are reducing the efficiency of the fan, and at the same time calling upon the fan for higher duty. The effect of this, of course, is that fans of much larger size are required to deal with the waste gases than would be necessary if the fans were employed for blowing cold air into the fires, instead of exhausting hot air from them. There is a further increased risk of break-down, due to the difficulties in keeping the fan shafts well lubricated and free from grit when working amongst the waste gases. I think Mr. White will bear me out in saying that the increased size of the fans and engines, which the system of exhausting air entails, is a serious matter on board all ships, and especially in war-ships, where every superfluous pound weight in machinery is cut down. I notice in Mr. Ellis's paper that one important point has been omitted, on which he ventured to say that information would be of great value: it is that he has not stated what volume of air he is passing through the fire, or the weight of air he is using per lb. of coal burnt. In so carefully written a paper, it is not likely that this has been omitted accidentally. No doubt there is a good reason for its omission; whether it be due to the difficulty in the way of measuring the hot gases, or from whatever cause, it is one which, if the information could be given, would greatly add to the value of the paper, for it is not necessary to point out that economy, or waste, largely depends on the volume of air passing through the fire; for, if that volume be insufficient to produce complete combustion, there is a large loss, owing to the fuel being imperfectly burnt. If, on the other hand, the volume of air is largely in excess of that necessary, the fuel may, or may not, be properly burnt; but whether properly burnt or not, a large amount of heat which might otherwise have been communicated to the water will be carried up the funnel. Information on this point would be of great value to the Institution.

Mr. R. R. BEVIS (Member): My Lord, I am afraid that all I can say will not add much to the information of the Institution. There is one point, however, which I do not think has been sufficiently touched upon in this paper, and that is the advantage of reducing the temperature in the escaping gases so as to enable the fans to be more effectually worked. I think that this is rather an important feature. There is also another point, that, with the great additional weight this apparatus requires, the question is whether it will not be better to utilise that weight in the ordinary form of boiler. Of course this is only information that could be obtained by actual experience. I do not know whether Mr. Ellis is able to give us any information on that subject. If so, perhaps he will do so. His paper is one of great importance, and we ought to be very much obliged to him for it.

Mr. F. GROSS (Visitor): My Lord and Gentlemen, with your permission I should be glad to make a few remarks. The points that have come more prominently before Mr. Ellis and myself are the practical working out of this system which Mr. Ellis has in hand. Mr. Fothergill has spoken, as most engineers speak, when they have not seen the boilers. If he had seen the boilers at work, many of the questions which he has asked would not have been asked. We quite admit that firing on land is not the same as firing at sea, but it has already been proved, in the one ship that has been running since March 1, that you can make improvements in firing at sea, and the results we have on land are certainly very nearly obtained in that ship so far as our system is concerned. With regard to the heating of the air, I think Mr. Fothergill made a slip with regard to the advantages stated as having taken place in Mr. Marshall's boilers, by speaking of ·68 instead of 6·8.

Mr. J. F. FOTHERGILL: I should wish to say that the absolute gain in economy by Mr. Spence's experiments due to the heating of the air was ·68.

Mr. F. GROSS: The size of the fan is very large, because we are trying to do with one boiler what in an ordinary way, with natural draught, is done with three or four, and it only requires an engine power which we estimate at 16 I.H.P. If you take it that with this 10 ft. 6 in. by 10 ft. 6 in. boiler you are able to get steam for 1,000 I.H.P. with an ordinary triple expansion engine, I think you will admit that the expenditure in size of fan is a mere trifle compared with the advantage that you obtain. We are trying to drive in the direction of making one boiler first do the work of two—to have two single-ended boilers where two double-ended have been used. That is only burning at the rate of 30 lbs. per square foot of grate. Presently we hope that you will have no difficulty in making up your mind to go to one boiler instead of three. We run at 45 lbs. without trouble, and economically. It is not only the burning of 45 or 60 lbs. per square foot of grate, but it is the burning of it with at least the same evaporation at 45 lbs. in one boiler as with natural draught in three boilers with plain tubes. That is a most important matter. To say we will burn with one boiler instead of three, and, per lb. of fuel, make you as much steam as you have had hitherto, is a most important advance. Mr. Fothergill has raised the question of what we mean by heat-absorbing as against heat-distributing surface. It was natural that with the use of the "Serve" tubes you should begin to discriminate between heat-absorbing surface and heat-distributing surface.

Mr. Fothergill will notice we give him both the items he desires. We say the total heat-absorbing surface of the tubes is 1303·6 sq. ft., but that the heat-distributing surfaces is only 741 ft. He will also notice that we have a small number of tubes. With that small number of tubes we have a large excess of heat-absorbing surface, and the heat-distributing surface will take care of itself. Mr. Fothergill points out that he has obtained in the *Iona* economical results, but he admits only burning at half the rate. The whole difference lies in that. At Messrs. Brown's works the result of the experiments was practically the same as in the *Iona* while burning at twice the rate, and with a heat-distributing surface within the boilers of 28·41 to 1, as against Mr. Fothergill's 72 to 1. Of course you must not forget the heat-absorbing surface outside the boiler, but the weight of that heat-absorbing surface is a different matter to the weight of another boiler. It is quite true that we have taken no analysis of the gases, but we thought that total absence of smoke proved sufficiently that we had perfect combustion. We may or may not be wrong in that, but the evaporation per lb. of fuel of course is a confirmation of our view. It is quite certain that using South Yorkshire coal, which is the smokiest in Great Britain, we are able to burn it without any smoke whatever. As to the quantity of air which Mr. Terry referred to, you must take it from all points of view. We have said that we prefer a small number of tubes widely spaced (knowing our heat-absorbing surface was there) to enable the water to get its proper circulation. In order to get the proper circulation of the water we prefer to have as few tubes as we can possibly have, spaced widely. With the small number of tubes which we have in this series of boilers, we have more air through the boiler than we require; that is, we have found by blocking up some of the tubes, even in this boiler, we get down to the quantity of air required, 17 lbs. to 20 lbs., instead of having 23 lbs. of air per lb. of fuel when the tubes, as shown in this boiler, are all of them being used. With regard to Mr. White's remark as to the air supply, I would at least say this much: that whilst at the "Atlas" Works the air supply is in all directions, yet in the one ship that has been running since March 1, the unasked-for report came that they thought they had the coolest stokehold on the Atlantic.

Mr. W. H. White: May I say one word? I was not speaking of the impossibility of doing this. I was alluding to the difference in the power that must be devoted to the ship.

Mr. F. Gross: I thought I would just state that. With regard to leaky tube ends, I understood Mr. White to say that they had not found in his experiments with induced draught any difference on the question of leaky tube ends. It remains, of course, to be seen why leaky tube ends so frequently do occur with forced draught and closed stokeholds; but we are coming to the conclusion that the "Serve" tube itself may be incidentally, if not entirely, the cause of our not having leaky tube ends. I may say that comes to us in this way. A well-known American railway which tried the "Serve" tubes found to its surprise, and to ours, that with the "Serve" tubes they have no leaky tube ends, while with the plain tubes they were absolutely unable to avoid them. They have come to the conclusion—of course it does not fully apply to the marine boiler—that the reason the "Serve" tube does not give leaky tube ends is because of its inherent stiffness. If it be not that, they do not know what it is; but the fact remains that, with the "Serve" tubes they have no leaky ends to their tubes. The main object of this system is to reduce the difficulties experienced by forced draught, and to show that without any trouble of any kind, and with economy, you are able to burn at twice and three, or even at four times the rate at which you have done with natural draught.

Mr. J. D. Ellis (Visitor): My Lord and Gentlemen, I think after the very efficient manner in which my respected friend, Mr. Gross, has answered all the questions, he has scarcely left me anything at all to say. It was proposed to me when I prepared to read this paper, that I should get some expert engineer to come down to Sheffield and verify the experiments which I was going to place upon record in this paper. I found it would take some time, however, and there was very little time to spare, and I did not think it necessary, for three reasons. In the first place, it must be evident to all you gentlemen that John Brown & Co. could not possibly afford to place before such an influential body as this any statement which they were not absolutely certain was quite correct. Secondly, these very experiments have been made in the presence of various members of the Institution, who could speak to their inaccuracy if they were inaccurate; and, thirdly, John Brown & Co. are still in existence, and all the details are at the "Atlas" Works, and I shall be most happy to see any member of this Institution who will favour us with his company, and see these experiments made in their own presence, and I hope and trust I shall soon have a visit from Mr. Fothergill, and I am sure he will be exceedingly welcome. The ship to which Mr. Gross has referred is the Inman steamer *Berlin*. This vessel is eighteen years old, and, I believe, has not been going very well, as her age might lead us to expect. It was decided by the Engineer of the Inman Company to try this system in the *Berlin*. It was placed in the hands of Messrs. Laird, and they did their very utmost to make a success of it. When we came to deal with an old ship not perfectly suitable for this kind of combination, gentlemen will quite easily understand that we did not arrive at such good results as we should have done with a vessel made entirely new and suitable for this combination. The vessel has been running ever since March 1, and, although I have not yet received the figures, she has done very much better than she has ever done in her existence before. The Inman Company are having two vessels fitted with this arrangement, one built by Messrs. Denny, and one by Messrs. Thomson, and other vessels are also being built with it. When those vessels get into the water no doubt we shall have very favourable information. Gentlemen, I do not know that I have anything further to say, beyond the fact that I am exceedingly obliged to you for the very favourable manner in which you have received my paper.

The **President** (the Right Hon. Lord Brassey, K.C.B.): Gentlemen, it now only remains for me to discharge an agreeable duty, which is to convey the thanks of the Institution, and I am sure of the public out of doors, to Mr. Ellis and to those who have worked with him in carrying out the very interesting experiments which have been described to us in the able paper which has been read to us this morning. I am sure we shall all feel grateful to Mr. White for having exercised some influence in persuading Mr. Ellis to overcome his reluctance to prepare a paper on this subject. Looking to the importance—whether for naval purposes or commercial purposes—of reducing the weight of boilers and the space which they occupy, any improvements which give promise of securing those great and much-desired advantages merit attention. Forced draught has been largely used in the Navy, and is now being more or less extensively used in connection with the mercantile marine. The first application of a new method must naturally present difficulties. The use of forced draught has been attended with difficulties, and those difficulties have not been as yet entirely removed. It must, therefore, be a source of great satisfaction to all interested in the mercantile marine of this country to know that many ingenious minds are engaged in the solution of this problem. I cannot but think that success in overcoming difficulties will be largely promoted when some men come to consider these matters rather from the outside, and taking a somewhat independent view. Mr. Ellis belongs to that class.

WEAR AND TEAR IN BALLAST TANKS.

By Andrew K. Hamilton, Esq., Principal Surveyor to Lloyd's Register, Cardiff; Member.

[Read at the Summer Meeting of the Thirty-fourth Session of the Institution of Naval Architects, July 12th, 1893; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

Nine years ago I had the honour to present before the Members of this Institution a paper on the subject of "Steam Ship Machinery Repairs," having special reference to the wear and tear experienced in the working of the engines and boilers of steamers, and expressed the hope that further papers would be forthcoming from other members relating their experience in regard to that important subject.

On learning that this Institution intended making Cardiff the scene of the present meeting, it occurred to me that a brief paper of my experience in regard to the wear and tear at this large repairing port would be appropriate, and at the same time interesting to many of the members now present.

The subject to which I now invite your kind indulgence and attention is "Wear and Tear in Ballast Tanks of Steamers."

During the time that I have been located at the Port of Cardiff I have enjoyed many opportunities of observing the opening up, condition and repairs to ballast tanks, of the many types of vessel frequenting this port, and I will now endeavour to place before you the result of such observations.

The two forms of ballast tanks now common consist of the ordinary or McIntyre, and the cellular double bottom.

As is well known to the members, the former is built upon the floors, and supported by fore and aft girders; and in the latter, *i.e.*, the cellular double bottom, the construction varies somewhat.

The various forms might be tabulated thus:—

As cellular double bottom No. 1, with the floors complete from centre line to wings of tank, lightened by large holes, and continuous centre keelson, with girders fitted intercostally between the floors.

Cellular double bottom No. 2, with centre keelson and side girders continuous, and the floors fitted intercostally as diaphragm plates.

Cellular double bottom No. 3, fitted with continuous centre keelson and side girders, and brackets for floors.

WEAR AND TEAR.

THE McINTYRE.—In this form of tank, excepting in the way of the boilers, the wear and tear is principally confined to the riveting of the angles at the bottom of the fore and aft girders, the rivets being often found loose and broken, more particularly at the wing keelsons; this attachment becoming loose allows the girders to cut into the reverse frames, in many cases breaking the fore and aft angles.

From the fact of these keelsons being in some cases found displaced at their bottom edges, it is possible to suppose that this movement is generated at times by the tank being filled after the vessel has left port, and the heavy body of water rolling about before the tank is full, strikes the girders with great force every time the vessel rolls.

Corrosion in these tanks, apart from the machinery space, is found to be slight, owing, no doubt, to the interior being nearly always in the same wet condition, and by the iron-work being covered with a deposit, more or less thick, of mud.

The caulking and top plating of these tanks are frequently found started and fractured; the result of heavy weights being dropped upon the ceiling, which, in some cases, is only removed from the tank top by a coating of tar sprinkled with cement.

The corrosion of the floors in these tanks is very slight, although they are occasionally found to be wasted in the neighbourhood of the limber holes, which may be attributed to the action of ashes and other foreign matter contained in the bilge water when set in motion by the movement of the vessel.

It is in the machinery space, within the range of the boilers, that the ravages from corrosion in this class of tank are to be seen, and the entire top plating has been found to be destroyed; the girders, keelson, and angles being also considerably wasted.

The boiler bearers have also been found to be perished, necessitating the blocking or lifting up of the boilers to effect repairs.

CELLULAR DOUBLE BOTTOM.—This description of tank differs in an important respect from the McIntyre, inasmuch as it is an integral part of the vessel's construction, and the continuity of strength of the inner bottom should be maintained in a fore and aft direction.

Cellular Double Bottom, No. 1.—In this cellular form of tank it is found that, like the McIntyre, they are little liable to internal corrosion apart from the machinery space, and I have no recollection of having met with a case where the internal construction has shown signs of starting or weakness, unless the vessel had taken the ground.

Like the McIntyre tank, however, its vulnerable part is in the machinery space, and in one case of a vessel with arrangement of D. B. (designated No. 1) which came directly under my notice, the entire tank top within range of the extreme heat of the boilers was found to be completely wasted, the floors were destroyed, having been corroded through, in a line at a distance of about 8 to 14 inches under, and parallel to, the tank top; the reverse bars on same, and the intercostals with their top angles, were deteriorated in a like manner, and to such an extent as to render the tank useless as such, and detrimental to the strength of the vessel.

Cellular Double Bottom, No. 2.—In a steamer with this arrangement of bottom it was found necessary, upon examination, owing to corrosion, to renew at least one length of plate of each of the side girders, the top plating, the intercostal floors with their top angles, and the entire boiler bearers.

In the cases quoted, and others which have come under my notice, the distance between the tank top and the boilers varied from 9 to 14 inches.

I have got two Plates illustrative of the dire effects of corrosion on plates situated in the machinery space of a vessel arranged under the heading of No. 1. Plate XIX. shows a complete floor plate with its lightening holes, and the extent of the corrosion is clearly visible, as in many places the plate is wasted through, and it will be seen that the upper part of the floor plate has suffered most, as already stated.

Plate XX. is an enlargement of the upper left-hand corner of the same floor plate, and shows more clearly the defects referred to.

In the cases described the material of which these tanks were constructed has not been stated; but I would mention that iron appears to suffer equally with steel under the conditions set forth, but, owing to the scantling of the former being heavier than the latter, the destruction has not been apparently so complete; and, I would also mention, that in none of the cases herein instanced were the vessels more than eight years old.

Having thus far laid before you some idea of the extent of the corrosion set up and its chief location in ballast tanks, I will proceed to describe a few of the methods adopted in effecting repairs to the various forms of tanks which I have met with.

In the case of the first-named tank (the McIntyre), as its construction is supplementary to, and therefore not a part of, the main structure of the vessel, it is not difficult to devise a repair which will render the tank serviceable.

The cellular double bottom cannot, however, be so easily dealt with, for, being part and portion of the main structure, it is necessary that the strength and efficiency be maintained, and the repairs are, consequently, of great importance, more especially in view of the great difficulties to be surmounted in effecting same in that portion of the tank situated in the machinery space where the corrosion, as before stated, is the greatest.

Feeling assured that it will be of great interest to all members of the profession, I will now proceed to describe the methods adopted to effect large repairs to this description of tank in the machinery space which came under my direct observation.

In the first case the repairs were effected while the steamer was afloat.

She was fitted with two single-ended boilers, supported on bearers, constructed in one piece across the vessel, no side bunkers in way of same. The plan adopted was to tie the two boiler bearers at centre line with a vertical rib of plate-iron about 12 in. by 1 in., with two strong angle irons on its lower edge, under this were placed two powerful screw-jacks resting over the centre keelson; the ends of the bearers were then secured to a vertical bar passing through the side stringer with a fine thread cut on its upper end, fitted with a nut. All being in readiness, the boilers, together with their bearers, were raised in a short time the necessary few inches to enable the repairs to be proceeded with. The tank top was cut away as far as required, seven floors on each side with the intercostals and their angles were removed and renewed, the tank top plating renewed, riveted, and caulked complete, the boilers and their bearers were lowered and secured in position, the tank then tested under water pressure, and found thoroughly satisfactory.

On examination of the boilers and fittings after this disturbance all steam and water joints were found to be intact; the stringers were also examined, and showed no signs of movement after the unúsual duty they had been put to. It may here be mentioned that the centre keelson and the stringers had been strongly fortified by heavy wood packings.

The method adopted to repair two other vessels of similar construction, but fitted with two double-ended boilers, each resting on three bearers, was to place the vessels in graving dock, remove four shell plates on each side of bottom, shore the boilers up from the dock bottom, and effect the necessary repairs to floors, intercostals, angles, and tank top through the bottom of vessel, and on completion of these repairs all steam and water joints were found intact.

Other cases could be cited with single and double-ended boilers, each varying slightly from the other, as the arrangement of the vessel demanded; but, perhaps, enough has been said to arouse attention to this matter, and so induce a more frequent examination by those interested, and in doing so these further notes on Wear and Tear will have served the purpose for which they were put together.

DISCUSSION.

Mr. B. **Martell** (Vice-President): I do not think, my Lord, that much need be said on this paper. It is the outcome of the experience of Mr. Hamilton, whose practical knowledge I can bear testimony to. I do not think I should have anything to say, were it not for one paragraph in particular which I see here. It says, "In the cases described the material of which these tanks were constructed has not been stated; but I would mention that iron appears to suffer equally with steel under the conditions set forth." Well, I must say that that is not my experience, and I wish Mr. Hamilton had given a few more cases in illustration of this statement. We only have two illustrations here. If he could have mentioned the number of cases that had come under his own observation, and the description of material of which the floors and inner bottom were composed, it would be rather more convincing. Now I should not like to let this paper go forth without a few remarks on this matter, because I am afraid it would destroy a good deal of the advice which we have found it necessary recently to give to the owners of steel steamships; that is, to this effect, that our experience shows that the finer material of steel does deteriorate more rapidly than the coarser description of iron. In fact, this has been found so from experience to such an extent, that many owners, in contracting for steel ships, are specifying that the deck and the inner bottom shall be of iron instead of steel, because their experience has shown that the corrosion is more rapid in steel than it is in iron. I do not say that this is inevitable, by any means, because if the steel were properly protected, as Mr. Hamilton points out here, that is, if greater care were exercised in keeping the surfaces properly coated, of course the steel could be made as durable as iron, and last for an indefinite period by thus hermetically sealing the surfaces. Unfortunately you cannot depend upon this in ships, and you have to take the matter as you find it. I have found, taking the outer bottom plating of a steel ship when she has been running eight or nine months without being coated on the outside, that very serious pitting has taken place in the outer surface of the bottom plating, indeed to a very much greater extent than has ever been observed within my experience of iron ships, showing the necessity of docking steel ships more frequently than iron ships, and of being careful to keep the surfaces coated both externally and internally; in fact, our experience has gone to this extent, and Mr. Hamilton will know that in the rules of Lloyd's Register Society we felt the necessity of drawing special attention to this, that steel ships ought not to run more than six months before being docked, and the bottom being coated. We never felt it necessary to put that in with regard to iron ships, and that is put in entirely from the result of experience. So with regard to steel decks. It is very difficult to coat a steel deck, and to keep the steel covered. The consequence is that rapid deterioration in some instances has taken place on steel decks, and it seems to take place more rapidly in a thinner material, and to a greater extent in proportion to its thickness, than it does in the thicker material. I am glad to have an opportunity here of emphasising what I have said elsewhere, that unless the owners of steel ships take great care to keep the surfaces coated, and coated with good paint, something with a good body that will harden and protect it, not the shoddy and cheap stuff that is often used now, that will wash off as soon as it is put on, but good paint—unless they do that they will find within a short time that they will be led into very serious expense attending the repairs of those vessels. We have to thank Mr. Hamilton for giving us the result of his practical experience, which will be found, I am sure, of value to the Institution.

Mr. J. R. FOTHERGILL (Member): My Lord and Gentlemen, as directly interested in shipping, and having the supervision of several steamers, I feel no hesitation in saying this question is one of very great importance, materially affecting the interest of owners, and engaging the serious consideration of all directly associated with shipping. I fully re-echo Mr. Martell's sentiments, that we are very much indebted to Mr. Hamilton for bringing this important subject forward, and it is to be hoped this paper will give rise to an important and useful discussion. Mr. Hamilton has given us an interesting account of the way in which certain extensive repairs were executed to ballast tank tops and floors whilst the steamer was afloat. Important as this useful information is, yet it appears to me this paper would have had a much higher value if Mr. Hamilton had given us his opinion as to how to prevent corrosion taking place. It is probable the extensive corrosion which takes place, more particularly in the ballast tank under the boilers, is largely due to two causes:—First, the tank is never pumped absolutely dry, and, secondly, to the heat of the boilers. As you are well aware, it is impossible to pump the tanks absolutely dry; where every care is used there will always be some two or three inches of water which the pumps cannot drain, and this amount more often reaches six inches where special attention is not given. When the ship rolls about this water is splashed all over the tank, and evaporation takes place, due to the heat of the boilers; corrosion is rapidly promoted, and extensive destruction is the result. The tank top under the boilers is destroyed in a similar manner, viz., constantly wetted by the bilge water, and dried by evaporation by the heat of the boilers. To combat this action very special attention should be given to pumping arrangements to dry tanks and bilges, and the boilers should be kept well up. Instead of the boilers being twelve inches only from the top of the tank, they should not be less than 2 ft. 6 in. We have found this very beneficial, and it also facilitates repairs to tank top and boiler bottom. It would much facilitate insuring the tanks being dry if a better arrangement of sounding pipes were introduced. You should be able to sound the tanks with the steamer in any trim, which is seldom the case. This would also insure the tanks being full when "run up," as it would facilitate the escape of the air. There is no doubt, as Mr. Hamilton says, the damage to girders, keelsons, &c., in the McIntyre bottom is due to the tanks not being full. I agree with Mr. Martell that under ordinary conditions steel corrodes more rapidly than iron. I would also advise the thickening up of the plates on the tank top under the boilers. Before sitting down, I wish again to emphasise, on behalf of the shipowners, the great and rapid destruction which I know of my own knowledge is going on in ballast tanks, particularly in steel steamers of four to six years old.

Sir RAYLTON DIXON (Member of Council): My Lord, I had marked the same paragraph that Mr. Martell alluded to, in the paper which we have just heard read; for it struck me as very extraordinary that Mr. Hamilton should state he considered that there was no difference, so far as he had observed, between the duration of iron and steel under the circumstances named. My experience has been quite contrary to that, and I fully agree with the remarks that have fallen from Mr. Martell, that whereas in three or four steel vessels, constructed seven and eight years ago, we have found exactly the same state of things as shown in this photograph, where the girders forming the tank have been entirely eaten away, I have never, in a considerable experience with iron ships, found any vessels, however old, in such a bad state as this. I agree with Mr. Martell with regard to the use of iron in the double bottom, as well as in the tanks; but I go further than that, and I daresay he will agree with it, and think that the plan that is being adopted now so very generally, of dispensing with the double bottom in the way of the boilers (taking care to see that the longitudinal strength is continued, but not having the enclosed space), is very advisable, and the advantage gained by the preservation of the ship is doubtless very great. I must say this, that in the cases that have come under my eye, to which I have alluded, the steel has evidently not been attended to, nor been coated, as Mr. Martell has so strongly pointed out. There is not the slightest doubt, in cases of this sort in steel structures, where there are enclosed spaces liable to damage—as under the boilers—that it is of vital importance that that part should be carefully and thoroughly coated. We have found similar occurrences in the bottoms of bunkers, also in the engine-room in the way of the boiler, where the spaces are exposed, and where the heat of the boiler also acts. With those cases it has not been so easy to deal, whether they were coated frequently or not, because the friction of the coal removes the paint, and it is more difficult to deal with them, and it is also more difficult to cover the material with paint there; but in the tanks I have spoken of, it was very evident that this means of preservation had been altogether neglected. With regard to the remarks of Mr. Fothergill, who has had a great deal of experience in this matter as to the necessity of pumping out the tanks dry, I cannot attach so much importance, because, although the ballast tanks of a steamer are pumped out, they cannot be got absolutely dry; and, though the running water is removed, there still, in such an enclosed space, must always be a certain amount of water that cannot be entirely pumped, and there is quite sufficient damp in that enclosed space to induce corrosion as much, or more, than if the water had remained; therefore, I cannot see that the pumping of the tanks, however dry, would get over the difficulty. I have nothing further to say. I simply spoke to mention some experience I have had lately of cases bearing out these photographs almost exactly, and to support the views of Mr. Martell as to the necessity of painting, and the advisability of dispensing with the enclosed space of a double bottom of any construction immediately under the boiler of a steamer; for, although the boiler may be raised 6 inches or 2 feet, there must be great heat, and, although the liability to corrosion is not so great as if the boiler were close to the tank top, it is quite sufficient to cause more corrosion than in any other part of the vessel.

Mr. J. H. Hallett (Member): I have had considerable experience in steamers fitted in the manner described in Mr. Hamilton's paper. The corrosion is always on the inside of the tanks, immediately under the boilers, on the inside of the top plating. I have applied several compositions of various thicknesses immediately under the boilers, but with no satisfactory results. I am of opinion that if some method could be adopted of passing a current of air through the tanks, so as to get rid of the moisture, some benefit would be derived, and, no doubt, it would add to the life of the tanks. To raise the boilers higher would make it extremely difficult to feed the furnaces with fuel. I would like to enter more fully into this matter, as, in my opinion, it is of very great importance to steamship owners and managers, as the cost of repairs to tanks of any sort is very great, and with such low freights it does not leave much margin for repairs. I will not at the present take up any more of the valuable time of this meeting, as it is so limited.

Mr. J. G. G. Rule (Member): My Lord, yesterday we had the privilege of listening to very able and interesting papers, upon the form and construction of special types of vessels; papers which, owing to the suggestive hints and other interesting points contained therein, must have been of great value to us all, and doubtless will be of general use in the consideration of the design and construction of steamers, which is a matter of the first importance in naval architecture. Next to the question of construction, that of the preservation of vessels after they are built should be very closely considered, with a view to retaining them as far as practicable in the condition in which they are first placed. We have just listened to a paper leading up to this subject, and it has opened up a very interesting discussion. One of the most important points with regard to the "wear and tear" of vessels is that which has been referred to by Mr. Hamilton this morning, under the head of "Wear and Tear in Ballast Tanks." As he stated in this paper, the deterioration of the double bottom compartment in the boiler space is a question which has to be seriously considered. Apparently the deterioration in the other compartments of the double bottom is somewhat slight, and need only to be briefly alluded to. One form of this deterioration is that already referred to by Mr. Hamilton as the result of the working of the riveting attaching the bottom of the girders to the top of the floors, in the McIntyre type of tank. This might be prevented by fitting, in all cases, double lugs, instead of single lugs, to connect the longitudinal girders to the floors, thus increasing the extent and efficiency of the riveting. Another form of deterioration to which the several compartments of the double bottom is subject, is that which is sometimes found to exist along the flange at the upper part of the margin or tank side plating. This latter is due partly to the strains brought on this particular part of the tank, and partly to the fact that in many cases a thin layer of cement is placed on the tank side plating, which eventually becomes loosened at the top and admits of water and dirt congregating along the edge of the tank, and in several cases of vessels of seven to eight years of age, the upper part of the tank side plating has been found broken, or corroded nearly through. Returning to the extensive corrosion which has taken place in the tanks under the boilers of steamers; many useful suggestions have been made for preventing this deterioration, but the question does not appear to be satisfactorily settled. Some owners and builders are dispensing altogether with the double bottom compartment in the boiler space, but it appears to me that this is a false step to take. If there be any part of the ship more than another that we require to ensure the safety of, it is the machinery space. It is well known that the inner bottom plating is a large factor of safety in cases of vessels stranding or otherwise injuring the outer bottom, and for this reason it is desirable that the double bottom in the machinery space should be retained. It appears to me that the matter might be remedied if, in the first place, the boilers be kept as far as practicable above the top of the tanks, and in the second place, if a non-conducting substance be used to cover the tank top under the boilers; seeing that the corrosion goes on owing to the variation of temperature, and to the alteration of moisture and excessive heat to which the tank is exposed, and which might be prevented by insulating as far as possible the tank top. It has been done at this port in several cases. Vessels have come under my inspection, where, on the occasion of their second periodical survey, a certain amount of deterioration has been found in the tank top under the boilers, and at my recommendation the owners have had the top of the tank covered with a layer of about 2½ inches of cement, mixed with a proportion of tar (about a gallon of tar to a barrel of cement), and after the vessels have been running four years, and have again come under survey, it was found that this has thoroughly protected the tank top, and the corrosion has been stopped, and the inside of the tank preserved. By carrying out such an idea as that, without having to resort to elaborate fittings (as just now suggested) for inducing a current of air through the tank, the whole case I think might be met, a large amount of deterioration thereby prevented, and its resultant expense saved.

Mr. H. H. West (Member of Council): My Lord, I think this is an eminently practical and useful paper. I value it because I know it records the experience of a man who does not take his knowledge at second-hand, and who will see for himself. What he tells you, as the result of his experience, you may be sure is absolutely correct, and has come under his own personal observation. I regret that this Institution has not had from Mr. Hamilton more papers o this kind; I know the practical bent of his mind. I have been associated with him as a colleague for a great number of years, and I know how competent he is to give us information that would be exceedingly useful to us. I hold it is one of the most valuable objects of this Institution to encourage and secure the interchange of experience on the vital problems of the maintenance and repair of our ships. Without some knowledge of these subjects no man can become a competent designer or constructor, either in naval architecture, or in any other branch of civil engineering. It is very startling to see how rapidly our best contrived structures may fall into inefficiency and dilapidation from unavoidable circumstances, or a little neglect. I say neglect, for I am sure, from my own personal experience, that the whole of this serious waste would not occur without some neglect on the part of those in charge. I have myself examined double bottoms, both inside and outside, under boilers, and where care and attention has been given to these parts I have not found the serious deterioration which is portrayed in this paper. At the same time, I know that some amount of waste is inevitable. The question is, How can we remedy it? Constant care is an expense, and the question is whether we can attack it at an earlier stage? It is manifest, as has been already said, that the main factor in this deterioration is the radiation of heat from the boiler to the tank top. Well, as Mr. Fothergill has said, the first suggestion is to lift the boiler further up, but there is manifestly a limit to which you can go in that direction. Some people have cured it in this way; by carrying the lagging of the boiler right round instead of stopping it at the level of the furnace bars. This may be open to some objections. I have myself suggested, and it has been actually carried out in one case, the introduction of what I may call a baffle platform of deals, or suitable non-conducting material, between the bottom of the boiler and the top of the tank, so arranged that a current of air should circulate between this baffle platform and the top of the tank. Unfortunately the vessel that was so fitted has since been lost, and I am not able to tell you what was the success, if any, of the experiment; but from experience I have had in exactly similar arrangements for somewhat different purposes, I feel confident it would be of value in this particular case. I am struck, as I am sure you must all be struck, by the ingenuity of the method of repair referred to on page 63, where the boilers were lifted the necessary height, and the repairs were effected under them while the ship was afloat; thus giving another instance of that Cardiff ingenuity which we have heard so much of, and which seems quite able to deal with every circumstance which may arise. In conclusion, my Lord, I would draw the attention of the meeting to the coincidence that, from two totally different points of view, the first paper of yesterday, and this paper of to-day, both condemn absolutely the practice of filling the water ballast at sea. It is rather remarkable that two days in succession, from such different points of attack, the same idea has been presented to us.

Mr. A. K. Hamilton (Member): My Lord and Gentlemen, with reference to Mr. Martell's query as to the number of cases I have had experience of, I regret not to be in a position to say how many steel vessels we have had, and how many iron, but I may say the majority were steel. I say that iron appears to suffer equally with steel. Given an equal thickness and similar conditions, I believe one would go through or be rendered useless as soon as the other, but as the iron is so much thicker than the steel it does not appear to have so much waste as the other. Those remarks will answer, I think, Sir Raylton Dixon's observations. Mr. Fothergill asked for some preventive. I avoided giving any, as I thought there was plenty of room for other papers on that subject. Mr. Hallett spoke about throwing a current of air into the tanks. I may inform him that there is a gentleman now in Cardiff who is about to patent a scheme for doing so. I especially have to thank Mr. West, my colleague of many years' standing; he has spoken in very kind words of me; and I also have to thank the members of the Institution for the kindly reception and friendly criticism given to my paper.

The **President** (the Right Hon. Lord Brassey, K.C.B.): Gentlemen, Mr. Hamilton has thanked the members of the Institution for the patient attention they have given to his paper, and for the discussion with which it has been followed. I can assure Mr. Hamilton that the Institution is very grateful to him, for he writes a paper upon a subject which we all recognise is of extreme practical importance. It is unfortunately the case that many and sometimes long voyages must be made with no cargo, and certainly with no remunerative cargo, and therefore the use of ballast tanks has become extremely desirable as a means of ballast for vessels. The paper which has been read to us describes a means by which, when injury has occurred through corrosion in ballast tanks, repairs may be effected. I did not quite understand from the paper to what degree facilities of access existed in the case of vessels whose injuries were described—facilities of access to all parts of their ballast-tanks. I think that must be extremely important. It is, no doubt, desirable that ingenuity should be applied to repairs when great injury has arisen, but the best of all treatments must be that suggested by Mr. Martell, which consists in that prevention which is better than cure. Where vessels are damaged the free use of anti-corrosive paint should be the best means of dealing with them, and that will prevent the liability of ballast-tanks from injury to corrosion. In any case we are grateful to Mr. Hamilton for his paper. It is pleasant that a paper should be read of such great value by a gentlemen resident in Cardiff. Before we disperse I would ask Mr. Holmes to read a paper by Mr. Blechynden. I regret very much that our able colleague Mr. Blechynden is not here to read it himself.

AN ACCOUNT OF SOME EXPERIMENTS ON THE TRANSMISSION OF HEAT THROUGH STEEL PLATES, FROM HEATED GAS AT THE ONE SIDE TO WATER AT THE OTHER.

By A. **Blechynden**, Esq., Member.

[Read at the Summer Meeting of the Thirty-fourth Session of the Institution of Naval Architects, July 12th, 1893; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

Object.—The object of the experiments was to ascertain the rate at which heat is conducted through steel plates from gas at a high temperature at the one side to water at a lower temperature, in process of being heated or evaporated, at the other, as in a steam boiler.

Firstly, with varying differences of temperature at the two sides; and,

Secondly, with varying thicknesses of plate.

The Apparatus.—The apparatus employed is illustrated in Fig. 1, Plate XXIII., and consisted essentially of two parts—a boiler, A, and a furnace, B.

The boiler A was 10 in. diameter inside and 12 in. high outside, and was constructed of tinned iron plate about 24 w.g. in thickness. In Fig. 1 it is shown in its final form with a jacket 1 in. wide (1) on its sides and top, and clothed with asbestos felt ·375 in. thick. The jacket was used as an air-case, but was so arranged that steam might be passed through it by means of the inlet pipe (6) and the outlet pipe (7). In most of the earlier experiments, however, the boiler was not so cased, but was simply clothed with asbestos felt.

The plate intended to be experimented upon was soldered into the bottom (3), and the pipes (4) and (5) served for the inlet of water, the outlet of steam, and for the insertion of mercurial thermometers, by means of which the temperature of the water was measured.

The boiler rested upon an asbestos pad (8), and was fitted with four arms, at the ends of which were vertical pins, which fitted into holes on the outer case of the furnace B, as an easy and accurate means of ensuring correct register of the plate (3) with the circular aperture in the asbestos pad (8) and with the mouth of the furnace.

The furnace consisted of an iron case (9) lined with fire-brick (10). There were two tubes, (11) and (12), near the top for the escape of the heated gas, and holes, (13) and (14), for the purpose of temperature measurements.

The fire was represented by the jets (15) (15), of which there were five, supplied with ordinary lighting gas from the main, and with air from a smith's blast. The jets impinged on a mass of asbestos lumps or balls such as are used in domestic gas-fires, and covered with two pieces of wire gauze (17), with the object of ensuring an equal distribution of the flame over the surface.

At first a coke fire was tried, but it was found impossible to maintain it at a uniform temperature for any length of time sufficient for the purposes of the experiments. Recourse was therefore had to the device described, which answered the purpose admirably.

The Plates.—The plates experimented upon were of Siemens-Martin's steel of the quality usually employed in the construction of steam boilers.

In the first stage of these experiments a different plate was used for each different thickness, with its natural or mill scale surface untouched. But it was found, either through the different properties of the materials or the characteristics of their surfaces, that such irregular, though doubtless, consistent enough results, were obtained with the different plates, that it was necessary to adopt some other method to eliminate these causes of variation. After some consideration it was deemed that, if a plate of the greatest thickness intended to be experimented upon, with one of its sides machined, were taken and tried at that thickness, and machined afterwards to the other thicknesses successively, and tried, the objectionable variables would, in the main, be eliminated. There would still remain the probable slight variation of density at different parts of the plate, and the possible difference in the smoothness of the surface of the machined side due to slight variations in the condition of the tool used; but it seemed as if these could not be such serious disturbing elements as those which the aim was to get rid of, and it is supposed that the latter had little effect on the results, as in the case of the two plates with which the most experiments were made, the machined surfaces were next the water, and it is well known that the capability of water giving out heat to, or absorbing it from, a metal plate is some hundreds of times greater than the similar capability on the part of air; so that any differences in the results with the varying thicknesses might with reasonable probability be assumed as almost entirely due to the difference in thickness.

The greater number of experiments were made with two plates, known as A and B. These were tried with the one side machined and the other "natural." Plate C was ·8125 in. in thickness, with both sides untouched. Plate D was ·5 in. in thickness with one side untouched. Plate E had both sides machined. There were other plates used for special purposes, but the experiments with those referred to have the most direct bearing on the subject.

The following table will at least be interesting, and may prove useful. It gives the specific gravities and contents of carbon of the principal plates experimented with :—

Plate.	Carbon per centum.	Specific Gravity.
A	·21	7·8176
B	·25	7·742
C	·22	7·8032
D	·23	7·8401
E	·24	7·777

Method of Experimenting.—In experimenting, the jets were first lighted, and then regulated to approximate equality, and were permitted to burn for some time, with the top of the furnace covered by a sheet of asbestos millboard or other material until the temperature of the furnace became steady. The cover was then removed, and the boiler, into which had been put a known quantity of water, was put in place. A thermometer was inserted in one of the tubes (4) or (5), and when its rise indicated that the water had reached the boiling point, the time was noted, and a commencement was made with the measurement of the furnace temperatures. These were taken at the points (13) and (14). At (13) the block was suspended at a distance of about ¼ in. to ½ in. from the plate, and at (14) it was about 2 in. from the incandescent mass of asbestos.

When water was added to the boiler during the course of an experiment, it was weighed, and its temperature noted at the time it was poured in.

When the experiment was concluded, a known quantity of water was put into the boiler to stop evaporation, and the resulting water weighed. From this datum was ascertained the quantity of heat transmitted through the plate during the course of the experiment.

Temperatures.—The temperatures of the water were measured by mercurial thermometers, and those of the furnace by the apparatus known as a Siemens Pyrometer. The blocks commonly used were of copper, but in some cases iron was used; the specific heats of both were compared with that of a piece of platinum, and the temperatures ultimately recorded depend on Pouillet's determination of the specific heat of platinum, which is given in the following table:—

SPECIFIC HEAT OF PLATINUM, IRON, AND COPPER.

Temperatures.		Specific Heat.		
Centigrade.	Fahrenheit.	Platinum (Pouillet).	Iron.	Copper.
Between 0° and 100°	Between 32° and 212°	0·0335	0·1095	0·0961
„ 0 „ 300	„ 32 „ 572	0·0343	0·1189	0·09974
„ 0 „ 500	„ 32 „ 932	0·0352	0·1279	0·1032
„ 0 „ 700	„ 32 „ 1,292	0·0360	0·1374	0·1068
„ 0 „ 1,000	„ 32 „ 1,832	0·0373	...	Melts.
„ 0 „ 1,200	„ 32 „ 2,192	0·0382	—	—

The mean specific heats of copper and iron as determined during the course of the experiments are given in the last two columns. They depend directly on Pouillet's determination of those of platinum.

The Surfaces of the Plates.—The plates A, B, and D, which had the side machined, were fixed in the boiler with the machined side next the water. After the plates were fixed in position, sand and a solution of caustic soda were put into the vessel, and the interior surface was well scoured, to get rid of all traces of grease and dirt, and then it was well rinsed out with clean water. The outer surface of the plate was also scrubbed with caustic soda and water, for the same purpose. Thus all experiments were begun with the surfaces in fairly similar condition. The expression "fairly similar condition" is used advisedly, "exactly similar" would have been much better, could it have been attained; but only those who have attempted experiments of this kind will fully realise the difficulties in the way of approaching approximate similarity.

Sources of Error.—Radiation and loss by contact of air with the outer surfaces of the boiler.

In the earlier experiments the exposed surface of the boiler was covered with asbestos felt to the thickness of about ·25 in., and, in order that proper correction might be made in the results for the losses due to radiation and contact with the air, measurements of these losses were made by placing the boiler in the position it would occupy during the experiments; but insulated from the fire by a plate covered with sheets of asbestos felt, and between the asbestos and the boiler bottom an air space of one-half inch. These tests were made with various temperatures of fire, and consisted in measuring the fall of the temperature of the water from nearly its boiling point in a given time, the vessel being quite full.

From these trials it was found that the loss was about 600 heat units per hour with the furnace at 1,000° Fahr., and the atmosphere at 60° Fahr. A slightly greater loss was experienced at the lower temperature, but the difference between the losses at the higher and lower temperatures was so small that it was assumed as being uniformly at the rate of 600 heat units per hour.

In order to minimise the loss arising from this cause the boiler was ultimately jacketed, as has already been described. The utter elimination of all loss by radiation, &c., might have been accomplished by surrounding the boiler with an atmosphere at the temperature of the water within it, and some attempts were made to do so by connecting the jacket to a steam pipe; but after one or two trials the idea of using steam was abandoned, as it was found so difficult to maintain the steam supply at the exact temperature required, and any slight difference caused extremely large variations in the evaporative results, as the rate of transmission of heat from steam to water is so much greater than the rate of transmission from the heated products of combustion, that in some of the trials with the furnace at a low temperature one degree of temperature in the jacket over the water in the boiler served almost to double the evaporation, and indirectly the apparent rate of transmission from the furnace. The space was thenceforward used as an air jacket only, and with this arrangement the loss from the boiler was found to be practically *nil.*

Temperature of the Furnace.—It is very probable that the temperatures recorded err in defect, as the pyrometer blocks must have lost some heat while being removed from their position in the furnace to the water-pot. This was minimised as much as possible by bringing the pot close to the furnace and so reducing the time of exposure to the atmosphere to a momentary duration. No attempt was made to estimate the amount of this loss, but it is believed to have been very small.

The Point at which the Temperatures were taken.—It may be thought that the low temperature of the boiler bottom would exercise such influence on the temperature of the pyrometer block when placed at the point (13) that the true temperature of the gases would not be indicated by it. To test this several experiments were made. One was by placing a small piece of asbestos millboard between the block and the plate, when it was found that the same temperature was indicated with as without. Again, holes were made at E and F (Fig. 2, Plate XXIII.), so that temperatures might be taken simultaneously at C, D, E, and F.

The first observations were made with the boiler removed and the furnace top closed with a piece of asbestos sheet over which was an iron plate. Under this condition, as might have been expected, the temperatures were alike at all the four points, viz., 1,780° Fahr.

The covering of the furnace was then removed, and the boiler placed in position, when the following temperatures were recorded:—

At E, F, and C	1,545° Fahr.
At D...	1,850° ,,
At a point 3½ in. under the plate...	1,580° ,,

It was thus evident that the temperatures recorded as at the point C were just equal to those of the escaping gases. (The record of 1,850° Fahr. at D indicates that the furnace temperature had increased since the previous experiment was made.)

It will be evident, from the latter experiment, that a comparison of the evaporative results, or the quantity of heat transmitted with the temperatures measured at C, would be misleading, and incorrectly represent the modulus of transmission unless the quantity of heated gas passing over the surface of the plate were unlimited; the comparison should be with some function of the initial and terminal temperatures. But, as in a considerable number of the earlier experiments the temperatures at C only were measured, a comparison of the evaporative results will be made with these temperatures, from which it will be seen that such broad general results will be obtained that, with a simple correction for the fact of the temperatures being terminal, the true co-efficient of transmission may be fairly approximated.

In some of the latter experiments the temperatures were measured at both the points C and D. At the higher temperatures little difficulty was experienced in obtaining what appeared to be fair means at the point D, but at some of the lower temperatures, through the difficulty of accurately regulating all the gas jets to uniformity, the local variations at the surface of the fire were so great as to render them at times apparently valueless. When such obvious irregularities were evident, the records were thrown out.

Results of the Experiments.—These are given in figures in the Tables 1 to 13, pages 79 *et seq.*, and are likewise shown graphically for the Plates A and B in the diagrams numbered 1 to 9 (Figs. 3 to 11, Plates XXI. and XXII.). The general results for all the plates are also shown relatively to each other in Diagram 10 (Fig. 12, Plate XXII.).

Diagrams 1 to 5 (Figs. 2 to 7) (Tables 1 to 5) give the results of the experiments with plate A, which was at first 1·1875 in. in thickness, and was afterwards reduced successively to ·75 in., ·5625 in., ·25 in., and ·125 in. in thickness, and tried at each thickness. The temperatures of the furnace, given in the records of the trials with this plate, are those measured at the point C (Fig. 2, Plate XXIII.).

Diagrams 6 to 9 (Figs. 8 to 11, and Tables 6 to 9) show the results obtained with the plate B, which was at first ·46875 in. thick, and was successively reduced to ·375 in., ·25 in., and ·15625 in. thick, and tried at each thickness. For its first three thicknesses, as with plate A, no temperatures were measured at the lower point (D, Fig. 2, Plate XXIII.); but in the latter experiments with it, at the smallest thickness, these temperatures were measured, and in these experiments the boiler was fitted with an air jacket.

Table 10 gives the results with the plate C ·8125 in. thick, with both sides rough.

Table 11, the results of plate D, ·5 in. thick, with one side—that next the water, as in A and B—machined. In the experiments with this plate, the temperatures were also taken at the lower point D, just over the fire, and the results are given in the Table referred to.

Tables 12 and 13 give the results of the trials with the plate E. This plate was machined on both sides; it was at first 1·1875 in. thick, and was afterwards reduced to ·1875. As with the plate D, the temperatures were measured at both the upper and lower points C and D. Only four experiments were made with the plate at each thickness.

Discussion of the Results.—If an examination be made of any of the diagrams Nos. 1 to 13, or of Tables 1 to 13, the broad general fact is evident that the heat transmitted through any of the plates per degree difference of temperature between the fire and the water is proportional to that difference; or, in other words, the heat transmitted is proportional to the square of the difference between the temperatures at the two sides of the plate, as will be seen from the fact that the ratio

$$\frac{\text{Heat transmitted per square foot}}{(\text{Difference of Temperatures})^2}$$

is a constant for each plate within the limits of the experiments, and the mean values of this ratio for the various plates are as follow :—

Plate.	Thickness. Inches.	Modulus for Temperatures at Top Station.	Modulus for Temperatures at both Upper and Lower Stations.
A	1·1875	·01552	—
A	·750	·01770	—
A	·5625	·02119	—
A	·25	·0230	—
A	·125	·02390	—
B	·46875	·023996	—
B	·3750	·02443	—
B	·250	·02568	—
B	·15625	·02611	·02064
C	·8125	·01819	—
D	·5000	·02367	·01747
E	1·1875	·014178	·00961
E	·1875	·019235	·01431

The figures for the moduli in the last column are calculated as for the mean of the squares of the differences of the temperatures on the assumption that the temperatures taken just over the fire, or point D, are the maxima, which would be approximately true, and that those at the upper station were equal to those of the escaping gases, which, as has been shown, was actually correct. The mean of the squares of the differences of temperatures was taken as being D·*d*, where D is the difference between the temperature at the upper station and the boiler, and *d* the difference between that at the lower station and that in the boiler.

The Table shows that there is a general rise in the value of the moduli with decrease of thickness; but, if the Diagram No. 10, which shows graphically the general relation of these moduli, be inspected, it will be seen that there are considerable irregularities in the curves joining the various points for each plate. This is perhaps no more than might be expected, because of the great difficulty of machining all the surfaces to the same degree of smoothness; and, notwithstanding the precautions taken, the difficulty of maintaining the surfaces uniformly clean. It was found that the very slightest trace of grease caused a very large fall in the rate of transmission; even wiping the outer surface of the plate with a piece of rag or of waste was sufficient to influence the result detrimentally.

There is also an apparent falling off in the increased efficiency of the thinner plates when they are under three-eighths of an inch or so, which seemed as if it might possibly be accounted for on the assumption that the thinner plates yielded to the cutting tool, and thus came to have more smoothly machined surfaces than the thicker.

That the smoothness of the surfaces was an important factor will be readily seen when the position of the points for the Plate E are compared with others. The Plates A and E were at first the same thickness, viz., 1·1875 in., yet the modulus for A is ·0155 in., while that for E is only ·01419 in. Plates B and E were ultimately reduced to nearly the same thickness, viz., B to ·15625 in. and E to ·1875 in., while their moduli differ widely, viz., for B ·02583 in. and for E ·019245 in. The differences are due to A and B having the receiving surfaces as from the mill, while E was very smoothly machined on both sides.

It may be worth while to compare the results for the various plates relatively to their carbon content:—

Plate.	Carbon.	Specific Gravity.
A	·21	7·8176
C	22	7·8032
D	·23	7·8401
B	·25	7·7420

Now, it will be observed that A, the lowest in carbon, is also the lowest in conductivity, while the others seem to follow in the order of the percentage; though, doubtless, the experiments should be extended to confirm this.

The rate of conduction has hitherto within this paper almost entirely been referred to the terminal temperature of the gases. This is not, however, that to which they should be referred, as has already been stated, but to a function of the initial and terminal temperatures, viz., D·*d*. In the cases of plates B, ·15625 in. thick, D, and E, these are given, and from these and others not here given it is evident that the values should be reduced to about ·74 of those given for the ultimate differences of temperature.*

The results of these experiments certainly point to the conclusion that the thinner the plates, forming part of the heating surface of a boiler, the higher should be the boiler's efficiency, always provided that the plates are clean; but it will be evident that, if the plates be coated with a covering of scale, or some bad conductor, then the less must be the influence of the thickness on the efficiency, while with a thick coat of oil the influence might become practically unimportant.

The fact that the heat transmitted is proportional to the square of the difference of the temperatures of the two sides of the plate shows the importance of high furnace temperatures if efficiency is aimed at, and emphasises the importance of rapid combustion, either by means of air supplied by fans or by height of funnel.

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* The results for the Plates D and E are given in Tables 11, 12, and 13. Those for the Plate B at thickness ·15625 in Table 9A.

Results of Experiments on the Transmission of Heat through Steel Plates.

No. 1. PLATE A.

Duration of Trial.		Temperature in Furnace.	Total Lbs. of Water Evaporated.	Heat Units Transmitted per Hour by Heating and Evaporation of Water.	Heat Units Lost by Radiation per Hour.	Total Units (with Radiation) Transmitted per Hour per Sq. Ft. H.	Difference in Temperature D.	Heat Units Transmitted per 1 deg. Diff. per Sq. Ft. per Hour $\frac{H}{D}$.	$\frac{H}{D^2}$.	Thickness of Plate.
Hrs.	Mins.	Deg.								
1	51	1,060	10·15	5,300	600	10,820	848	12·78	·01505	1·1875
1	49	1,205	14·0	7,460	„	14,780	993	14·85	·01498	„
1	27	1,225	8·11	7,845	„	15,500	1 013	15·26	·01505	„
2	3	1,425	25·1	11,800	„	22,750	1,213	18·73	·01545	„
1	54	1,440	25·1	12,750	„	24,450	1,228	19·9	·01622	„
2	37	1,490	38·05	13,950	„	26,750	1,278	20·9	·01637	„
								Mean	·01552	
No. 2. PLATE A.										
1	4	838	3·44	3,120	600	6,820	626	10·89	·01741	·75
2	1	1,000	11·27	5,380	„	10,950	788	13·9	·01765	„
2	1½	1,125	15·45	7,380	„	14,650	913	16·04	·01757	„
1	33	1,270	16·79	10,480	„	20,300	1,058	19·18	·01811	„
1	48	1,445	26·45	14,150	„	27,100	1,233	21·92	·01788	„
								Mean	·01770	
No. 3. PLATE A.										
2	6	775	6·65	3,058	600	6,705	563	11·90	·02110	·5625
1	57	920	9·97	4,950	„	10,180	708	14·37	·02030	„
1	8½	1,175	11·85	10,000	„	19,450	963	20·18	·02094	„
1	7	1,360	17·98	15,500	„	29,550	1,148	25·7	·02241	„
								Mean	·02119	

No. 4. PLATE A.

Duration of Trial. Hr.	Duration of Trial. Mins.	Temperature in Furnace. Deg.	Total Lbs. of Water Evaporated.	Heat Units Transmitted per Hour by Heating and Evaporation of Water.	Heat Units Lost by Radiation per Hour.	Total Units (with Radiation) Transmitted per Hour per Sq. Ft. H.	Difference in Temperature D.	Heat Units Transmitted per 1 deg. Diff. per Sq. Ft. per Hour $\frac{H}{D}$.	$\frac{H}{D^2}$.	Thickness of Plate.
1	51	715	5·06	2,645	600	5,950	503	11·81	·02350	·25
1	25	858	6·52	4,450	„	9,260	646	14·35	·02230	„
1	19	935	8·11	5,930	„	11,970	723	16·55	·02290	„
1	14	1,040	9·97	7,820	„	15,450	828	18·65	·02255	„
1	7	1,105	10·9	9,460	„	18,470	893	20·65	·02310	„
1	7	1,190	13·61	11,750	„	22,650	97	23·15	·02365	„
								Mean	·02300	
				No. 5. PLATE A.						
1	3	950	6·55	6,030	600	12,170	738	16·48	·02230	·125
1	1	1,120	10·18	9,690	„	18,850	908	20·75	·02285	„
1	25	1,210	18·27	12,500	„	24,030	998	24·1	·02415	„
1	6	1,295	16·48	14,460	„	27,620	1,083	25·48	·02352	„
1	24	1,335	28·28	16,100	„	30,620	1,123	27·25	·02426	„
1	13	1,345	20·45	16,240	„	30,900	1,133	27·27	·02410	„
1	13	1,350	20·65	16,450	„	31,300	1,138	27·48	·02410	„
1	3	1,530	26·10	24,000	„	45,100	1,318	34·21	·02595	„
								Mean	·02390	

No. 6. PLATE B.

Duration of Trial.		Temperature in Furnace.	Total Lbs. of Water Evaporated.	Heat Units Transmitted per Hour by Heating and Evaporation of Water.	Heat Units Lost by Radiation per Hour.	Total Units (with Radiation) Transmitted per Hour per Sq. Ft. H.	Difference in Temperature D.	Heat Units Transmitted per 1 deg. Diff. per Sq. Ft. per Hour $\frac{H}{D}$.	$\frac{H}{D^2}$.	Thickness of Plate.
Hr.	Mins.	Deg.								
1	10	625	2·09	1,780	600	4,270	413	10·32	·02495	·46875
1	7	850	5·09	4,400	„	9,175	688	14·38	·02255	„
1	23	855	6·41	4,500	„	9,350	643	14·53	·02260	„
1	0	1,205	12·68	12,235	„	23,550	993	23·70	·02385	„
1	30	1,240	20·64	13,300	„	25,500	1,028	24·80	·02410	„
1	8	1,280	17·28	14,720	„	28,140	1,068	26·30	·02462	„
1	19	1,335	21·86	16,000	„	30,450	1,123	27·10	·02410	„
1	0	1,340	16·82	16,230	„	30,850	1,128	27·34	·02425	„
1	3	1,360	18·28	16,800	„	31,940	1,148	27·80	·02420	„
1	0	1,465	21·38	20,610	„	38,950	1,253	31·10	·02474	„
								Mean	·023996	

No. 7. PLATE B.

1	3	862	5·0	4,610	600	9,570	650	14·74	·02270	·375
1	10	868	6·15	5,080	„	10,420	656	15·87	·02421	„
1	17	1,170	15·69	11,800	„	22,750	958	23·74	·02479	„
1	8	1,180	13·92	11,880	„	22,880	968	23·62	·02440	„
1	4	1,320	17·62	16,000	„	30,400	1,108	27·40	·02472	„
1	21	1,500	30·7	22,000	„	41,450	1,288	32·15	·02498	„
1	8½	1,520	27·0	22,910	„	43,150	1,308	33·0	·02520	„
								Mean	·02443	

No. 8. PLATE B.

Duration of Trial.	Temperature in Furnace.	Total Lbs. of Water Evaporated.	Heat Units Transmitted per Hour by Heating and Evaporation of Water.	Heat Units Lost by Radiation per Hour.	Total Units (with Radiation) Transmitted per Hour per Sq. Ft. H.	Difference in Temperature D.	Heat Units Transmitted per 1 deg. Diff. per Sq. Ft. per Hour $\frac{H}{D}$.	$\frac{H}{D^2}$.	Thickness of Plate.
Hrs. Mins.	Deg.								
1 4	585	1·5	1,360	600	3,595	373	9·63	·02584	·25
1 1	725	3·13	2,975	„	6,560	513	12·77	·02495	„
1 10	985	8·93	7,410	„	14,700	773	19·0	·02460	„
1 9	1,035	10·45	8,780	„	17,220	823	20·94	·02544	„
0 57	1,060	9·25	9,370	„	18,310	848	21·6	·02545	„
1 15	1,067	12·66	9,770	„	19,020	855	22·28	·02600	„
1 4	1,320	18·15	16,500	„	31,380	1,108	28·3	·02550	„
1 12	1,340	21·62	17,460	„	33,150	1,128	29·39	·02604	„
1 6	1,480	26·55	23,300	„	43,800	1,268	34·6	·02730	„
				No. 9. PLATE B.			Mean	·02568	
1 17	755	4·67	3,520	600	7,550	543	13·88	·02558	·15625
1 20	950	9·38	6,780	„	13,540	738	18·35	·02490	„
1 3	1,185	14·0	12,850	„	24,650	973	25·3	·02600	„
1 7	1,270	17·45	15,150	„	28,900	1,058	27·3	·02583	„
1 6	1,335	19·65	17,320	„	32,900	1,123	29·28	·02604	„
1 10	1,460	27·8	23,050	„	43,400	1,248	34·8	·02790	„
1 5	1,475	25·3	22,550	„	42,400	1,263	33·58	·02658	„
		With Air Jacket. No Addition for Radiation.							
3 21	588	6·99	2,019	0	3,700	376	9·86	·02625	air jacket
1 36	717	5·06	3,595	0	6,600	505	13·06	·02590	„
2 0	794	10·28	4,979	0	9,140	582	15·67	·02690	„
1 46	1,341	32·6	17,850	0	32,750	1,129	29·10	·02570	„
1 21	1,367	25·95	18,540	0	34,050	1,155	29·48	·02550	„
1 32	1,450	35·1	22,100	0	40,550	1,238	32·78	·02650	„
							Mean	·02611	

No. 9A. PLATE B.

WITH AIR JACKET. NO ADDITION FOR RADIATION.

Duration of Trial.		Temp. at Top of Furnace.	Temp. at Bottom of Furnace.	Heat Units Transmitted per Hour by Heating and Evaporation of Water.	Heat Units Transmitted per Hour per Sq. Ft. H.	D Diff. Top.	d Diff. Bott.	$\frac{H}{D}$.	$\frac{H}{D \times d}$.	$\frac{H}{D^2}$.	Thickness of Plate.
Hrs.	Mins.	Deg.									
1	36	717	867	3,595	6,600	505	655	13·06	·01995	·0259	·156
2	0	794	904	4,979	9,140	582	692	15·67	·02265	·0269	,,
1	46	1,341	1,537	17,850	32,750	1,129	1,325	29·10	·02195	·0257	,,
1	21	1,367	1,850	18,540	34,050	1,155	1,638	29·48	·01800	·0255	,,
								Mean	·02064		

No. 10. PLATE C.

Duration of Trial.		Temperature in Furnace.	Total Lbs. of Water Evaporated.	Heat Units Transmitted per Hour by Heating and Evaporation of Water.	Heat Units Lost by Radiation per Hour.	Total Units (with Radiation) Transmitted per Hour per Sq. Ft. H.	Difference in Temperature D.	Heat Units Transmitted per 1 deg. Diff. per Sq. Ft. per Hour $\frac{H}{D}$.	$\frac{H}{D^2}$.	Thickness of Plate.
Hrs.	Mins.	Deg.								
1	3	864	3·95	3,638	600	7,776	652	11·91	·01829	·8125
1	2	975	5·70	5,325	,,	10,860	763	14·25	·01865	,,
1	1	985	5·93	5,630	,,	11,420	773	14·80	·01912	,,
1	9	990	6·07	5,100	,,	10,450	778	13·46	·01730	,,
1	4	990	6·05	5,475	,,	11,140	778	14·31	·01841	,,
1	5	1,060	6·95	6,200	,,	12,475	848	14·70	·01735	,,
								Mean	·01819	

No. 11. PLATE D.

Duration of Trial.	Temp. at Top of Furnace.	Temp. at Bottom of Furnace.	Heat Units Transmitted per Hour by Heating and Evaporation of Water.	Heat Units Transmitted per Hour per Sq. Ft. H.	D Diff. Top.	d Diff. Bott.	$\frac{H}{D}$.	$\frac{H}{D \times d}$.	$\frac{H}{D^2}$.	Thickness of Plate.
Hrs. Mins.	Deg.	Deg.								
1 30	651	743	2,318	4,250	439	531	9·66	·01820	·02200	·5
1 30	967	1,279	7,180	13,200	755	1,067	17·49	·01640	·02316	,,
1 31	950	1,354	7,140	13,110	738	1,142	17·75	·01560	·02428	,,
1 29	956	1,177	7,400	13,580	744	965	18·23	·01892	·02455	,,
2 40	980	1,280	7,620	13,980	768	1,068	18·26	·01710	·02380	,,
1 41	1,059	1,396	8,820	16,200	847	1,184	19·13	·01615	·02260	,,
1 40	1,091	1,347	10,200	18,730	879	1,135	21·32	·01880	·02430	,,
1 33	1,122	1,422	11,120	20,410	910	1,210	22·45	·01858	·02470	,,
							Mean	·01747	·02367	

No. 12. PLATE E.

Duration of Trial.	Temp. at Top of Furnace.	Temp. at Bottom of Furnace.	Heat Units Transmitted per Hour by Heating and Evaporation of Water.	Heat Units Transmitted per Hour per Sq. Ft. H.	D Diff. Top.	d Diff. Bott.	$\frac{H}{D \times d}$.	$\frac{H}{D^2}$.	Thickness of Plate.
Hrs. Mins.	Deg.	Deg.							
1 38	513	735	774	1,420	301	523	·00901	·01560	1·1875
1 53	652	896	1,520	2,790	440	684	·00927	·01442	,,
2 0	856	1,125	2,855	5,230	644	913	·00890	·01264	,,
2 2	1,285	1,550	8,800	16,150	1,073	1,338	·01126	·01405	,,
						Mean	·00961	·01418	

No. 13. PLATE E.

1 32½	534	648	1,091	2,005	322	436	·01430	·01938	·1875
2 0	771	989	3,276	6,010	559	777	·01382	·01920	,,
2 0	955	1,242	5,641	10,360	743	1,030	·01354	·01880	,,
1 45	1,340	1,625	13,550	24,880	1,128	1,413	·01559	·01955	,,
						Mean	·01431	·01923	

Boiler surrounded top and sides by air jacket, which was well covered with asbestos. No allowance has been made for loss by *radiation*. This plate was *machined* on *both* sides.

DISCUSSION.

Mr. A. F. **Yarrow** (Member of Council): My Lord, I have nothing to say on this paper except to express my great appreciation of its value. We have not tried any experiments bearing upon the rate of conduction of heat through plates, but I would take this opportunity of drawing attention to what is self-evident, namely, that, at whatever rate heat is conducted through plates, the thinner the plate is the quicker the heat will pass through it, and consequently the mean temperature of the plate, if thin, will be considerably lower than the mean temperature if thick. Having in view the trouble caused by the over-heating of tube plates, I think it must be admitted that, after giving due weight to other practical considerations, the thinner the tube plate is the better, in order to prevent over-heating. Those, gentlemen, are the only remarks I have to make.

The **President** (the Right Hon. Lord Brassey, K.C.B.): I apprehend there is hesitation in interposing to discuss this paper arising out of the known fact that in a few moments we must compulsorily leave this room in order to attend another engagement which lies before the Institution. I am quite sure that Mr. Blechynden fully appreciates that his paper was not altogether a paper suitable for discussion, while yet it is one of those papers which it is exceedingly valuable to print and circulate with our Transactions. Speaking as an absolute layman upon the subject, I think I am not altogether wrong in recognising that, while on the one hand the thinner the plate the more perfect the transmission of heat, yet on the other hand you may carry the thinness of the plate so far as to involve serious loss from the want of durability of the boiler. I am sure you will all desire that the thanks of the Institution should be conveyed to Mr. Blechynden for his valuable contribution.

PRELIMINARY PROCEEDINGS.

THURSDAY MORNING, JULY 13, 1893.

The following gentlemen, having been duly recommended by the Council, were unanimously elected Members of this Institution:—Mr. P. H. Adamson, of Messrs. Mackie & Thomson, Glasgow; Mr. J. Rennie Barnett, chief draughtsman to Messrs. G. L. Watson & Co., Glasgow; Mr. W. H. Dugdale, shipyard manager to Messrs. Palmers' Shipbuilding and Iron Company, Limited, Jarrow-on-Tyne; Mr. W. Martin Davey, consulting engineer and surveyor, Liverpool; Mr. Henry Fownes, manager forge department, Messrs. J. Spence & Son, Newcastle-on-Tyne; Mr. Alex. Gray, consulting engineer, Newcastle-on-Tyne; Mr. R. Hodge, general manager to Messrs. C. S. Swan & Hunter, Wallsend-on-Tyne; Mr. Karl J. A. Isakson, ship and engineer surveyor to Lloyd's Register of Shipping, Stockholm; Mr. G. F. Mackrow, chief constructor at H.M. Indian Marine Dockyard, Bombay; Signor G. Manaira, of Messrs. E. Cravero & Co., Genoa; Mr. Robert Mitchell, superintending engineer to the Hong-Kong and Whampoa Dock Company, Hong-Kong; Mr. W. H. Martin, manager to the Royal Shipbuilding and Engineering Company, Holland; Mr. A. L. Oswald, of Messrs. T. R. Oswald, Milford Haven; Mr. J. Pattison, manager to Mr. J. H. Hallett, consulting engineer, Cardiff; Mr. G. Pope, special surveyor of hulls and machinery for the Union Pacific Railway Navigation Company, Port Oregon; Mr. J. W. Reed, manager of engine works department at Messrs. Palmer's Shipbuilding and Iron Company, Limited, Jarrow-on-Tyne; Mr. H. M. Rounthwaite, 15, Nicosia-road, Wandsworth Common.

The following gentlemen were elected Associates:—Mr. J. T. Bennett, Mr. S. Barnett, Mr. T. Jack, Mr. A. Johnson, Mr. G. Johnstone, Mr. H. Mechan, and Mr. J. Watt.

ON THE PRESENT POSITION OF WATER-TUBE BOILERS AS APPLIED FOR MARINE PURPOSES.

By J. T. Milton, Esq.,
Chief Engineer Surveyor to Lloyd's Registry of Shipping, Member of Council.

[Read at the Summer Meetings of the Thirty-fourth Session of the Institution of Naval Architects, July 13th, 1893; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

At the present time the boiler question is attracting considerable attention amongst marine engineers, who have by no means arrived at a unanimous conclusion as to the types of boilers which best satisfy the peculiar requirements of different classes of vessels. To see that this is so, we have only to look at the plans adopted in different vessels having presumably the same requirements, to find great divergency of practices. For instance, in the war-vessels of our own and foreign countries, we see large vessels, which may have to keep the sea for long periods, in some cases fitted with ordinary tubular boilers worked with the closed stokehold system of forced draught, and in others with water-tube boilers worked with natural draught; while in another case, a reference to our own Transactions will show that a combination of ordinary cylindrical and locomotive type boilers has been adopted. In smaller types of ships which may not be required to be continuously under steam, we find vessels having apparently similar requirements fitted, in some cases, with ordinary cylindrical boilers, in others, with the locomotive-marine type, while in some water-tube boilers of peculiarly light construction are used.

Turning to merchant vessels, we find some passenger steamers of great speed fitted with ordinary boilers working under natural draught, others employing different forms of forced draught with the same type of boilers, while in still other cases water-tube boilers are used. Again, while most cargo vessels are fitted with boilers working under natural draught, several are fitted with forms of forced or induced draught, some using only plain boiler tubes, while, on the other hand, "Serve" tubes are not uncommon.

In view of this divergency of practice it is thought that it would be interesting to draw attention to, and to put on record, what is being done at the present time with water-tube boilers, especially in view of the fact that, owing probably to prejudice arising from the failures several years ago of a few unsuccessful types of these boilers, their use in British vessels has till very recently been confined to a few torpedo boats, or to vessels of similar class. It is proposed, therefore, in this paper to give a statement of some cases in which water-tube boilers have been successfully used, and in which they may be fairly said to have passed out of the experimental stage, and also to give a short description of the various types of boilers employed.

It is well to bear in mind that the objects aimed at in designing boilers for different classes of vessels may be entirely different, and to remember that the success or otherwise of any design should be judged from the way in which it fulfils these special objects, and not from a point of view of general utility for all purposes. As an extreme instance, it is evident that a boiler which would give satisfactory results in a cargo vessel would not be of much service in a torpedo-boat.

The use of water-tube boilers, instead of those of the ordinary types, has generally arisen from the desire of obtaining some or other of the following advantages. The relative importance of these not always being the same has no doubt led to the various designs being adopted in different cases.

(1) The means of obtaining higher working pressures than are practical with ordinary boilers owing to the excessive thickness of plates which would be necessary both for the shell and also for the heating surfaces.

(2) Economy of maintenance due to the comparative ease with which in some designs every part of the boiler, both external and internal, can be examined and cleaned, and if necessary renewed, it being with some types possible to entirely reboiler a vessel without opening decks, &c.

(3) A decrease of space required and also of weight of boilers and accessories necessary for producing a given power, or an increase of power obtainable with a given weight and in a given space.

(4) It is also generally claimed for all classes of water-tube boilers that they are less liable than ordinary boilers to derangement or damage through accident or neglect; and also that, even in the case of rupture, the damage which would result would be much less than with ordinary boilers, owing to the much less quantity of water they contain.

There is one important point, viz., "durability," which is indirectly included in the Condition 2, as to which experience is at present deficient. Although in special cases ordinary boilers have been replaced within two or three years, it is well known that few have become worn out in less than ten or twelve years, when treated with ordinary care, while many cases are within our knowledge of such boilers being now in use after twenty years' service. It is obvious that no such record of service can yet be recorded with water-tube boilers in general, although lengthened experience has been obtained with some special kinds.

Turning to actual cases of the use of these boilers, we must frankly admit at the outset that we are indebted for our experience to the French engineers, who successfully used these boilers before they were placed in any British vessel. In the French Navy they are not looked upon as experimental, for, according to the "Carnet de l'Officier de Marine," edited by Mons. Léon Renard, it appears that the whole of the French war-vessels which are now being built, or which have been lately finished, are, or will be, furnished with water-tube boilers. Those in the larger vessels are either of the Belleville or the Lagrafel-D'Allest types, these being employed in about equal proportions, while in smaller and lighter vessels boilers of the Oriolle, Du Temple, Normand, Thornycroft, and similar types are used.

It appears that so long ago as 1879, the despatch vessel *Le Voltigeur* was fitted with Belleville boilers. She has since seen considerable sea service, and her boilers have given satisfaction. After two commissions of about three years each, her boilers were reported to have needed no repairs. We find also that the *Milan*, launched in 1885, and the *Alger*, in 1889, have also been fitted with these boilers. In view of the present practice of the French naval authorities it can only be concluded that their use has given satisfaction.

Turning to merchant vessels, so long ago as 1871 the S.S. *Isère*, of 287 tons, was fitted with Lagrafel boilers; in 1873 the S.S. *Blidah*, of 267 tons, and *Medeah*, of 236 tons, were similarly fitted, and their boilers are still in these vessels In 1874 the S.S.S. *Paoli* and *Spahis* were fitted with this type of boiler, which were in use for seven and eleven years respectively, until the vessels were lost. The S.S.S. *Colon*, *Cabile*, and *Caid* were also fitted with these boilers in 1874, 1875, and 1876, and although these vessels are now withdrawn from service, their boilers were in use for many years. The S.S. *Liban* of 1,332 tons, built in 1882, was refitted with the Lagrafel-D'Allest boilers in 1891, and the S.S. *Dom Pedro*, of 2,999 tons, was similarly refitted at about the same time. The former of these vessels is engaged in general trade, the latter is running regularly between Europe and South America.

In 1884 the then new steamer *Ortégal*, of 3,570 tons, belonging to the Messageries Maritimes Cie., was fitted with compound engines with cylinders of 36 in. and 64 in. by 42 in. stroke, and with Belleville boilers. The S.S. *Sindh* belonging to the same Company was also reboilered with this type several years ago. The Company's latest and largest vessels, the *Australien*, built in 1889, the *Polynésien*, in 1890, and the *Armand Béhic* and *Ville de la Ciotat*, built in 1892, are each fitted with similar boilers. These last four vessels are each of about 6,500 tons, they are fitted with triple expansion engines indicating regularly about 5,000 I.H.P. at sea, which gives them a mean speed on the round voyage of about 15½ knots.

The Oriolle boiler, made by Mons. P. Oriolle, of Nantes, was fitted last year in the S.S. *Mitidjah*, a vessel of 1,160 tons, and has also been fitted in several smaller vessels. Experience with this boiler is not so great as with the types previously mentioned.

The Babcock & Wilcox boiler has been fitted in some small vessels, and recently a large boiler working at 200 lbs. pressure has been fitted in the British S.S. *Nero*, a vessel of 1,053 tons, owned by Messrs. T. Wilson & Sons, of Hull. Experience with this boiler will be watched for with great interest.

Turning our attention again to war-vessels, we find that in our own Navy the Thornycroft and Yarrow boilers have given great satisfaction in torpedo vessels, and in their comparative lightness in proportion to their evaporative power have enabled higher speeds to be obtained than could be realised with the older form of locomotive-marine boilers. The former type, also, is being fitted to H.M.S. *Speedy*, a torpedo cruiser of 4,500 I.H.P. It has been successfully fitted in some foreign war-vessels of similar class, and both these types of boiler are to be used in the specially fast cruisers, whose speed of 27 knots recently stated by the First Lord of the Admiralty, could not possibly be realised except by the use of both engines and boilers which will give the maximum of power on the minimum of weight.

In the French Navy the Normand and Du Temple boilers are used for similar vessels.

For particulars of the actual results realised by some of these boilers, reference may be made to *Engineering*, of January 16, 1891, and December 23, 1892, and to *The Engineer*, of July 15, 1892.

The first type of boiler to which attention will be drawn is that of the Babcock & Wilcox Company, shown in Plate XXIV., which represents that fitted in the S.S. *Nero*. The working pressure in this case is 200 lbs. per sq. in., but it is evident that, so far as considerations of strength only are concerned, there need be no difficulty in constructing similar boilers to work at very much higher pressures. In this boiler there are two sets of tubulous heating surfaces, each possessing separate circulating systems. One of these is a modification of the well-known land boiler made by this firm, and consists of a number of pairs of "headers" of sinuous form, connected by bundles of tubes, having an inclination of about 1 in 4, placed immediately over the fire. The modification from the land boiler being that each tube of the latter is replaced by a set of four smaller tubes, the ends of each set of four being expanded through one tube-door. Above these sets of tubes, and partly outside of the casing, is a pair of receivers—the upper being a steam chest, and the lower being, in ordinary working, about half-full of water and half of steam. The circulation in this part of the boiler takes place from the lower receiver, down the back headers, upwards through the sloping tubes and the front headers, then through the connecting pipes into the receiver. The bottom of each of the back headers is connected to a settling chamber, to which the blow-off cock is attached.

The other circulating system consists mainly of a number of vertical tubes on both sides of the boiler, forming part of its casing. These tubes are connected at the bottom to two horizontal pipes of square section, and at their top ends they either enter directly into the lower receiver below the water-line, or are connected to two other horizontal pipes, which open into the receiver at about the water level.

The circulation takes place from the receiver, down the three or four back tubes, along the bottom horizontal pipes, up the other vertical tubes into the receiver either direct or through the upper horizontal pipes. In the front of the boiler there are other tubes forming part of the framework of the boiler, which also are connected to this circulating system.

Above the boiler, in the base of the chimney, is placed a tubulous feed-heater consisting of five horizontal headers on one side, and four on the other, connected across from side to side by means of numerous pipes so arranged that the water, being delivered from the feed-pump into the bottom box on one side, passes through these pipes from side to side, and finally emerges from the upper box, being thence led to the boiler. The circulation in this heater is thus purely a mechanical or forced circulation depending on the working of the feed-pump. The heating surface of the heater is only about one-sixth of that of the boiler; and, as it is placed in the coolest part of the boiler, it is not expected that sufficient heat will be extracted by it to raise the water to the temperature of ebullition, so that no steam will be formed in it, but the whole of the evaporation will be effected in the boiler itself. In this particular boiler the tubes over the fire are 1½ in. internal diameter and 7 ft. long; the vertical tubes at the sides are 3 in. diameter, spaced 5 in. from centre to centre, and about 9 ft. long; while the feed-heater tubes are 3 in. diameter and about 7 ft. 6 in. long.

The side casing consists of 2 in. of brickwork resting against the vertical tubes, then a sheet of ¼ in. asbestos, backed by wrought-iron plates. The front and back of the boiler consist mainly of doors made to give access to the headers and to the numerous small tube doors. There are three firing doors, and the grate area may be made either continuous from side to side, or it may be divided by brick partitions into three grates, one for each door, according to the plan which may be found to give better control over the firing, &c.

A peculiarity in this boiler is that all the joints of the tubes with the headers, cross tubes, and receiver, are made with ordinary rolled or expanded joints, no screwed stay tubes being used. The makers contend that these joints, when properly made, give perfect tightness and sufficient structural strength to resist all strains likely to come upon them; while, by avoiding varying thickness of tubes in the same part of the boiler, they prevent any straining taking place due to expansion with varying temperatures. Even the square tubes are connected together by having round holes made at the adjoining parts, and round nipples expanded into both holes. In the event of accident or mismanagement of the boiler occurring, such as shortness of water, overheating through deposits, &c., the makers consider that the loosening of a few only of the tubes would result, and that the holding power of the remainder would be much more than sufficient to prevent any general dislocation of the boiler.

To give access to the tube ends for the purpose of expanding them there must necessarily be numerous holes which have to be closed by special doors. In this boiler these doors are placed outside, not inside, as is usual in ordinary boilers, so that the pressure tends to force them off. They are made with faced joints, metal to metal; no jointing of any kind being used. The nut of the holding bolt is also faced on to the door, and is close ended. The plug or dog placed inside the boiler is made in one piece with the bolt, and is so formed that, in the event of the breakage of a bolt and its door falling off, a slight leakage only will result, and not a rush of steam, water, &c.

The importance of such a detail as this will be appreciated when it is considered that there are several hundreds of such doors in an ordinary sized boiler.

The Lagrafel-D'Allest boiler which is shown in Plate XXV. is made by the Forges et Chantiers de la Méditerranée, at Marseilles, and by the Fraissinet Company of the same city. It possesses a certain resemblance to the internal part of the Babcock & Wilcox boiler. The numerous sinuous headers of the latter are, however, replaced by water chambers, those of the front and back each forming only one water space. These chambers or water spaces are formed of plates, retained in parallel positions, about 5 in. apart, by means of numerous screw stays. They are closed at the bottom and sides, but they open at their upper portions into a cylindrical steam chest, which is nearly horizontal, sloping a little towards the back of the boiler. The chambers extend down to about the level of the fire grate. They are connected by a number of water tubes placed above the fire, these tubes forming the main portion of the heating surface. A few tubes are also fitted at the sides of the fire, in order to protect the sides of the casing.

In the manufacture of the boiler both plates of the chambers have to be pierced with as many holes as there are tubes, those in the outer plates being slightly larger in diameter than the tubes. The tubes are secured to the inner plates by means of expanded joints, access for this purpose being obtained through the holes in the outer plate, in the same manner as in the Babcock & Wilcox boiler; the latter holes are closed by specially constructed doors, which in this case are placed *inside* the boiler, each being secured by a bolt and cross-bar, the joint being made by means of a thin asbestos washer and a ring of thin copper wire.

It should be noted that there are no stay tubes in this boiler. The water chambers are each connected to the horizontal steam chest at their upper portions, and at this part, therefore, do not need such stays. At the lower parts the necessary strength to resist separating the slabs is obtained by the friction of the tube joints, which are all expanded or rolled joints. The tubes generally employed are about 2¾ in. outside diameter, ¼ in. thick, and are pitched about 4 in. apart from centre to centre. "Serve" tubes are recommended by the makers for the lower row of tubes.

The working water-level is a little above the bottom of the receiver, and the circulation of the water and steam is such that the water supply enters each tube at its lower end from the back water space, passes along the tube, where part of it is vaporised, the mixture of steam and water escaping into the other water chamber and rising direct into the receiver without having to pass through the upper tubes, as in the Belleville boiler. The water so carried over traverses the bottom of the steam receiver and passes down the other water chamber, where the process is repeated.

The feature distinguishing this boiler from all others is the arrangement made for the circulation of the products of combustion amongst the tubes. The boilers are usually arranged in pairs, each part having its own feeding and water circulation, independent of the other; but a combustion chamber is common to the fires of both parts, being arranged between the two nests of tubes.

The tubes are placed mainly over the fire, the bottom row being at a height of about two feet above the grate bars. Over the bottom row of tubes and resting on them, preventing the passage of the gases between the tubes, are placed a number of specially shaped tiles, and a similar set are fitted upon the top row. Baffle plates are fitted to cover the spaces between the tubes for about the upper two-thirds of their depth at the sides remote from the combustion chamber. These arrangements are shown in Plate XXV., the arrows showing the direction which the products of combustion are compelled to take. They pass under the lower row of tubes into the combustion chamber, thence they proceed sideways between the tubes, emerging at the lower edge of the side of the nest of tubes, whence they proceed under the steam-chests on their way to the chimney.

In the Lagrafel, which was the older form of this boiler, the products of combustion passed directly from the fire up amongst the tubes, as is now done in some other forms of water-tube boiler. The reason for altering the design was owing to its being considered that the gases immediately arising from the fire have not been properly burned, and that by passing them directly amongst the tubes they become cooled below the critical temperature at which union between the gases and the oxygen of the air takes place; so that imperfect combustion and loss of economy results. If this is so in practice, most of the other types of water-tube boiler must be inefficient from this cause.

The interior of the tubes and water chambers can be readily examined or cleaned through the numerous small doors, and the removal of any tube in case of necessity can be made in a short time, the tube being either replaced or the holes plugged.

The Oriolle boiler, shown in Fig. 3, Plate XXVI., made by Mons. P. Oriolle, of Nantes, bears some resemblance to the Lagrafel boiler, being constructed of two water chambers connected by a number of tubes. Only one of these chambers, however, is connected with the steam receiver, the connection being made by means of a pipe. The tubes are placed directly over the fire, a few, however, being placed at the side of the fire, as in the Lagrafel-D'Allest boiler. The tubes are placed in diagonal rows, so that one tube is immediately over the space between the two below it. The products of combustion pass from the fire directly up amongst the tubes, and this arrangement of tubes produces a more efficient action of the hot gases than would result if the tubes were arranged in rows vertically over one another. It will be seen that in the arrangement for the circulation of the furnace gases this boiler is similar to the older form of Lagrafel boiler.

The working water-level is some distance below the upper rows of tubes. The circulation takes place within the boiler itself, being upwards along the lower rows of tubes, into the front water chamber, back along the rows of tubes nearest the water-level, down the back chamber, then through the tubes again, and so on. The tubes used are about 2 in. in diameter, and it is stated that the circulation is so rapid that no deposit takes place in them, even if impure water is used.

It will be noticed that several of the tubes are above the working water-level, and when working must only contain steam which therefore must become, to some extent, superheated. It is probable that the surfaces of these tubes having only steam on one side of them, will prove less efficient for absorbing the heat from the furnace gases than the similar surfaces in other boilers which have water in contact with them, and, further, these tubes may be expected to waste much more rapidly than other parts of the boiler.

The Belleville boiler (shown in Plate XXVII.) consists of a series of sets of tubes placed side by side over the fire, and enclosed in non-conducting casings. Each set of tubes, called by the maker " an element," is constructed in the form of a flattened spiral, and consists of a number of straight tubes connected at the ends by means of screwed joints to junction boxes made of malleable cast iron. The junction boxes of each element are placed vertically over one another, and are so constructed that the upper end of one tube is at the same level as the lower end of the next tube in the spiral. The junction boxes at the back end of the elements are close ended, but those of the front end have holes in them to permit of the inspection of the inside of the tubes, these holes being closed by specially constructed doors. The examination of the interior of the boiler is made by means of an electric light fixed to the end of a rod which can be inserted in any tube. The tubes used in boilers for war-vessels are about 3 in. diameter, while those for merchant vessels are generally about 5 in. diameter. The thickness of the tubes in the latter case is about ¼ in. except the two bottom rows, which are made about ⅜ in.

The tubes are all slightly inclined to the horizontal, the lower box of each element is connected by means of a bolted joint to a horizontal cross tube at the front of the boiler called a feed-collecting tube. Each element is connected also at its upper part by a bolted joint to the lower part of the horizontal steam chest or receiver, which latter is outside the boiler casing. An external pipe connects the bottom of the steam chest with a separating chamber, which again is connected with the horizontal feed-collecting tube. The boiler feed, as delivered by the feed pump, enters the steam chest at the end opposite to that to which the circulating pipe is attached. The working water-level in the boiler is a little above the bottom of the steam chest. The circulation takes place by each element receiving a supply of water from the horizontal feed collector into its bottom tube. This water is partly evaporated in the lower tube, and passes partly as steam and partly as water through the back junction box into the tube above it, where a further portion is evaporated, and so on. Each tube therefore has to convey all the steam made in those tubes of the same element which are below it as well as that formed within itself. A mixture of steam and water is thus continuously discharged from each element into the receiver. The water so circulated mixed with the fresh feed water passes along the receiver bottom through the external circulating pipe into the separating chamber, and thence into the horizontal feed collector to be again circulated through the elements.

It will be seen that the tubes nearest the fire, and which therefore are exposed to most heat, contain relatively more water and less steam than those higher up in the boiler. Also, as the circulation depends upon the greater density of the water unmixed with steam in the external circulating pipe as compared with that of the mixture of steam and water in the elements, it follows that the greater is the average quantity of steam as compared with the water in the elements, the more rapid will be the circulation. The fact, therefore, that the whole of the steam formed in the lower tubes has to pass through the upper ones before being delivered into the steam chest, will increase the circulation beyond that which would result if each tube discharged its steam direct into the receiver, as is the case with the boilers previously described. On the other hand, it will be noticed that the water has to reverse its direction of motion each time it passes out of one tube into another, and this, no doubt, has a retarding effect on its velocity.

The use of the separating chamber is peculiar to this boiler, and, together with the method of feeding, is the outcome of considerable experience. Marine engineers who are familiar with ordinary boilers, fed with water from surface condensers, know how detrimental are the deposits which accumulate on the heating surfaces from the presence of grease and small quantities of sea-water in the feed, and some anxiety must be felt on this account in all vessels engaged on long voyages, necessitating the boilers being under steam for very long periods, even when the minimum amount of grease is used for the cylinders, piston rods, &c., and the feed make-up is provided by an evaporator. A slight leak in the condenser, for instance, will contaminate the feed in spite of an evaporator.

In working this boiler the feed water is treated with a small quantity of lime in very dilute solution. It is delivered from the feed pump into the receiver at the end remote from the external circulating tube; it thus has to pass along the whole length of the bottom of the receiver, where it becomes mingled with the mixture of steam and water issuing from the elements. Its temperature must therefore be raised to that of ebullition before it enters the circulating pipe. At this temperature all the lime salts which are contained in the small quantity of sea-water which may be mixed with the feed, as well as the lime in solution, with which the feed is purposely treated, separate out in a solid but non-crystallisable form, which, being in an extremely fine state of division, is stated to become mixed with the oil particles which may be in the feed water, and to form a kind of mud, which separates and falls to the bottom of the separating chamber, owing to the water being comparatively quiescent at that part. The effluent feed water is thus purified before it enters the parts of the boiler comprising the heating surface, which therefore do not become encrusted. Experience shows that this actually takes place to a considerable extent, there being practically no deposit on the heating surfaces, even when sea-water make-up is used, while a white muddy deposit is found in the separating chamber.

It should be mentioned that in working the Lagrafel-D'Allest boiler the feed water is similarly treated with lime, an amount about 4 lbs. per 24 hours per 1,000 I.H.P. being used, an arrangement being adopted whereby this small quantity can be regularly and continuously added to the feed; but in this boiler the separation cannot take place before the entry of the feed amongst the heating surfaces. The deposit takes place mostly in the lower part of the back chamber where the water is quiescent.

It is to be noted that in the Belleville boiler the junctions throughout are made with either bolted or screwed joints, no expanded joints being used. The tubes are simply screwed into the back junction boxes, the joint being secured with a thin checknut. The front junction boxes are fitted with screwed nipples, over which and over the front end of the tube a socket or collar is screwed, the joint being also backed up by a checknut. At this end of the tubes, therefore, a double thickness of metal is exposed between the fire and the water. What will appear as a novelty to English engineers is the use of malleable cast iron for the junction boxes, which are exposed to the same pressure as the rest of the boiler, and also to a considerable amount of heat.

It has been stated that the internal surfaces of the tubes may be examined from the front ends, and they may also be cleaned if necessary. The external surfaces are cleaned by means of a steam jet inserted in the spaces between the junction boxes.

The ease with which repairs to these boilers may be effected is shown from the fact that a boiler may be shut off from the others, emptied, any element disconnected by breaking the upper and lower bolted joints, brought out into the stokehold, and any one tube taken out by cutting through the screwed socket connecting it to the front junction box and unscrewing it from the back box; a new tube and socket can then be inserted, the element replaced, the boiler refilled, and steam again raised in about six hours, the whole work being done by one skilled engineer, assisted by firemen.

It will be noticed that the boilers previously described are composed of straight tubes of comparatively large diameter, the designs admitting of more or less perfect inspection and cleaning of the whole of the internal surfaces. Those remaining to be described are in marked contrast, being composed of small tubes in proportion to their length, and in only one out of the four are the tubes straight, in the other three neither inspection nor cleaning of the internal surfaces being practicable.

The Thornycroft boiler was fully described by Mr. Thornycroft at the spring meeting of this Institution in 1889. Plate XXVIII., representing the boiler, is reproduced from the Transactions of that year. It consists mainly of three horizontal cylinders, the upper one being the steam chest. The upper is connected to the two lower chests by two circulating tubes of large size external to the boiler casing, and by a multitude of small tubes bent into tortuous curves within the casing, these small tubes forming the heating surfaces. In the external rows these tubes are placed side by side in contact in order to protect the casing, while the inner rows are similarly placed side by side to form a continuous arch over the fire, and to compel the products of combustion to pass uniformly around the other tubes forming the heating surfaces. A peculiarity of this boiler is that all the tubes enter the upper half of the steam chest. The tubes are 1 in. and 1¼ in. in diameter. The working water-level is such as to permit the upper chest to contain a considerable quantity of water. The tubes being so small in diameter, the evaporation in them renders the density of the mixture of water and steam they contain so much less than that of the water, which is without admixture of steam, in the external circulating pipe, as to cause a rapid circulation even through the upper or highest tubes. The water brought over by the tubes is separated from the steam by means of the baffle plates.

The products of combustion enter the lower parts of the spaces between the tubes and traverse nearly the whole length of the tubes in the direction of their length. It is difficult to see how the outside of the tubes can be freed from soot and the lower parts of the spaces between the tubes from an accumulation of ashes and dust. These points, combined with the impossibility of examining them internally and the difficulty of localising any tube which may become defective, and of renewing it when discovered, will, it is thought, prevent the introduction of this boiler for use in ocean-going steamers, but the results obtained by it, as regards its evaporative power in proportion to its weight, combined with its evaporative economy in proportion to the fuel consumed, show how eminently suitable it is for purposes where enormous power is of more consequence than very prolonged efficiency. Particulars of these results may be found in the references quoted, and also in Mr. Thornycroft's paper read at the Institution of Civil Engineers.

A modified form of this boiler, containing two fire grates, has been proposed by Mr. Thornycroft, in which there are one upper, or steam chamber, and three lower water chambers, the centre and largest of these being between the two fire grates.

Fig. 6, Plate XXIX., reproduced from *The Engineer* of July 15, 1892, represents a cross section of the Normand boiler, which is seen to present some of the features of the Thornycroft boiler. There are the same three horizontal cylindrical receivers, the upper being a steam chest and the two lower being water chambers, the main point of difference being, that all the heating tubes are connected to the lower half of the steam chest instead of to the upper half. There are in this boiler external circulating tubes placed at both ends instead of at one end only, as in the Thornycroft boiler. A reference to the sketch will show that while the shapes of the heating tubes are different from those in the other boilers, considerable trouble appears to have been taken to prevent any of them from being straight.

Fig. 7, Plate XXIX., shows a cross-section, &c., of the Du Temple boiler, as fitted in torpedo-boats. This also bears some resemblance to the two former boilers, but there are some important differences. Like the Normand boiler, there are two external circulating tubes at each end connecting the upper with the lower chambers, and the heating tubes also enter the upper chamber along the bottom half. These heating tubes are of small diameter, and of the zig-zag shape shown, and have the peculiarity of having their lower portions made of reduced diameter. The water chambers are made of comparatively small cross section, but they are fitted throughout their length with doors, which give access to their interiors. The fire grate is situated between brick sides, so that the whole of the length of the heating tubes is above the level of the fire. The products of combustion rise straight up from the fire between the tubes, so that the direction of motion of the gases is across the length of the tubes instead of along it, as in the Thornycroft boiler.

The Yarrow boiler is represented by Figs. 8 and 9, Plate XXVI., which are reproduced from *Engineering* of January 16, 1891. In this boiler also there are one upper and two lower horizontal chambers, connected by two circulating tubes external to the casing, and by a number of small heating tubes, which in this case are straight. In the smaller boilers the upper chamber is made in two halves, bolted together, to enable the upper half to be removed. The lower chambers are each made with a flat side, forming a tube plate, the lower portions being of semi-cylindrical form, bolted to the tube plates. By removing these parts the tubes are accessible from both ends, and, being straight, they may be examined and cleaned as well as their small diameter will permit. The outside of all the tubes also may be cleaned from soot, &c., the casing being made portable (as shown in Fig. 8) to permit of this. The fire grate is placed between the lower chambers, and the products of combustion pass between the tubes on their way to the chimney, their direction of motion being across the length of the tubes, as is the case in the Du Temple boiler.

In both the Yarrow and Thornycroft boilers the heating tubes are made of seamless steel. In some cases they have been galvanised. Seamless tubes are used, not so much on account of their strength being greater than that of lap-welded tubes of the same diameter and thickness, as to ensure freedom from small local defects in the weld, which, although not materially impairing the strength, may, by reason of the less thickness of sound metal they present, permit a small amount of corrosion to perforate the tube, in which, of course, even a minute pinhole, permitting the escape of steam or water, will necessitate the removal of the tube.

A combination of water-tube and ordinary smoke-tube boiler is now being tried by Messrs. Anderson & Lyall, of Glasgow. In this boiler the water tubes are placed over the fire, and receive the fullest heat of the products of combustion, which, after entering a combustion chamber, pass through the smoke tubes, which are surrounded by water. In this form of boiler the ordinary furnace flue is dispensed with, and the casing of the part of the boiler containing the tubes is of considerably smaller diameter than the shell of an ordinary boiler containing the same heating surfaces, so that thinner plates and less weight both of boiler and water are needed. The makers have at present only made one boiler on this plan, and they are now engaged in making experiments with it to determine the most advantageous proportions for the various parts, with the view of adopting the plan for marine purposes.

The experiences given in the paper as to the time during which some of the boilers have been in use, and the fact that their use is extending amongst those most familiar with them, show that so far as safety is concerned water-tube boilers can be made satisfactory. The point upon which many will wish for information is that of their economy as steam raisers on ordinary service. Unfortunately I am unable to supply this information.

In the paper to which reference has been made, however, some information will be found as to the efficiency of the Thornycroft boiler, and I am indebted to Mons. D'Allest for some information given in the Appendix as to the results of trials made upon the Lagrafel and Lagrafel-D'Allest boilers by Mons. Taton, a French Naval engineer.

In each case of these trials the coal used was carefully weighed, the firing being regulated to burn 50, 75, 125, and 150 kilos per hour per square metre of the grate area. The feed water was measured, and it was noted that there was practically no water (priming) carried off with the escaping steam. The results with the modern form of the boiler show a very good efficiency, and if such results can be obtained in ordinary working with water-tube boilers, the higher pressures they will admit of should lead to more economical results being obtained.

APPENDIX.

RESULTS OF EXPERIMENTS MADE AT MARSEILLES WITH LAGRAFEL AND LAGRAFEL-D'ALLEST BOILERS, UNDER THE DIRECTION OF MONS. TATON, ENGINEER OF THE FRENCH NAVY.

PARTICULARS OF BOILERS.

LAGRAFEL-D'ALLEST BOILERS.

	Trials Nos. 1, 3, 5, and 6.	Trial No. 2.	Trial No. 4.
Grate surface	3·3 sq. metres, = 35·9 sq. feet.	2·86 sq. metres, = 30·8 sq. feet.	4 sq. metres, = 43 sq. feet.
Proportion of grate to heating surface	$\frac{1}{30}$	$\frac{1}{35}$	$\frac{1}{25}$
Tubular surface		96·7 sq. metres	= 1,040 sq. feet.
Plate heating surface		3·3 ,,	= 36 ,,
Total heating surface		100 ,,	= 1,076 ,,
Section of chimney		·95 ,,	= 10·2 ,,

LAGRAFEL BOILER.

Grate surface	3·3 sq. metres	= 35·9 sq. feet.
Tubular surface	96·7 ,,	= 1,040 ,,
Plate heating surface	3·3 ,,	= 36 ,,
Total heating surface	100 ,,	= 1,076 ,,
Section of chimney	·95 ,,	= 10·2 ,,
Proportion of grate to heating surface		$\frac{1}{30}$

Trials Nos. 1, 2, 3, and 4 made with the Lagrafel-D'Allest boilers, and Nos. 7, 8, and 9 with the Lagrafel boilers, were made with natural draught. Nos. 5 and 6, with Lagrafel-D'Allest boilers, with forced draught.

	LAGRAFEL-D'ALLEST BOILERS.						LAGRAFEL BOILERS.		
	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.
Duration of trial	6 hrs.	6 hrs. 45 mins.	6 hrs.	6 hrs.	3 hrs.	3 hrs.	6 hrs.	3 hrs.	3 hrs.
Weight of Cardiff Coal burned during the trial	1,008 kilos	1,430 kilos	1,512 kilos	1,800 kilos	1,224 kilos	1,512 kilos	1,512 kilos	756 kilos	1,008 kilos
Ditto, per hour	168 ,,	211·8 ,,	252 ,,	300 ,,	408 ,,	504 ,,	252 ,,	252 ,,	336 ,,
Ditto, per square metre of grate per hour	50·45 ,,	74 ,,	75·67 ,,	75 ,,	122·5 ,,	151 35 ,,	75·7 ,,	75·7 ,,	100·9 ,,
Weight of ashes, &c. ...	80 ,,	121·5 ,,	233 ,,	153 ,,	104 ,,	128·7 ,,	—	—	—
Water evaporated during the trial...	10,760 litres	13,700 litres	13,970 litres	16,150 litres	9,820 litres	13,230 litres	10,170 litres	4,110 litres	6,580 litres
Ditto, per hour	1,793 ,,	2,029·6 ,,	2,328·3 ,,	2,691·6 ,,	3,273·3 ,,	4,410 ,,	1,695 ,,	1,370 ,,	2,193·3 ,,
Ditto, per square metre of heating surface ...	17·93 ,,	20·29 ,,	23·28 ,,	26·91 ,,	32·73 ,,	44·1 ,,	16·95 ,,	13·7 ,,	21·9 ,,
Ditto, per kilo of coal ...	10·67 ,,	9·58 ,,	9·23 ,,	8·97 ,,	8·02 ,,	8 75 ,,	6·72 ,,	5·43 ,,	6·526 ,,
Temperature of feed ...	25° C. = 77° F.	25° C. = 77° F.	21°·5 C. = 70°·7F.	27° C. = 80°·6 F.	20°·5C. = 68°·9F.	21° C. = 69°·8 F.	22° C. = 71°·6 F.	22°·5C. = 72°·5F.	23° C. = 73°·4 F.
Ditto of evaporation ...	148° C. = 298° F.	148° C. = 298°F.	148° C. = 298° F.	148° C. = 298° F.	148° C. = 298° F.	148° C. = 298° F.	148° C. = 298° F.	148° C. = 298° F.	148° C. = 298° F.
Evaporation from and at 212° F. (kilos)... ...	12·43	11·14	10·8	10·4	9·4	10·24	77·8	6·34	7·62

Results of Experiments made with Lagrafel-D'Allest Boilers under the Direction of French Naval Officers, and of Representatives of the Forges et Chantiers de la Méditerranée.

	Trial No. 1.	Trial No. 2.	Trial No. 3.
Date of trial	June 29, 1892.	July 2, 1892.	July 6, 1892.
Duration of trial	6 hours.	12 hours.	6 hours total.
Weight of Cardiff coal burned during the trial	4,500 kilos.	5,400 kilos.	2,700 kilos. during 1st 3 hours. 3,375 ,, ,, 2nd ,,
Do. per square metre of grate per hour	100 kilos.	60 kilos.	120 ,, ,, 1st ,, 150 ,, ,, 2nd ,,
Water evaporated during the trial	44,125 litres.	54,370 litres.	25,654 litres ,, 1st ,, 31,169 ,, ,, 2nd ,,
Do. per hour	7,354 litres.	4,530 litres.	8,551 ,, ,, 1st ,, 10,389 ,, ,, 2nd ,,
Do. per square metre of heating surface	29·41 litres.	18·12 litres.	34·2 ,, ,, 1st ,, 41·55 ,, ,, 2nd ,,
Do. per kilo. of coal ...	9·80 litres.	10·068 litres.	9·501 ,, ,, 1st ,, 9·235 ,, ,, 2nd ,,
Temperature of feed	48·75°C.=119·75°F.	51° C. = 123·8° F.	52° C.=125·6° F. mean during both periods.
Do. of evaporation... ...	194° C. =381° F.	194° C. = 381° F.	194° C.=381° F.
Evaporation from and at 212° F. (kilos)	11·25	11·51	10·85 during 1st 3 hours. 10·54 ,, 2nd ,,

Results of Similar Trials on another Vessel.

Date of trials	Feb. 12, 1890.	Feb 19, 1890.	Feb. 25, 1890.
Duration of trials	3 hours.	3 hours.	8 hours.
Coal burned per sq. metre of grate surface per hour	223·4 kilos.	175 kilos.	75 kilos.
Water evaporated per kilo. of coal	8 24 kilos.	9·07 kilos.	9·43 kilos.

Results of Official Trials of S.S. "Liban," made in October, 1890, with Speed of Engines varied in accordance with the Powers Developed.

Duration of trials	8 hours.	24 hours.	8 hours.	8½ hours.
I.H.P. per square metre of grate (French measures)	66·1	86·2	132 9	147
Do. per square foot of grate (English measures)	6·06	7·9	12·1	13·45
Coal per I.H.P. (French) per hour	·614 kilos.	·667 kilos	·732 kilos.	·808 kilos.
Do. per I.H.P. (English) ...	1·37 lbs.	1·49 lbs.	1·63 lbs.	1·8 lbs.

DISCUSSION.

Monsieur V. **Daymard** (Member): Before opening the discussion on Mr. Milton's remarkable paper, let me offer him many thanks for what he said on the important work accomplished by some of my countrymen, French engineers, in making the water-tube boilers practical and successful for marine purposes. I give these thanks in the name of MM. Belleville, Lagrafel, D'Allest, Normand, and Oriolle, all of whom I know personally, and whose labours in that way I have been able to appreciate. Mr. Belleville particularly, during more than forty years, endeavoured to improve the type he created so long ago as 1849. With an indefatigable perseverance and intense ingenuity he worked to supersede the numerous difficulties incessantly occurring from the rapid deterioration of tubes or other parts of the boilers, and from feed, and also from priming. He succeeded at first with steam-boats and launches, but the work was a great deal more difficult with steamships built for long voyages. Encouraged and helped by the officials of the Navy, he arrived, in 1879, with the *Voltigeur,* at a result which was considered satisfactory, and which caused the adoption of his boilers in several very important ships of war. For my part, I have nothing to add to the information supplied by Mr. Milton on the different types of water-tube boilers to which he referred. Up to now I have not ordered water-tube boilers for the ships of my company (Cie. Générale Transatlantique), but I followed with the greatest interest the development of their use, especially by the Messageries Maritimes. Owing to the results known, and the numerous advantages of water-tube boilers, which increase in importance as the pressure increases in new engines, I intend to make shortly a serious trial of them in one of the ships of my company; and, if I can arrive at conclusive results, I will be happy to submit them to this Institution. I again pray Mr. Milton to accept my thanks and congratulations for his interesting and useful paper.

Mr. A. F. **Yarrow** (Member of Council): My Lord, the Institution is undoubtedly under a great obligation to Mr. Milton for having collected together so much valuable matter, and for having so ably dealt with the subject, which must be looked upon as among the most pressing of the day. We have all been forced to the conviction that, if pressures increase in the future as they have done in the past, there will be no option left to engineers but to abandon old forms of boilers in favour of the water-tube type, which is specially adapted to meet the requirements of high pressures. Mr. Milton in his paper has brought forward numerous very interesting facts, and many members of the Institution doubtless have been surprised at the already extensive employment of water-tube boilers abroad. It would seem that this particular advance has been greatly promoted in France owing to the fatherly care of the Government over the lives of the people; as in the case of stationary boilers, the law in some places practically prohibits the use of any boiler which is not subdivided into parts of small cubic capacity. Anyone who has devoted attention to the subject cannot fail to be greatly perplexed by the variety of designs and variations in the types of water-tube boilers before the public, both in France and the United States. They have, however, distinguishing features which enable them to be placed in well-defined groups; for example, the Belleville boiler may be looked upon as representing one of the types, in which the circulation takes a very long and sinuous course, the water and steam ascending from the lower to the upper part of the boiler, having to pass through pipes first in one direction and then in another. As the circulation is dependent partly upon the difference in the weight of the ascending and descending columns, and partly upon the resistance offered to the circulation by the friction of the water in the tubes, it follows that those designs which involve a long and tortuous passage for the water and steam are not so well adapted for a high rate of combustion as those boilers in which the passage of the water from the lower to the upper part is short, direct, and as free from resistance as possible—such, for example, as in Normand's boiler, which in this respect has a decided superiority over many others. In fact, I do not think we should be far wrong, when comparing designs of water-tube boilers, to come to the conclusion that the rate of combustion for which they are adapted is in proportion to the simplicity and directness of the circulation, and that the more nearly the tubes approach the vertical the more suited they are to withstand considerable forced draught. Turning now to another point, I would draw attention to the very marked difference in the designs of water-tube boilers in regard to the amount of elasticity and freedom to move of the various parts. In the D'Allest, Oriolle, and Yarrow boilers the tubes are straight, and rigidly secured at both ends; while, on the other hand, in the Thornycroft, Belleville, and Babcock and Wilcox boilers considerable liberty of movement is allowed to each tube or set of tubes. It would seem to be correct for the tubes to be free to contract and expand as circumstances require; at the same time, it might be a question whether, with rigidly fixed tubes, their own elasticity is not sufficient to allow for the necessary changes. Experience alone could determine this point; but it is known that in locomotive and marine boilers no practical difficulty has been found by the tubes being straight, nor any gain by their being curved, although the tubes in different parts of the boilers are subject to great differences of temperature. Touching the question of economy, judging only by the experience of my own firm, with equal weights of boilers developing the same power, the locomotive and water-tube boilers I have found to be on an equality; but by substituting for the locomotive boiler (which, if well designed, is very economical) one of equal power of the water-tube type, there is a saving in weight of about 15 per cent. These figures apply, assuming that both boilers are subject to the same amount of forcing, but when only moderate firing is necessary, the economy of the water-tube boiler rises much more rapidly than that of the locomotive; in other words, with equal forcing the two types of boiler, if of equal weight, have the same economy, but the water-tube boiler, if required, can be forced to a much greater extent. One difficulty to be met with in the introduction of water-tube boilers has been the rapid pitting which occurs when steel or iron tubes are used. Even galvanising only postpones, but does not avoid this. M. Normand, as well as my firm, frequently adopted copper tubes, and, although there has not been yet sufficient experience to enable a decided opinion to be expressed, there seems a reasonable probability that copper tubes would have a decided advantage over those of steel as regards durability, provided the design of the boiler be such that the tubes cannot become overheated. I would like to add that in the introduction of water-tube boilers, M. Normand was, as usual, well to the front, and I think I am only expressing the feeling of the Institution when I say that it is a source of regret that this gentleman does not favour the meetings occasionally with his presence, for one who occupies so distinguished a position in the profession would be a most welcome guest.

Mr. Sydney Barnaby (Member): My Lord, in the unavoidable absence of Mr. Thornycroft, I would like to say a few words upon Mr. Milton's paper. Valuable as is the information given in the paper concerning the principal features of a number of different types of water-tube boilers, I venture to think that, what is most worthy of note is the evidence it affords of the great advance which the water-tube boiler has made in public opinion since Mr. Thornycroft read the paper on "Water-tube Boilers for Warships" in 1889, which has been alluded to by Mr. Milton. At that time any proposal to introduce them either into war-vessels or the merchant service was regarded with disfavour in this country. They were then considered as suitable for torpedo-boats, but for them alone. Mr. Milton's predecessor, with the memory of the failure of the earlier types of water-tube boilers vividly before him, strenuously opposed any attempt to re-introduce a type associated in his mind only with disaster. Mr. Milton is now wisely content to pass over these old failures, and, recognising that the lessons taught by them have been duly taken to heart by the designers, or some of them at least, of the modern types, has given them all his very careful attention; and his views are worthy of very great respect. The fact that all French war-vessels now building, and those which have been lately finished, are, or will be, furnished with water-tube boilers, shows the extent of the favour accorded to them in France. There are at the present time fitted in vessels, afloat or building, boilers of the Thornycroft type representing more than 70,000 I.H.P. This, I think, compares well with the record of any other water-tube type. No doubt many of the difficulties connected with the safe working of water-tube boilers have disappeared since it has become possible to rely upon the use of distilled water under ordinary conditions. Still, although the greater part of the salts in solution in the make-up feed water are now deposited in the distilling apparatus, it is necessary to provide against the contingency that some amount of sea-water will probably find its way into the boilers through leaks in the condensers, and it may also become necessary at times to make up from the sea in case of a breakdown. We have always considered it very important that the feed-water should be delivered into the upper part of the boiler where the heat is sufficient to immediately separate the salts. When this is done, our experience is similar to that described in connection with the Belleville boiler, in which I believe this method of introducing the feed has been recently adopted with great advantage, namely, that the salts are not deposited in the steam generating tubes, which are kept clean by the circulation, but find their way into the bottom tubes, where the water is quietest, and from which they can be readily removed. There is one remark in the paper concerning circulation which I think is not quite correct, namely, that the circulation in the Belleville boiler must be greater than in those in which each tube discharges its steam separately into the receiver. Mr. Milton states that the greater the average quantity of steam as compared with water in the generating tubes, the more rapid will be the circulation. Now there is obviously a limit to this, as when all the steam generated in the bottom tubes has to escape through those above, as it has to do in the Belleville boiler, the upper tubes may become full of steam only, in which case, as in the Perkins boiler, there is no circulation of water. Mr. Thornycroft showed in his paper on boilers read at the Institution of Civil Engineers that the maximum circulation of water takes place when the density of mixed steam and water in the tubes is about one-half that of water. Mr. Milton says that few boilers become worn out in less than ten or twelve years, and that he knows of many in use after twenty years' service. These boilers have probably had more than one set of tubes during their lifetime, because I believe the life of tubes is not more than from four to six years, at least, in locomotive boilers, and it must be remembered that a new set of tubes makes a water-tube boiler as good as new. Then as to the construction of the firebox, Mr. Milton very properly points out that when the gases are passed directly among the tubes they are cooled too soon, and imperfect combustion must result. Also when the products of combustion can go straight up the chimney without being obliged to change their course among the tubes, as is the case in a number of water-tube boilers, such as the first type of the Lagrafel-D'Allest, the efficiency must be small. I am inclined to think that the improvement in the D'Allest boiler made by putting firebricks of special shape over the lower rows of tubes can hardly be permanent. I think the very large firebox in the Thornycroft boiler has much to do with the high efficiency obtained. There is plenty of room for good combustion, and the gases leave the firebox at the bottom in order to pass among the tubes. When burning 30 lbs. per foot of grate the evaporation is as much as 12 lbs. of water per pound of coal, and at a lower rate of combustion it rises to 13·4 lbs. Mr. Milton has expressed a doubt as to whether the lower parts of the spaces between the tubes can be freed from ashes, and the outside of the tubes from soot in the Thornycroft boiler. In H.M.S. *Speedy*, in which there are eight boilers, they are so arranged that it is possible to walk round each boiler. Along the whole length of the lower tubes where dust and ashes can accumulate there are placed portable collecting boxes, which can be readily cleared. We adopt the same plan for cleaning the outside of the tubes as that which, I believe, is employed in the case of the Belleville boiler, a steam jet is played among them by means of a flexible hose. The *Geyser*, a Danish cruiser fitted with these boilers, has recently returned from an experimental cruise during which it was found that, after running for many days continuously, the boilers were not sooted up, and they were worked up to full power at the end of the trial. The new type of Thornycroft boiler, with two furnaces, is being employed in the 27-knot " Destroyers," the principal advantage being that three boilers can be used instead of six.

Mr. W. J. Pratten (Member): My Lord and Gentlemen, I beg to endorse all that has been said by previous speakers as to the importance of the communication made by Mr. Milton to this Institution. He has collected in this paper all the best known and approved types of water-tube boilers. I should like to make a few remarks upon this paper. I had the opportunity of going to Marseilles and taking two trips in steamers belonging to the Messageries Maritimes Cie., the *Polynésien* and the *Armand Béhic*, and of seeing the working of their Belleville boilers. I must say I was much impressed by all I saw. The French engineers have shown us the way, and what can be done with water-tube boilers. They have overcome many difficulties, and they may still go farther, and make them a complete success. Of course there are disadvantages in connection with the Belleville boilers which can be readily seen by most engineers. There are a great many different parts, and the tubes require very frequent cleaning. You have to use special coal, or else the tubes get covered with soot, and there follows a loss in evaporative power. They also require more superintendence and very careful manipulation. The boilers are made for 230 or 240 lbs. pressure, but they are only worked at 160 lbs. in the engines. This does not tend to economy. However, there is much to be said for the type. An English engineer might hesitate to put 60 to 100 boilers in an Atlantic liner because of the great complication. In the *Armand Béhic* and the *Polynésien* there are 20 boilers for about 5,000 I.H.P. at sea, which must be multiplied by five. For passenger steamers like the new Cunarders the number of fittings to keep in order would be very large. The consumption of coal was stated by the officials to be about the same as in the ordinary Scotch boiler in use in our Mercantile Marine, though I think, if the figures put before me were compared with our best types, they would be found less economical. The cost is also greater, and the weight saved is only that due to the water in the boilers. The ordinary cargo tramp cannot be expected to take up with Belleville boilers, although in large mail steamers and for the Government service I think there is an opening for them. As Mr. Milton well points out, any ailment can be quickly remedied, and there is no boiler in which, if any tube is defective, it can be replaced with the same amount of speed and certainty.

Mr. J. McGregor (Member): My Lord and Gentlemen, I am sure we are all very much indebted to Mr. Milton for having brought the subject of present water-tube boilers before us. But I must say I think he would have added greatly to the value of the paper, had he dwelt a little upon the experience gained with them at an earlier date. A number of engineers here have given a great deal of attention to the matter of water-tube boilers for the last twenty or thirty years, and between the years 1860 to 1870 a number of different varieties of these boilers were made for use, and much experience of their merits gained, which I think of the utmost importance in considering new types. I happen to have had much to do with them, and have had opportunities of studying closely the results obtained, but they did not fulfil the expectations, and were not continued. One or two of the principal were the Rowan boiler, the Rowan and Haughton boiler, the Howard boiler, &c., a number of which came under my notice for several years, and I hoped that this discussion would have elicited a little more of the experience of others, as the merits of a design can only be gauged in the light of experience. The objects aimed at in using water-tube boilers have been admirably set forth by Mr. Milton, but we found eventually that they were not so satisfactorily attained as with other boilers. We found that they were by no means free from serious accident. We also experienced a great amount of trouble in keeping the tubes in order. They burst out unexpectedly, and were troublesome to replace. There was much trouble also in keeping the casings in order, and all this without any appreciable advantage. I also found in their working a great tendency to prime, and I believe some of the principal makers of tubulous boilers at the present day do not guarantee, for ordinary working, a higher rate of evaporation per unit of area than from half to three-quarters of that of an ordinary boiler, which must militate considerably against their adoption. But for some purposes, more particularly when transport enters into the consideration, there are advantages in them. I think we are much indebted to Mr. Milton for the trouble he has taken, and for having brought this matter before us.

Mr. W. H. **White**, C.B., LL.D., F.R.S. (Vice-President): My Lord and Gentlemen, before I make any remarks, I should like, with your permission, to ask Mr. Yarrow a question. I understood him to say that his experiments showed an economy in weight with the water-tube boilers compared with the locomotive boiler of 15 per cent.; but a disadvantage in consumption of 10 per cent. What I want to know is if he will be so good as to say what were the relative degrees of forcing of the two types of boilers when giving the same power.

Mr. A. F. **Yarrow**: It is rather difficult for me to say that; I do not know exactly what standard I can take. With the same weight of boiler, if we increase the surface of the tubulous boiler, so as to bring up the weight to the locomotive boiler, they are on a par; if we reduce the heating surface so that we can develop equally in both cases we are shorter in economy as against the tubulous boiler by 10 per cent.

Mr. W. H. **White**: Against the locomotive boiler?

Mr. A. F. **Yarrow**: No; the tubulous boiler. If we diminish the surface in the tubulous boiler so that we can get the same result out of both, it is only obtained at the sacrifice of increase of coal consumption.

Mr. W. H. **White**: The tubulous boiler will in that case give greater power.

Mr. A. F. **Yarrow**: No, the same power.

Mr. W. H. **White**: With equal weights in the two types of boilers?

Mr. A. F. **Yarrow**: With equal weights and giving the same power the economy is the same, but the tubulous boiler will have the advantage. If it is required to develop more it could do so by the sacrifice of the coal consumption.

Mr. W. H. **White**: This matter has engaged my closest attention for a long period. We cannot as yet say much respecting our own experience on the subject, or in that way decide on the point raised by Mr. Yarrow. Mr. Thornycroft, however, in his paper, read at the Institution of Naval Architects, claimed a superiority in the development of power, for a given weight, in the tubulous boiler as compared with the locomotive, and he also claimed a considerable economy in coal consumption.

Mr. A. F. YARROW: Economy in weight?

Mr. W. H. WHITE: Yes. Taking the trials of the *Geyser*, Danish cruiser fitted with tubulous boilers of the Thornycroft type, it will be seen that the economy of consumption was very good. I asked the question about forcing, because Mr. Thornycroft has stated, in the course of his comparisons between locomotive and tubulous boilers, that, with a very moderate forcing, his type of tubulous boilers gave results in development of power equal to those obtained with considerable forcing in the locomotive type. Passing to the general question, I wish, first of all, to join in the expression of thanks to Mr. Milton for having put together what I believe to be the best summary of facts relating to water-tube boilers which exists in the English language. There is a large literature in French on this subject, which, I dare say, many gentlemen are familiar with. At the time of the Exhibition of 1889 a very excellent summary was prepared by M. Mauplou, and published, dealing with the whole question up to that date. Mr. Milton comes to this matter with some unique qualifications. We are proud to know that Mr. Milton was trained in the Admiralty service. He quitted that service for the Mercantile Marine. He has occupied an important position as a manufacturing engineer, and in that capacity dealt with both mercantile and war-ship machinery. He now occupies the important position of Chief Engineer Surveyor at Lloyd's Registry. With such a career, he has been able to look at this matter from an "all-round" point of view, and the conclusions he reaches, as well as the facts he states, are of very great importance to all who are engaged in the design of ships and their machinery. Speaking in the absence of my friend, Mr. Durston, the Engineer-in-Chief of the Royal Navy, I must say that the Admiralty has displayed the greatest desire to assist builders from the first in developing water-tube boilers. No sooner did Mr. Thornycroft bring forward his water-tube boiler than he was given an opportunity of putting it into a second-class torpedo-boat, and having a trial with it. I am sure that the members of that firm would be ready to acknowledge the assistance which the Admiralty gave in that way. As other English engineers have brought forward other types of water-tube boilers with features in them which promised success, the Admiralty has caused trials to be made. Messrs. Yarrow and Mr. J. S. White, of Cowes, are amongst the number of those who have been at work in this direction, and have been assisted by the Admiralty, who have permitted experimental boilers to be tried in boats and torpedo-boats. I regret that Mr. White has not been able to say anything on this occasion about his work in connection with water-tube boilers. The Admiralty has considered it desirable to attack this matter from the "small end." First of all, water-tube boilers were fitted in second-class torpedo-boats. Then came the trial in first-class torpedo-boats with water-tube boilers developing from 1,200 to 1,500 horse power. Now we have under construction by Messrs. Thornycroft the *Speedy*, of 4,500 H.P. with water-tube boilers. The trials of that vessel will be watched by the whole engineering world with the greatest interest, and they are now very near commencement. That is not all that has been done. In the "torpedo-boat destroyers," to which reference is made in the paper, no less than four types of water-tube boilers will be tried: two of Messrs. Yarrow's, one of Messrs. Thornycroft's, and one by a French maker. Arrangements have been made also for a trial of the Belleville type of boiler in the *Sharpshooter*, a sister vessel of the *Speedy*, and of the Du Temple boiler in another vessel of the class. That embraces a great series of trials of different types of boilers. English engineers, who are always ready to acknowledge what French engineers have done in this matter, will have the opportunity of seeing in English ships the trials of French inventions going on side by side with the trials of water-tube boilers designed and made in England. In this matter we all ought to acknowledge the courtesy with which our foreign colleagues have behaved throughout. It may be, primarily, as a matter of business; but there has been much more than business in this matter. The readiness with which facts have been placed at the disposal, not merely of the Admiralty, but of English engineers, by their French compeers and colleagues in the profession, is beyond all praise. Speaking for the Admiralty, I feel bound to say publicly that the courtesy of the Messageries Maritimes in allowing an English engineer officer to take passage in one of the largest ships fitted with Belleville boilers, and to see the working of those boilers, on a voyage to and from the East, is an act we are glad indeed to acknowledge. What may come of this no one can tell. The French have undoubtedly taken a lead in the use of groups of water-tube boilers and the device of types. But we may venture to hope that English engineers will not allow them to keep that lead. I say that in no unkind spirit, and I am sure M. Daymard will join with me in saying that from the competition already in existence, and which must continue, the whole shipping world is likely to derive benefit. For war-ship purposes, as Mr. Milton says in the paper, there are already types of small swift ships which could not have been in existence but for the use of the locomotive boiler. Although Mr. Yarrow has spoken in such generous terms of the water-tube boiler, I believe he is not disposed to admit that his old friend, the locomotive boiler, is as yet entirely out of court. Mr. Yarrow is now building for the Admiralty two vessels of the torpedo-boat destroyer class. In one of them he will have the locomotive boiler, and in the other the water-tube boiler, and the comparative performances will be of great interest. So far as I have been able to study this matter in the publications which have come under my notice, general experience does not accord with Mr. Yarrow's results as to the relative inferiority in economy of coal consumption in water-tube and locomotive boilers. I quite understand that Mr. Yarrow is giving us his own experience and stating facts; but, taking the general consensus of opinion and the published results of trials, I do not think that the balance of testimony is in that direction. In the paper which Mr. Elgar has read on "Fast Steamships," reference was naturally made to the possible influence upon the future of steamship design of the introduction of water-tube boilers. The very facts to which Mr. Pratten alluded—viz., that an enormous power has to be put into ships, and that an enormous number of parts would be required if that power was to be developed in water-tube boilers—have another side to them. Modifications of water-tube boilers may be made which will meet the objection Mr. Pratten raised. In that case, the saving in weight possible with water-tube boilers will be of enormous advantage to vessels of very great engine power and high speed. I do not wish to occupy more time, except to say that I am quite confident that English engineers will deal with this matter satisfactorily, and that Mr. Milton's paper will be succeeded by many others, in which we shall hear of the progress, and probably the triumph, of water-tube boilers designed and made in England.

Mr. R. R. Bevis (Member): I am afraid my experience of this kind of boiler now under discussion will prevent my giving an opinion about it, but I hope to be able to give some further information when I have completed the upwards of 7,000 H.P. of tubulous boilers we now have under construction. I quite endorse the sentiments already expressed with regard to Mr. Milton's paper.

Mr. Reavell (Visitor): My Lord and Gentlemen, I feel gratified at the opportunity of making one or two remarks before this assembly on this occasion, seeing that I am not at present a member of the Institution, although I am engaged in the construction of one of the types of boiler under consideration, namely, that of the Babcock and Wilcox type described by Mr. Milton in his most interesting paper. It possesses several advantages, I think, over some of the other types, but there are one or two points about it which, as they have already been raised in the paper or discussion with reference to water-tube boilers, I should like particularly to speak upon. One is, that there is no difficulty whatever in designing boilers which shall be of equal power to some of the largest of the ordinary marine type of boiler hitherto used, so that in vessels of the largest power there need not be a greater number of boilers than there are at present of the ordinary type. Another point is, that as far as the renewal of tubes is concerned, if a tube should fail and require renewal, in a boiler of this type, I think that, as compared with the method proposed by Mr. Belleville, the method we should propose to adopt is more satisfactory, because the renewal could be carried out more quickly. I mean a tube could be cut out and be replaced by an entirely new tube and the steam raised again in, I think, a shorter time, as far as experience tells us, than is required to withdraw one of the elements of the Belleville boiler, to replace the tube and replace the element. The boiler which is at present at work in the *Nero*, a cargo boat of Messrs. Wilson, of Hull, has not yet been at work sufficiently long to enable us to give accurate figures as to its results. The vessel left for the Baltic about a week ago, and, therefore, we cannot very well speak as to how its results, under continuous working at sea, will compare with the results taken from ordinary boilers; but with regard to the question of weight there is a saving of about 25 per cent., and that is not obtained by too great a reduction in the amount of water space, the weight of water in the boiler being upwards of five tons.

Mr. J. Watt (Associate): My Lord and Gentlemen, I think this is a very interesting paper of Mr. Milton. The boiler on board ship is considered the most vital part of the ship, and, therefore, the question is one that requires no ordinary consideration. Some of the types of boilers in the paper before us were explained by Mr. J. F. Flannery some thirteen or fourteen years ago, and recorded in the Transactions of this Institution. It is now some twenty-five years since I gave this subject attention, and it was from the failure of other boilers that I went into the investigation of the cause of those failures, and some years ago I wrote a paper on water-tube boilers. There are four points that have to be considered in designing efficient water-tube boilers, which, with your permission, I will read:—

(1) The tubes should be arranged in a position to absorb the greatest amount of heat, by causing the flame to travel in an upward direction and at right angles to their axes.

(2) The tubes should be in a horizontal or inclined position as the most efficient to emit heat.

(3) The steam generated should have free and unobstructed escape to the steam chest or receiver.

(4) The circulation or supply of water to the tubes must be copious to prevent overheating.

But there is also a fifth point without which the boiler is not much use, and that is, that every facility must be given for examination, cleaning, or repair. These five points, or laws, which I have laid down ensure that boilers constructed on them will meet with the greatest success, and boilers have now been working for over seventeen years which were based on these laws, and are still successful and doing good work. What I mean by efficient boilers are boilers constructed that will come up to these laws as much as possible. And the more you deviate from them, the more you come into an unfortunate class of water-tube boilers. Mr. S. Barnaby (I am quoting from his speech) said that the boiler he represented evaporated 10 lbs. of water per lb. of coal. That is a very high estimate for a boiler, and it is remarkable to get such a result as that. But, if you look at the tables again, he takes over 2 lbs. of coal per indicated horse-power per hour, that is 20 lbs. of feed water per indicated horse power per hour. Now, all modern triple-expansion engines consume but 12 lbs. or 13 lbs. of feed water per horse-power per hour. The conclusion come to is this, that the remainder of the water must be passed over in the form of spray, so that for every indicated horse-power there are 7 lbs. of water carried over into the cylinders. In the paper before us we learn some indications of what a water-tube boiler ought to be, and the advantages to be derived from their adoption. I will supplement these advantages more in detail. The first is pressure. If you compare the water-tube boiler with the ordinary shell boiler, I think you can see that you can with ease practically obtain any amount of pressure required. Then, with regard to safety, you can get a greater degree of safety with the water-tube boiler than with the shell boiler; it is more subdivided, and there is a smaller percentage of water to cause a dangerous explosion. Then the space. The space occupied by a water-tube boiler is something like 15 or 20 per cent. less than that required for the ordinary shell or tubular boiler. Then the weight is another consideration. The weight is considerably less than the ordinary shell boiler. I think it is quite possible to get 60 or 70 I.H.P. for every ton weight of boiler, including water, uptake, and funnel. Then as to the efficiency. From tests made I have got 10 lbs. of water evaporated per lb. of coal without any priming. With regard to the working, my experience is, the men can command far better steam and with less labour. Steam can be raised in considerably less time. To be able to thoroughly examine a boiler externally and internally, to replace easily any defective tube, and to be able to get to any part for cleaning or repairs, is a source of great satisfaction to all concerned. Whatever may be the present or past difficulties affecting water-tube boilers, they are not insurmountable. More study given to the physical laws governing their working, coupled with higher pressures, lighter boilers, and greater speeds, will shortly facilitate their general adoption.

The PRESIDENT: I am sorry to have to remind you that in half an hour from now we shall have to be in the train.

Mr. F. GROSS (Visitor): I should like to claim your indulgence to say that, as the result of two or more years' experiments made at our works, we yet believe it will only be pressure, and not any other consideration, which will kill the ordinary Scotch type of boiler, seeing that to-day you can attain such high rates of evaporation with great economy, compared with the water-tube boiler; as per particulars before us here.

Mr. S. BARNABY (Member): My Lord, one word of explanation. The explanation of the high water consumption is that one boiler out of two was supplying the engines, therefore the engines were only working at half their power. The trial referred to was one made by Professor Kennedy.

Mr. J. T. MILTON (Member of Council): My Lord and Gentlemen, I am very pleased to express my gratitude for the very favourable reception given to my paper. Practically there is no adverse criticism. The nearest approach thereto has been by Mr. McGregor, who thought if I had given the ancient history of water-tube boilers it would have been better. I have not had time to do that. We should not have had the patience in this meeting to hear all the ancient history, some of which is already recorded in the Transactions of this Institution, and I thought it was best to give the particulars of modern boilers which apparently do not give the troubles which Mr. McGregor met with many years ago. It has been pointed out by Mr. Yarrow, Mr. Barnaby, and Mr. Pratten, that the Belleville boiler would probably not stand forced draught. I need hardly mention that it is not necessary for a boiler to stand forced draught, and also if that boiler does not stand forced draught without priming, the same thing cannot be said of other types of water-tube boilers. As will be seen from the paper, the D'Allest boiler has been successfully used under forced draught, and the Yarrow, Thornycroft, and Normand boilers have all given great satisfaction under very hard forced draught.

The President (the Right Hon. Lord Brassey, K.C.B.): Gentlemen, Mr. Milton has expressed his gratitude to the Institution and to those who are present here, for the patient hearing and intelligent appreciation which they have shown of his paper. I can assure Mr. Milton that the Institution is most grateful to him for the paper which he has prepared. He has brought together, as Mr. White has told us, the fullest description of all that is most recent in practice in reference to the tubulous boiler. Mr. Milton has shown in every paragraph of his paper a fulness of professional knowledge which reflects the greatest credit upon himself and the great department with which he was originally connected—the Navy—and now Lloyd's Register, in which he holds the most important office of its chief engineer. It does not appear to have been claimed on behalf of the tubulous boiler that it offers any advantage in regard to economy of fuel, or in regard to durability. The advantages which are claimed are those of economy of weight, economy of space, facility for repair, and the limitation of damage in cases of accident and repair. Those are important advantages, and it appears to be established that, at least for torpedo-boats, where there are special requirements for the use of steam at high pressure, the tubulous boiler does offer distinct advantages. When we come to larger vessels, the position is evidently, as yet, more doubtful. In France the use of the tubulous boiler has received the greatest development, and the system has been long under trial; but even in France we find our colleague, M. Daymard, still doubtful as to whether, or not, he shall introduce it generally in the great service over which he presides. The use of the tubulous boiler in vessels of the largest type can only be determined by experiments, and, indeed, with regard to all these matters, mere theoretical discussion will not avail to arrive at conclusive decisions. You must depend upon the results of experiments, and I am sure that all the mechanical world will be glad to know that these experiments are now being tried in the Admiralty, under the supervision of Mr. White and Mr. Durston. They are being tried by Mr. Yarrow and many others, and I have no doubt from year to year we shall be hearing the results, and that, by and by, conclusive decisions will be arrived at as to whether or no this system is applicable for vessels of the largest class. Gentlemen, for his contribution on this most important subject, I once more, on your behalf, return our grateful thanks to Mr. Milton. There is one more acknowledgment due to writers of papers. Mr. Bryan is the author of a paper which has been taken as read, and it is of so scientific a character that it is only suited to be taken in that way. I invite members of the Institution to read this carefully, and to be present at our next meeting and give us their conclusions.

ON THE THEORY OF THIN PLATING, AND ITS APPLICABILITY TO CALCULATIONS OF THE STRENGTH OF BULKHEAD PLATING AND SIMILAR STRUCTURES.

By G. H. Bryan, M.A.

[Communicated to the Summer Meeting of the Thirty-fourth Session of the Institution of Naval Architects, July 13th, 1893; the Right Hon. Lord Brassey, K.C.B., President, in the Chair.]

Section 1.—Introduction.

(1) In his able and interesting communication on "Some Considerations Relating to the Strength of Bulkheads," read at the last meeting of the Institution, Dr. Elgar has clearly proved the necessity of placing engineers in possession of both theoretical and experimental data relating to the strength of plating when bent under normal pressure. The advisability of dealing with the subject from an experimental point of view, was considered at some length in the discussion which followed on the reading of Dr. Elgar's paper, and the favourable way in which the proposal was received by many of the members may afford some justification for my communicating the present paper to the Institution.

Dr. Elgar has expressed the opinion that further experimental investigations are required before any mathematical calculations can be accepted as exact or trustworthy. Nevertheless it would obviously be impossible to derive their full value from experiments alone, without the aid of further mathematical calculations by which to connect together the various results arrived at.

The investigation of the stresses in a sheet of plating when subjected to flexure has occupied the attention of mathematicians ever since the beginning of the present century, and the theory commonly known as Kirchhoff's in its present form, as developed by Love and other mathematicians, leaves little to be desired from a theoretical point of view. In Vol. ii. of his just completed "Theory of Elasticity," Love has treated the theory from several different standpoints, and has shown that all the successive steps of the investigation are either mathematically rigorous in themselves, or are first approximations which may be justified by proceeding to a second or higher degree of approximation. But investigations of this nature are hardly likely to commend themselves to practical men with limited time at their disposal, and consequently we find some engineers, even at the present time, making use of the earliest theory of thin plating, as proposed by Euler and Bernoulli at the close of the last century; a theory which regards a sheet of plating as equivalent to a sheet of thin parallel strips or wires in one direction, combined with a similar sheet of wires, crossing the former at right angles. Some engineers adopt the hypothesis that these strips support the pressure applied to the plating by means of their resistance to flexure after the manner of a beam bent under a heavy load. This was Bernoulli's hypothesis, but it was found to disagree with experiment when applied to determining the vibrations of a thin plate, and it leads to equations that are now known to be incorrect. Another theory, viz., that which regards the strips as resisting the pressure by their tensions, is, however, open to much more serious objection. If the strips are in a state of tension, they must be stretched upon a framework strong enough to support the tensions of all the strips in the same way that the frame of a pianoforte keeps the strings in a state of tension. Such a framework will have to support thrusts equal to the sum of the tensions of all the strips put together, and this circumstance alone would require it to be made as heavy as the whole sheet of plating which it supports. But furthermore, the tensions in those strips which were attached to the sides of the framework near their middle points would produce bending moments in the latter which would make it the weakest portion of the whole structure, unless it were made far more massive than the sheet of plating.

(2) According to Dr. Elgar's theory, a *continuous* sheet of plating of circular form may have its central portion in a state of tension while there is no radial tension at the edge. Such a plate will simply *rest on* the support afforded by its boundary, without being *stretched* across it in any way. For this distribution of stress to be possible, Dr. Elgar has shown that there must be tangential compression of the plating, —*i.e.*, compression at right angles to its diameter—in the portions near the edge.

It will be noticed that this distribution of stress is not analogous to anything that would be possible in the case of a beam or wire, a series of parallel beams, or a piece of plating bent into a cylindrical shape. To form a conception of such a distribution of stress, we may suppose the middle portion to represent a membrane in a state of tension, while the outer portion represents a rigid hoop across which this membrane is stretched, and the latter, by its resistance to tangential compression, prevents the inner portion from contracting.

An excellent illustration of this theory is afforded by the behaviour of a sheet of paper. If a circular piece of notepaper is laid resting on the rim of a glass or a saucer, which it slightly overlaps, a considerable weight can be placed in the centre without its sinking down. That there is tangential compression in the neighbourhood of the edge may be at once shown by cutting little wedges out round the margin (Fig. 1, Plate XXX.); when the tangential stress has thus been removed, the paper will readily give way under a much smaller load than before. Another point noticed by Dr. Elgar, namely that, unless the edges of the plate are firmly built-in or clamped to the supporting framework, there will be a tendency to collapse by buckling round the circumference, is also readily illustrated by means of a sheet of a paper.

(3) The above theory probably gives a very good idea of the stresses set up when a very thin circular sheet of plating has been subjected to pressures sufficiently great to cause it to bulge out very considerably from the plane form. If the plating, instead of being perfectly flat, is at all curved or buckled, the stresses in question—which, by the way, depend on the stretching of the plate (*vide* Section 2 below)—will always be important, however small the pressures. In any other case, where a perfectly flat sheet of plating is only *slightly* bent, the stresses due to its resistance to bending will alone be of importance.

In the present paper I propose to show how the mathematical theory of Kirchhoff and Love can be applied to calculate the stresses in plating that is bent under pressure. Instead, however, of going through the long and complicated analysis by which the results arrived at have been rigorously justified, I shall endeavour to obtain them by simpler, if less rigorous, methods. In this way I hope to show that the theory of a bent plate is really not much more complicated than the well-known theory of a bent wire or beam. At a future time I would be prepared to apply the results to calculate the stresses in a circular, elliptic, or rectangular area exposed to fluid pressure, in the hope that such calculations may serve as a basis for future experimental or other investigations on the subject.

As the theory of the bent beam is so well known to engineers, it will be convenient to take this theory as the starting-point, and to trace the points of resemblance, as well as the points of difference, between the behaviour of a bent plate and that of a beam. By this means it will be easy to see why Euler's and Bernoulli's early theories had to be abandoned by mathematicians, and, if I can persuade engineers to follow their example, my work will not have been undertaken in vain.

SECTION 2.—DEFINITIONS.

(4) A *thin plate* is a sheet of metal (or other material) bounded by two parallel plane surfaces at a small distance apart, this distance being, of course, the *thickness* of the plate. If a third plane be supposed to be drawn midway between the two bounding surfaces, and parallel to both of them, this plane is called the *middle surface* of the plate. If the plate were sliced in two down its middle surface, it would be

divided into two plates, each of half the thickness of the original plate. And conversely, we may suppose the plate built up by distributing layers of matter of equal thickness on either side of its middle surface.

The middle surface of a plate plays an analogous part in determining the distribution of stress in it to the axis or middle line of a bent wire or beam. In a beam, the bending moment and the distribution of stress across any section are known in terms of the curvature of this middle line, and if the beam is in a state of tension, this tension and the additional stresses which it produces across any section are known in terms of the extension of the middle line. Similarly in a bent plate, the distribution of stress at any point is known in terms of the curvatures and extensions of its middle surface. The relations connecting them form the subject of Kirchhoff's theory, and, although his results are only first approximations, they may be regarded as correct for all practical purposes.

(5) In a beam the distribution of stress may assume three different possible forms, according to whether the deformation to which the beam is subjected is of the kind known as (i.) extension, (ii.) flexure, or (iii.) torsion. In the first kind all the fibres of the beam are extended, and the action across any section reduces to a tension or pull, which prevents the beam from breaking in two. In the second, the axis of the beam is unaltered in length, and some of the fibres are extended, while others are compressed. The action across any section gives rise to a couple, which is the bending moment given by the well-known formula $\frac{EI}{\rho}$. Both these kinds of deformation have their analogues in a sheet of plating, but there is nothing in a plate analogous to torsion in a beam. It is, therefore, convenient to divide the stresses in a plate into two kinds: (i.) those due to *stretching*, which occur when the middle surface is extended or compressed in some directions; and (ii.) those due to *bending*, which occur when all lines drawn in the middle surface remain unaltered in length, but the surface itself becomes curved (or, if originally curved, its curvature changes). The stresses described in Dr. Elgar's paper belong to the former class, and he has neglected all stresses belonging to the latter.

(6) Hence all problems which relate to calculating the strength of plating, which supports given loads, naturally fall into three classes:—

(i.) Those in which the load is mainly supported by the stresses due to stretching, those due to bending being comparatively unimportant.

(ii.) Those in which the load is mainly supported by the stresses due to bending, and no appreciable stretching takes place.

(iii.) Those in which stretching and bending play equally important parts.

We shall now find the relations between stress and strain when a sheet of plating is stretched without being bent, and in Section 4 we shall show how these results enable us to find the stresses at any point of a bent plate.

SECTION 3.—RELATIONS BETWEEN STRESS AND STRAIN IN A STRETCHED PLATE.

(7) When the two ends of a beam are pulled apart, the beam elongates in the direction of its length, and its breadth at the same time contracts. The "ratio of lateral contraction to longitudinal elongation," or, as it is commonly called, "Poisson's ratio," is, perhaps, next to Young's modulus, the elastic constant with which engineers are most familiar, and its value for most substances lies between $\frac{1}{3}$ and $\frac{1}{4}$.

Let σ denote this quantity, E Young's modulus. Then, if a beam whose cross section is of area ω have its ends pulled apart with a force P, the tension per unit area is $\frac{\mathrm{P}}{\omega}$, and therefore

(i.) the length of the beam increases by $\frac{\mathrm{P}}{\mathrm{E}\,\omega}$ of itself;

(ii.) the diameter decreases by $\frac{\mathrm{P}\,\sigma}{\mathrm{E}\,\omega}$ of itself.

(8) Now let A B C D (Figs. 2, 3, Plate XXX.) be the middle surface of a rectangular piece of plating of thickness $2\,h$, and let the pairs of opposite edges be pulled apart with forces P′, Q′ per unit length of edge, applied perpendicular to the edges, the surfaces of the plate being subjected to no stress. Then, since the thickness of the plate is $2\,h$, the tension across A B per unit area of the section A′ B′ B″ A″ of the plate perpendicular to A B is $\frac{\mathrm{P}'}{2\,h}$.

Hence the tension P′ produces

(i.) An elongation along B C of amount $\frac{\mathrm{P}'}{2\,h\,\mathrm{E}}$;

(ii.) A contraction along A B of amount $\frac{\mathrm{P}'\,\sigma}{2\,h\,\mathrm{E}}$;

(iii.) A contraction of the thickness by the fraction $\frac{\mathrm{P}'\,\sigma}{2\,h\,\mathrm{E}}$ of itself.

Combining this system of strains with the system of strains similarly produced by Q′, we see that, if $e_1\,e_2$ are the elongations of B C and A B,

$$e_1 = \frac{\mathrm{P}'}{2\,h\,\mathrm{E}} - \frac{\mathrm{Q}'\,\sigma}{2\,h\,\mathrm{E}}; \qquad e_2 = \frac{\mathrm{Q}'}{2\,h\,\mathrm{E}} - \frac{\mathrm{P}'\,\sigma}{2\,h\,\mathrm{E}}. \tag{1}$$

Hence, solving for P Q, we have the principal tensions given in terms of the principal elongations by the relations

$$\mathrm{P}' = \frac{2\,h\,\mathrm{E}}{1-\sigma^2}(e_1 + \sigma\,e_2); \qquad \mathrm{Q}' = \frac{2\,h\,\mathrm{E}}{1-\sigma^2}(e_2 + \sigma\,e_1), \tag{2}$$

while the total amount by which the thickness of the plate contracts is, by (iii.),

$$= 2h\left(\frac{P'\sigma}{2hE} + \frac{Q'\sigma}{2hE}\right) = \frac{(P' + Q')\sigma}{E}$$

$$= 2hE\frac{\sigma}{1-\sigma}(e_1 + e_2). \qquad (3)$$

(9) If the sides of A B C D are not parallel to the directions of the principal tensions in the plate, there will be in addition equal tangential or shearing stresses applied along the edges of A B C D. Let their amount be U′ per unit length of edge; this will be equivalent to $\frac{U'}{2h}$ per unit area of the faces A′ B′ B″ A″, B′ C′ C″ B″. Also the figure A B C D will no longer be rectangular after strain, but its angles will differ from right angles by a small amount (the shear). Let this be denoted by *s*.

The stress-strain relations (1) or (2) and (3) will still hold good, and in addition we shall have the relation

$$U' = 2h\mu s = \frac{hE}{1+\sigma}s, \qquad (4)$$

where μ denotes the simple rigidity of the substance, and is connected with the other elastic constants by the relation

$$\mu = \frac{E}{2(1+\sigma)}. \qquad (5)$$

Section 4.—The Stresses and Strains in a Bent Plate.

(10) Consider in the first place a beam H K L M whose cross section is the rectangle H′ K′ K″ H″. Let this beam be so bent that its central line forms an arc of a circle whose centre O is in the line bisecting the sides H′ K′, H″ K″ (Fig. 4, Plate XXX.). If H, K, the middle points of H′ H″, K′ K″ be joined, the line H K will divide the section of the beam into two parts, one of which, H K′, will be extended, while the other, H″ K, will be compressed. Since no stresses act on the faces of the beam, the cross section of the extended portion will contract and that of the compressed portion will expand, so that the cross section, instead of remaining rectangular, will be distorted into the well-known form H′ K′ K″ H″ represented in Fig. 5, Plate XXX.

(11) But suppose a number of such beams are placed side by side, so as to form a arge continuous rectangular sheet of plating, and let this plating be bent into the form of a cylinder (Fig. 6, Plate XXX.) whose is axis parallel to A B. Then the action of the contiguous portions of the plating prevents the section H′ K′ K″ H″ from being distorted into the form of Fig. 5; hence, anywhere in the middle of the plating, such sections as H′ K′ K″ H″, which were originally rectangular, will have to remain

rectangular (Fig. 7, Plate XXX.). Instead, therefore, of there being *no stress* across K″ L′, or H″ M′ in a direction parallel to O O′, or A B (as would be the case in a beam), there is *no strain* in this direction. In fact those particles of the plate which were originally in a plane perpendicular to the axis of the cylinder will remain in that plane after the plate is bent, and the middle surface of the plate will be devoid of any strain whatever. The lines H′ H″ and K′ K″ must therefore continue to remain parallel after the bending has taken place. In the bent beam the faces deviated considerably from parallelism, and if produced they would intersect on the side of the section remote from the centre of curvature (Fig. 5).

For this reason both the stresses and the strains in a sheet of plating bent into a cylinder are different from those in a beam. Bernoulli's theory and the ordinary "beam" theory of engineers neglect the mutual action of the strips into which they suppose the plate to be divided, and the superposition of a second series of strips placed perpendicularly to the first does not in any way represent this action. This circumstance alone would suffice to show that such theories must inevitably lead to erroneous results in all cases. And still greater errors are introduced when (as usually happens) the strips do not coincide in direction with the lines of curvature on the bent (middle) surface of the plate (*vide* paragraph 14, below). Granted that these theories afterwards take account of the effect of superposing a second series of beams placed perpendicular to the first, this does not make matters any better, for when certain terms have been left out of a system of equations, the addition of a lot of fresh terms found independently does not make up for their loss.

(12) If, therefore, ρ is the radius of the cylinder, P (Fig. 8) any point in the material of the plate at a distance P B $= z$ from its middle surface, then the strains and stresses at P are determined from the following considerations:—

(i.) The strain in the tangential direction P X is $\frac{z}{\rho}$.

(ii.) The strain along P Y, parallel to the axis of the cylinder, is zero.

(iii.) There is no stress in the radial direction P O′.

Hence, if P, Q, R denote the principal stresses, e, f, g, the principal strains at P in the directions P X, P Y, P O′, we have

$$e = \frac{z}{\rho}; \qquad f = 0; \qquad R = 0.$$

The two first give

$$\frac{P}{E} - \frac{Q\sigma}{E} = \frac{z}{\rho}; \qquad \frac{Q}{E} - \frac{P\sigma}{E} = 0,$$

whence the stresses at P are given by

$$\mathrm{P} = \frac{\mathrm{E}}{1-\sigma^2}\frac{z}{\rho}; \qquad \mathrm{Q} = \frac{\mathrm{E}\,\sigma}{1-\sigma^2}\frac{z}{\rho}; \qquad \mathrm{R} = 0; \tag{6}$$

and from condition (iii.) of § 8, or equation (3), it is readily inferred that

$$g = -\frac{\sigma(\mathrm{P}+\mathrm{Q})}{\mathrm{E}} = -\frac{\sigma}{1-\sigma}\frac{z}{\rho};$$

whence the three strains are given by

$$e = \frac{z}{\rho}; \qquad f = 0; \qquad g = -\frac{\sigma}{1-\sigma}\frac{z}{\rho}. \tag{7}$$

Both the strains and the stresses are proportional to z, the distance from the middle surface, and they are, therefore, greatest at the two surfaces of the plate, where $z = \pm h$ (the half thickness).

(13) Lastly, suppose the plate, instead of being bent into a cylinder, is bent into a curved surface of some other form. Let P O be the normal to the middle surface through any point P, and let P X, P Y be drawn parallel to the lines of principal curvature through B. Then, if ρ_1 ρ_2 are the principal radii of curvature O_1 B, O_2 B, we have only to add together the strains and stresses due to the two curvatures, and we find that at P, the principal stresses are in the directions P X, P Y, and O P, and are given by

$$\mathrm{P} = \frac{\mathrm{E}\,z}{1-\sigma^2}\left(\frac{1}{\rho_1}+\frac{\sigma}{\rho_2}\right); \qquad \mathrm{Q} = \frac{\mathrm{E}\,z}{1-\sigma^2}\left(\frac{1}{\rho_2}+\frac{\sigma}{\rho_1}\right); \qquad \mathrm{R} = 0, \tag{8}$$

and that the principal strains are

$$e = \frac{z}{\rho_1}; \qquad f = \frac{z}{\rho_2}; \qquad g = -\frac{\sigma}{1-\sigma}\,z\left(\frac{1}{\rho_2}+\frac{1}{\rho_1}\right). \tag{9}$$

It will be noticed that Bernoulli's theory would give

$$\mathrm{P} = \frac{\mathrm{E}\,z}{\rho_1}; \qquad \mathrm{Q} = \frac{\mathrm{E}\,z}{\rho_2},$$

which expressions are obviously wrong.

(14) If A B C D is a small rectangular element of the plate (Fig. 9) whose sides are lines of curvature, it may easily be deduced from the relations (8) by taking moments about A B, B C, that the action across the section A′ B′ B″ A″ gives rise to a couple whose axis is A B, and whose moment per unit length of the side A B is

$$\frac{2}{3}h^3\frac{\mathrm{E}}{1-\sigma^2}\left(\frac{1}{\rho_1}+\frac{\sigma}{\rho_2}\right),$$

and the action across the section B′ C′ C″ B″ gives rise in like manner to a couple about B C as axis, whose moment per unit length of B C is—

$$\frac{2}{3}h^3\frac{\mathrm{E}}{1-\sigma^2}\left(\frac{1}{\rho_2}+\frac{\sigma}{\rho_1}\right).$$

These couples may be regarded as the bending moments about the lines of principal curvature; $\frac{2}{3}h^3$ is the moment of inertia of the section of the plate per unit length of its trace on the middle surface. Calling this I, we have, therefore, if M_1 M_2 denote the bending moments,

$$M_1 = \frac{EI}{1-\sigma^2}\left(\frac{1}{\rho_1} + \frac{\sigma}{\rho_2}\right); \qquad M_2 = \frac{EI}{1-\sigma^2}\left(\frac{1}{\rho_2} + \frac{\sigma}{\rho_1}\right). \qquad (10)$$

The lines of principal curvature on the middle surface of the plate cross each other at right angles, and their form depends on the way in which the plate is bent. In the case of a rectangular plate bent under pressure the lines of curvature are *not* parallel to the edges of the plate, as might at first sight be erroneously supposed. We shall not find it necessary to determine their form.

The corresponding expressions for the couples on an element whose sides are not in the direction of the lines of curvature of the bent plate are rather more complicated. They will not be required in calculating the strength of the plating, though it would be necessary to find them, in order to prove the differential equation and boundary conditions which determine the form of a plate when bent under pressure. For our purpose it will be sufficient to state the equations without proof (Section 6).

SECTION 5.—CONDITIONS OF SAFETY.

(15) The object of our investigations is to find the least thickness of plating that will safely support a given load. The condition to be satisfied depends on what theory is followed in measuring the tendency to rupture at any point. It is observed, however, that, since the strains and stresses given by equations (6), (7) are proportional to z (the distance from the middle surface), the tendency to rupture, according to every theory, is greatest at one of the bounding surfaces of the plate where $z = \pm h$.

(16) If we follow Lamé's theory that the greatest stress or tension is the measure of the tendency to rupture, this stress must be less than $\frac{T_0}{\Phi}$, where T_0 is the breaking tension of a bar and Φ the factor of safety.

Hence the principal curvatures at any point must satisfy the conditions—

$$\frac{\Phi E}{1-\sigma^2}\left(\frac{h}{\rho_1} + \frac{\sigma h}{\rho_2}\right) < T_0; \qquad \frac{\Phi E}{1-\sigma^2}\left(\frac{h}{\rho_2} + \frac{\sigma h}{\rho_1}\right) < T_0.$$

In what follows it will be convenient to suppose $\rho_2 > \rho_1$, so that $\frac{1}{\rho_1}$ is the *greatest* principal curvature. With this limitation, the condition of safety is or

$$\left.\begin{aligned} &\frac{\Phi\,E}{1-\sigma^2}\left(\frac{h}{\rho_1}+\frac{\sigma h}{\rho_2}\right) < T_0 \\ &\frac{\Phi\,E\,h}{1-\sigma^2}\left\{\frac{1-\sigma}{\rho_1}+\sigma\left(\frac{1}{\rho_1}+\frac{1}{\rho_2}\right)\right\} < T_0 \end{aligned}\right\} \qquad (11)$$

(17) If we adopt Saint Venant's theory that the greatest strain measures the tendency to rupture, this strain must be less than $\frac{T_0}{\Phi E}$.

Therefore by (9)

$$\Phi\,E\frac{h}{\rho_1} < T_0; \qquad \Phi\,E\,\frac{h}{\rho_2} < T_0; \qquad \frac{\Phi\,E\,\sigma}{1+\sigma}\left(\frac{h}{\rho_1}+\frac{h}{\rho_2}\right) < T_0.$$

Since $\sigma < \frac{1}{2}$ and we have taken $\rho_2 > \rho_1$, the conditions of safety becomes

$$\Phi\,E\,\frac{h}{\rho_1} < T_0. \qquad (12)$$

This is the simplest condition of safety, and it is probably nearer the truth than Lamé's condition.

(18) A somewhat different condition of safety is found by taking the tendency to rupture to be measured by either—

(*a*) The difference between the greatest and least principal strains.

(*c*) The difference between the greatest and least principal stresses.

(*b*) The maximum shearing strain.

(*d*) The maximum shearing stress.

Each of these four hypotheses leads to the same conditions of safety, and for our bent plate these assume the forms—

$$\Phi\,P < T_0; \qquad \Phi\,Q < T_0; \qquad \Phi\,(P \backsim Q) < T_0;$$

when $z = h$. Therefore

$$\frac{\Phi\,E}{1-\sigma^2}\left(\frac{h}{\rho_1}+\frac{\sigma h}{\rho_2}\right) < T_0; \qquad \frac{\Phi\,E}{1-\sigma^2}\left(\frac{h}{\rho_2}+\frac{\sigma h}{\rho_1}\right) < T_0;$$

and

$$\frac{\Phi\,E\,h}{1+\sigma}\left(\frac{1}{\rho_2}\backsim\frac{1}{\rho_2}\right) < T_0.$$

If the principal curvatures are in the same direction and $\rho_2 > \rho_1$ we get the same condition (11) as on the first hypothesis, viz.—

$$\frac{\Phi\,E}{1-\sigma}\left(\frac{h}{\rho_1}+\frac{\sigma h}{\rho_2}\right) < T\,.$$

The third condition applies to cases in which the curvatures are in opposite directions (so that the plate is bent into a surface of anticlastic curvature), and the radii of curvature are such that

$$\rho_2 \text{ lies between } -\sigma\rho_1 \text{ and } -\frac{\rho_1}{\sigma}. \qquad (13)$$

In this case the condition of safety is

$$\frac{\Phi E h}{1+\sigma}\left(\frac{1}{\rho_1} \backsim \frac{1}{\rho_2}\right) < T_0, \qquad (14)$$

where one of the quantities $\rho_1\,\rho_2$ is negative, so that $\frac{1}{\rho_1} \backsim \frac{1}{\rho_2}$ is the *sum* of the two principal curvatures in opposite directions. This condition is not required in the cases which are of most interest from a practical point of view.

SECTION 6.—DIFFERENTIAL EQUATION AND BOUNDARY CONDITIONS OF A BENT PLATE.

(19) Suppose a plate originally flat to be bent by given loads applied perpendicularly to its middle surface and distributed over its area. Let x, y be the co-ordinates of any point on the middle surface referred to axes in its plane before bending, and suppose that, when bent, it is displaced through a distance w perpendicular to that plane. Then if Z be the load *per unit area* of the plate in the neighbourhood of the point (x, y), the differential equation for w is

$$C\left[\frac{d^4 w}{d x^4} + 2\frac{d^4 w}{d x^2\, d y^2} + \frac{d^4 w}{d y^4}\right] = Z, \qquad (15)$$

where the constant

$$\left.\begin{aligned} C &= \frac{2}{3}h^3\frac{E}{1-\sigma^2} \\ &= \frac{E I}{1-\sigma^2} \end{aligned}\right\} \qquad (16)$$

with the notation of equation (10) of § 14.

(20) The boundary conditions to be satisfied by w at the edge of the plate depend on how the plate is attached to the supporting framework.

(i.) In most bulkheads and similar structures the edges are either firmly clamped or built in, or attached to angle irons which allow no side play. Hence the displacement w must vanish at the edge; and, in addition, the tangent plane at every point of the edge must remain fixed when the plate is bent. Hence w must satisfy the boundary conditions

$$w = 0; \qquad \frac{d w}{d x} = 0; \qquad \frac{d w}{d y} = 0; \qquad (17)$$

at all points of the edge. These three equations are not all independent; they are really equivalent to two conditions.

(ii.) If, instead, the plating is merely "supported," or hinged to the edges, so that it can turn about them, the condition

$$\mathrm{w} = 0 \qquad (18)$$

must still be satisfied; and the other condition is that no couple must be applied about the edges. For a straight edge in the direction of the line $y = 0$, this condition becomes

$$\frac{d^2 \mathrm{w}}{d y^2} + \sigma \frac{d^2 \mathrm{w}}{d x^2} = 0;$$

or, in virtue of (17),

$$\frac{d^2 \mathrm{w}}{d y^2} = 0. \qquad (19)$$

(21) The principal curvatures at any point of the plate are given by the equations

$$\left.\begin{aligned} \frac{1}{\rho_1} + \frac{1}{\rho_2} &= \frac{d^2 \mathrm{w}}{d x^2} + \frac{d^2 \mathrm{w}}{d y^2}, \\ \frac{1}{\rho_1 \rho_2} &= \frac{d^2 \mathrm{w}}{d x^2} \frac{d^2 \mathrm{w}}{d y^2} - \left[\frac{d^2 \mathrm{w}}{d x \, d y}\right]^2 \end{aligned}\right\} \qquad (20)$$

from which we have a quadratic equation for ρ_1 ρ_2, viz.—

$$\frac{1}{\rho^2} - \frac{1}{\rho}\left(\frac{d^2 \mathrm{w}}{d x^2} + \frac{d^2 \mathrm{w}}{d y^2}\right) + \frac{d^2 \mathrm{w}}{d x^2} \frac{d^2 \mathrm{w}}{d y^2} - \left(\frac{d^2 \mathrm{w}}{d x \, d y}\right)^2 = 0 \qquad (21)$$

(22) In order, therefore, to calculate the strength of plating exposed to pressure, the processes are as follow:—

(i.) Find a solution of the differential equation (15) which satisfies the required boundary conditions at the edges of the plate.

This determines w at any point in terms of x and y.

(ii.) Hence write down the equation (21) and find expressions for radii of curvature of the plate at any point.

(iii.) Substitute these in the conditions of safety (11), (12), or (14), and hence write down the condition that they may be satisfied at every point of the plate. If this is the case, the plate will be strong enough to bear the load applied to it.

(iv.) The condition thus found assumes the form of a relation expressing the fact that the breaking tension exceeds a certain expression which is a function of x and y, it must therefore exceed the maximum value of the expression. Theoretically this maximum would have to be found by means of the differential calculus, and the point at which it occurs would be the weakest point of the plate. Practically it is generally possible from the symmetry of the plate to infer whereabouts its weakest point must lie and to materially simplify the calculations in processes (3) and (4). Since the thickness enters into the conditions, we may use them to determine the least thickness of plating that is capable of sustaining a given load.*

(23) The chief difficulty of the problem is in the first process, which consists in finding a solution of the differential equation (15) satisfying the required boundary conditions. The only cases in which this has hitherto been done are that of a circular plate under uniform pressure or loaded symmetrically (given by Thomson and Tait), and that of a rectangular plate whose edges are supported without being built in, and which has been investigated by Saint Venant.

I find that the solution assumes a very simple form when the boundary of the plate is elliptical (or in the form of any conic section), and is built in, provided that the pressure is either uniform over the plate, or is hydrostatic pressure proportional to depth. Although the case of a rectangular plate with built-in edges seems to be unsolvable (except by the help of elliptic functions, and, therefore, quite unsolvable for all practical purposes), I think it will be possible from the solvable cases to form definite conclusions with regard to the strengths of plates such as occur in bulkheads. I only regret that it has been found too late to incorporate into the present paper the results which I have arrived at so far; but I trust the delay may allow of this work being put into a more complete form before it is published. When this has been done, and a few experiments have been performed in this connection, I think the remarks which Sir Edward Harland made at the last meeting of this Institution, regarding the absence of any definite results in Dr. Elgar's paper, will have been fully met.

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* It might be objected that the stresses of equations (8) are calculated on the supposition of no stress perpendicular to the plating, and are therefore incorrect when the plating is bent by normal pressure Z. This point is considered fully in the mathematical investigations above referred to. When the plating is very thin the stresses of § 13 are large compared with the pressure Z, and therefore to a first approximation the normal pressure may be omitted from the stress system at any point. The tendency to rupture does not depend on this normal pressure to any appreciable extent. If we wished to proceed to a higher approximation, as would be necessary if the thickness of the plate were not very small in comparison with its length and breadth, we should no longer be able to omit the normal pressure from the stress system. The same thing is true in the case of a bent beam, as is well known.

CONCLUDING PROCEEDINGS.

The **President** (the Right Hon. Lord Brassey, K.C.B.): Gentlemen, this is the last meeting at which papers will be read, and it is therefore a suitable opportunity for formally tendering on behalf of the Institution our acknowledgments to those at Cardiff, and they are very many, who have received us with such extreme kindness and such generous hospitality. I said yesterday, speaking as a layman on behalf of the body over which I have the honour to preside, that I think it might be fairly claimed for them that, whether they are naval architects, or marine engineers, or shipbuilders, or shipowners, they are doing good service to their country and to the community, and I think I may accept it that, this warm reception which we have obtained here in Cardiff is intended to give an assurance to those concerned in the various interests which are embodied in the Institution of Naval Architects that their services to the community, to commerce, to trade, to civilisation, and to the extension of the greatness and interests of the country, are fully appreciated. I am sure I shall only be giving expression to a universal sentiment when I beg to move, on behalf of the Institution of Naval Architects, a cordial vote of thanks to the Reception Committee and to the following gentlemen and Corporations who have entertained the Institution with so much kindness and lavish hospitality. I desire to include in the motion the names of the Mayor of Cardiff, the Marquis of Bute, the Lord Windsor, the Bristol Channel Centre of the Institute of Marine Engineers, the Chairman and Directors of the Bute Dock Company, the Chairman and Directors of the Barry Railway Company and of the Taff Vale Railway Company, the Chairman and Directors of the Rhymney Railway Company, the Cardiff Incorporated Chamber of Commerce, the Cardiff Incorporated Shipowners' Association, and, last but not least, to the Executive and the Members of the Local Reception Committee. To each and all of these I desire on behalf of the Institution to move that a cordial vote of thanks be tendered for their kindness and generous hospitality.

Sir **Nathaniel Barnaby**, K.C.B. (Vice-President): My Lord, Members and Associates of the Institution of Naval Architects, in rising to second this motion I should like to say that it has been our view, in talking over the arrangements for these Summer Meetings at the Council, that we should avoid putting those gentlemen who may invite us to visit them to expense. It has been our view that if they would give us the facilities for our meetings we should be deeply grateful for that. I had nothing to do with the communications made with Mr. Heywood, acting on the part of Cardiff, and I am sure those who had could not have understood the intention of our entertainers. If they had they might have hesitated to accept the splendid hospitality which has been accorded to us here. I have the greatest pleasure in seconding the resolution proposed by our noble Chairman.

(Carried with acclamation.)

Mr. B. **Martell** (Vice-President): Gentlemen, I beg to make a few remarks in connection with a pleasing duty I have to perform, and which I am sure you will endorse with a great deal of enthusiasm. I have to propose a grateful vote of thanks to our noble President for the manner in which he has presided over us. You all know the great disappointment we felt when we had not the pleasure, on the first day of our meetings, of the presidency of his lordship, and although his place was ably supplied by our esteemed friend Sir Nathaniel Barnaby, yet that did not compensate us for the loss of our President, and how happy we felt on the next day when we saw he had arrived here to preside at these meetings. We all feel that Lord Brassey possesses very eminent qualities for the position he fills in connection with this Institution. He has a very practical order of mind, and he is capable of dwelling on the salient points of all questions brought before us here, and of placing them before you in such a practical form as enables you to appreciate the papers and the remarks in connection with them. Therefore I think you will agree with me that our thanks are due to Lord Brassey for presiding over us, and we trust he will be present for many years to fill the office which he so ably and so gracefully fills now.

Mr. JOHN SCOTT, C.B., F.R.S.E. (Member of Council): I beg to second the vote of thanks to our noble President so ably proposed by Mr. Martell.

(Carried with acclamation.)

The PRESIDENT (the Right Hon. Lord Brassey, K.C.B.): Mr. Martell, Mr. Scott, and Gentlemen, I am most grateful to you for your kind vote of thanks. I only wish that I in the least degree deserved all the kind things my friend, Mr. Martell, has said of me. I can only say to you that I am deeply grateful, and once more thank you, and further than that, in length of speech, I am sure you would not desire me to go, seeing that in a few moments we must be seated in the train on our way to the Barry Docks.

PROCEEDINGS IN LONDON.

SPRING MEETINGS OF THE THIRTY-FIFTH SESSION.

INSTITUTION OF NAVAL ARCHITECTS.

MARCH 14, 15, AND 16, 1894.

INTRODUCTORY PROCEEDINGS.

The Spring Meetings of this, the thirty-fifth Session of the Institution of Naval Architects, were held on March 14, 15, and 16, in the Hall of the Society of Arts, John-street, Adelphi.

The opening meeting was presided over by Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President of the Institution, who commenced the proceedings by calling on the Secretary, Mr. George Holmes, to read the report of the Council, which was as follows:—

ANNUAL REPORT OF COUNCIL, 1894.

The Council reports with much pleasure that the past year has been one of the most active and prosperous periods in the history of the Institution. The finances are in a satisfactory condition. The annexed Statement of Receipts and Expenditure shows that the Institution has been managed economically, and the receipts bear testimony to the increasing membership and the more extended sale of the publications.

Owing to the unavoidable absence of the President of the Institution, Lord Brassey, on public duty in India, as Chairman of the Royal Commission on Opium, the Council invited its senior Vice-President, Admiral the Right Hon. Sir John Dalrymple-Hay, to preside at the General Meeting.

The Council have had under consideration new rules defining the position, duties, and mode of appointing Trustees to hold the property of the Institution. Copies of the proposed Rules have been issued to all Members and Associates, and will now be submitted for your approval, together with the proposed Trust Deed.

The Council accepted last year a most cordial invitation from the Incorporated Chamber of Commerce of Cardiff to hold a Summer Meeting of the Institution at that Port. The Meetings took place on July 11 and following days, and proved to be among the most successful ever held by the Institution. Nothing could exceed the kindness and hospitality of the various Corporations and individuals at Cardiff who took part in the reception and entertainment of the members.

Many excellent papers were read, and excursions arranged to the Bute Docks and the adjacent works; to Caerphilly Castle, where the members were entertained by the Marquis of Bute, K.T.; to the Penarth and Barry Docks, where they were entertained by the Chairman and Directors of the Barry Railway Company; to Ilfracombe by steamer, on the invitation of the Cardiff Incorporated Chamber of Commerce and the Cardiff Incorporated Shipowners' Association. The members were also entertained at a Conversazione at the Park Hall by the Bristol Channel Centre of the Institute of Marine Engineers, and at a Garden Party at Penarth by Lord Windsor. The best thanks of the Institution are due to the Chairman and Members of the Local Reception Committee, and to the various private individuals, Corporations, and Railway Companies who did so much to promote the instruction and enjoyment of the members of the Institution.

The Council is pleased to announce that they have received a most cordial invitation from the Mayor and Corporation of Southampton to hold a meeting at that port during the coming summer. The invitation has been accepted, and the meeting will be held during the month of July. The exact date and full particulars of the Meetings will be issued as soon as possible, and the Council trust that they will be supported on that occasion by a large gathering of the members.

The Council much regret to announce the loss by death during the year of one of the Honorary Associates of the Institution, Vice-Admiral Paris, and of two members of the Council, viz., Rear-Admiral Long and Mr. Henry Laird, who were both well known to the members, and took an active part in the proceedings of the Institution. Mr. Laird had been a member of the Council since the year 1877, and Admiral Long had only been elected an Associate Member of the Council a few days before the unfortunate accident which caused his death. The Institution has also lost during the year a former Associate Member of Council, Mr. E. A. Cowper, who was a most distinguished engineer, and formerly President of the Institution of Mechanical Engineers. The circumstances of the lamentable calamity which caused the death of Admiral Sir George Tryon, who was an Associate of the Institution, are still fresh in the public mind. The recent death of Mr. Cornelius Thompson, who was an Associate, removes a well-known shipowner, to whose enterprise the introduction of the triple-expansion engine for marine propulsion was largely due.

Owing to the death of Mr. Henry Laird, a vacancy occurred among the representatives of the Institution on the Sub-Committee for Surveyors of Lloyd's Registry of Shipping. The vacancy was filled by the election of Mr. Alexander Adamson, of the Naval Construction and Armaments Company at Barrow-in-Furness. Mr. Adamson has kindly accepted the nomination of the Council.

The Council has much pleasure in announcing that two papers of such exceptional merit were read at the last Spring Meetings that they decided to award a gold medal to the author of each of them; viz., to George A. Calvert, Esq., for his paper "On the Measurement of Wake Currents," and to Herr Otto Schlick for his paper "On an Apparatus for Measuring and Registering the Vibrations of Steamers."

INSTITUTION OF NAVAL ARCHITECTS.

Dr. *Statement of Receipts and Payments for the Year 1893.* Cr.

RECEIPTS.	£	s.	d.	£	s.	d.
To BALANCE, Dec. 31, 1892, at the Bankers	559	15	3			
,, BALANCE, Dec. 31, 1892, in Secretary's hands	69	9	7½			
				629	4	10½
,, Annual Subscriptions				1,984	9	1
,, Life Subscriptions				63	0	0
,, Admiralty Grant				250	0	0
,, Sale of Volumes				219	14	4
				£3,146	8	3½

PAYMENTS.	£	s.	d.	£	s.	d.
By RENT	200	0	0			
,, Housekeeper and Cleaning ...	37	14	0			
,, Despatch of Volumes	58	16	6			
,, Printing Volume XXXIV. ...	571	0	8			
,, Stationery...	11	16	6			
,, Insurance...	2	10	0			
,, Postages and Telegrams... ...	55	13	11			
,, Petty Disbursements	19	3	0			
,, Banker's Charges	2	0	2			
,, Salaries and Wages	752	17	3			
				1,711	12	0
,, Expenses, Spring Meetings ...	32	19	0			
,, ,, Summer Meetings ...	76	8	3			
,, Reporting	45	0	0			
				154	7	3
,, Translating	7	10	0			
,, Auditors' Fee	5	5	0			
,, Investments, 2¾ per cent. Consols	788	1	10			
,, Advertising	28	17	1			
				829	13	11
,, Cash at Bankers, Dec. 31, 1893...	425	13	11			
,, in Secretary's hands	25	1	2½			
				450	15	1½
				£3,146	8	3½

LIBRARY FUND.

RECEIPTS.	£	s.	d.
To BALANCE AT BANKERS, December 31, 1892 ...	6	14	3
,, ENTRANCE FEES	149	2	0
,, DIVIDENDS ON INVESTMENTS	94	14	4
	£250	10	7

PAYMENTS.	£	s.	d.
By LIBRARY EXPENSES	30	19	11
,, FURNITURE AND REPAIRS	7	12	6
,, INVESTMENTS 2¾ PER CENT. CONSOLS	211	18	2
	£250	10	7

H. MORGAN, TREASURER.
GEORGE HOLMES, SECRETARY.

We have examined the above-written entries with the books and vouchers, and find them correct.

BALL, BAKER, DEED, CORNISH & Co.,
CHARTERED ACCOUNTANTS.

February 13 1894.

The following is a List of Donations to the Library:—

"Transactions of the Liverpool Engineering Society," for 1893. *Presented by the Institution.*

"Proceedings of the Royal Society," for 1893. *Presented by the Royal Society.*

"Minutes of the Proceedings of the Institution of Civil Engineers," Vols. CXII., CXIII., CXIV., and CXV. *Presented by the Institution of Civil Engineers.*

"Proceedings of the Institution of Mechanical Engineers," for 1893. *Presented by the Institution of Mechanical Engineers.*

"Journal of the Iron and Steel Institute," for 1893. *Presented by the Iron and Steel Institute.*

"Journal of the Society of Arts," for 1893. *Presented by the Society of Arts.*

"Transactions of the Institution of Engineers and Shipbuilders in Scotland," Vol. XXXVI., 1893-94. *Presented by the Institution of Engineers and Shipbuilders in Scotland.*

"Transactions of the Society of Engineers," for 1893. *Presented by the Society of Engineers.*

"Transactions of the Institute of Marine Engineers for 1893-94." *Presented by the Institute of Marine Engineers.*

"Lloyd's Register of British and Foreign Shipping," 1893-94. *Presented by the Committee of Lloyd's Register.*

"Lloyd's Register of Yachts," for 1893-94. *Presented by the Committee of Lloyd's Register.*

"Annual Report of the Royal National Lifeboat Institution," 1893. *Presented by the Royal National Lifeboat Institution.*

"Transactions of the North-East Coast Institution of Engineers and Shipbuilders," Vol. IX., 1892-93. *Presented by the North-East Coast Institution.*

"The Scientific Proceedings of the Royal Society of Dublin," for 1892. *Presented by the Royal Society of Dublin.*

"North of England Institute of Mining and Mechanical Engineers," for 1893. *Presented by the North of England Institute.*

"Transactions of the Hull and District Institution of Engineers and Naval Architects," for 1893. *Presented by the Hull and District Institution.*

"Report of the U.S. National Museum" of the year ending June, 1891.

"Year Book of the Imperial Institute." *Presented by the Council of the Institute.*

"Engineer," for 1893. *Presented by the Proprietors.*

"Engineering," for 1893. *Presented by the Proprietors.*

"Iron," for 1893. *Presented by the Proprietors.*

"Iron and Coal Trades Review," for 1893. *Presented by the Proprietors.*

"Field," for 1893. *Presented by the Proprietors.*

"Army and Navy Gazette," for 1893. *Presented by the Proprietors.*

"Shipping World," for 1893. *Presented by the Proprietors.*

"Saturday Review," for 1893. *Presented by the Proprietors.*

"Marine Engineer," for 1893. *Presented by the Proprietors.*

"English Mechanic," for 1893. *Presented by the Proprietors.*

"Revue Maritime," for 1893. *Presented by the French Ministry of Marine.*

"Rivista Maritima," for 1893. *Presented by* H. Clauson, Esq.

"Germanischer Lloyd," for 1893. *Presented by the Committee of the Germanischer Lloyd.*

"Annalen Für Gewerbe und Bauwesen," for 1893-4. *Presented by the Proprietor.*

"The Journal of the Franklin Institute," for 1893. *Presented by the Institute.*

"Proceedings of the United States Naval Institute," for 1893. *Presented by the Institute.*

"Ordnance Notes," for 1893. *Presented by the Ordnance Office, War Department, Washington, D.C., United States.*

"Proceedings of the Royal Society of New South Wales," Vol. XXV., 1893. *Presented by the Royal Society of New South Wales.*

"Annual Report of the Chief of Ordnance to the Secretary of War of the United States," 1893.

"A Study of the Effects of Smokeless Powder in 57 mm. Gun." *Presented by the Chief of Ordnance U.S.A.*

"The Naval Annual," 1893. By the Right Hon. Lord Brassey, K.C.B.; F. K. Barnes, Esq., M.I.N.A.; and Captain Orde Browne, R.A. *Presented by the Right Hon.* Lord Brassey, K.C.B.

"The Year's Naval Progress," Annual of the Office of Naval Intelligence. *Presented by the Secretary of the United States Navy.*

"Iron and Steel Manufacture." By F. Kohn, Esq. *Presented by* JOHN E. ELMSLIE, Esq.

"Marine Electric Lighting" (Special Number). *Presented by the Proprietors of the Electrical Plant.*

"Notes on the Reactive Influence of Steam." By W. J. MILLAR, Esq. *Presented by the Author.*

"Principes de la Machine à Vapeur." By Mons. E. WIDMANN. *Presented by the Author.*

"Presidential Address to the Institution of Marine Engineers." By W. H. WHITE, Esq., C.B., LL.D., F.R.S. *Presented by the Author.*

"Transactions of the American Society of Mechanical Engineers." *Presented by the Council.*

"Reference Map of the United States." *Presented by the American Society of Civil Engineers.*

"Extracts from Steamship Log-book." *Presented by* C. HAMPDEN WIGHAM, Esq.

"Proceedings of the Royal Society of Canada." *Presented by the Council.*

"Le Correnti Dell' Atlantic." *Presented by* Signor Cav. SALVATORE RAINERI.

"The Technology Quarterly and Proceedings of the Society of Arts." *Presented by the Massachusetts Institute of Technology.*

"Report of Tests of Metals and other Materials made at Watertown Arsenal," for the years ending June 30, 1891, and June 30, 1892. *Presented by the Chief of Ordnance, U.S.A.*

"Marine Boilers." By C. E. STROMEYER, Esq. *Presented by the Author.*

"Journal of the United States Artillery." *Presented by the Editor.*

"The International Columbian Naval Rendezvous of 1893 and Naval Manœuvres of 1892." *Presented by* Lieutenant-Commander W. S. COWLES, United States Naval Attaché.

"On the Analysis of certain Curves arising in Engineering Investigation." By Professor W. F. DURAND, M.A., M.Soc.M.E. *Presented by the Author.*

"The Uses of Logarithmic Cross-Section Paper." By Professor W. F. DURAND, M.A., M.Soc.M.E. *Presented by the Author.*

"Abridgments of Specifications." *Presented by the Comptroller of the Patent Office.*

"Minutes of the Proceedings of the International Maritime Congress, London, 1893." *Presented by the Congress.*

"The Interdependence of Abstract Science and Engineering." By W. ANDERSON, Esq., D.C.L., F.R.S. *Presented by the Council of the Institution of Civil Engineers.*

"Messrs. Seaton and Rounthwaite's Pocket-Book of Marine Engineering Rules and Tables." *Presented by* A. E. SEATON, Esq.

"On the Manchester Ship Canal." *Presented by* J. ABERNETHY, Esq.

"Modern System of Naval Architecture." By J. SCOTT RUSSELL, Esq., F.R.S. *Presented by* J. ABERNETHY, Esq.

"Some Remarks on the Belleville Water-Tube Boiler." *Presented by* JOHN SAMPSON, Esq.

"Manual of Naval Architecture." Third Edition. By W. H. WHITE, Esq., C.B., LL.D., F.R.S. *Presented by the Author.*

"On Hydrostatics." By Professor A. G. GREENHILL, M.A., F.R.S. *Presented by the Author.*

"Théorie du Navire." By Messieurs J. Pollard et A. Dudebout. *Presented* by Mons. E. BERTIN.

"An Account of the Strata of Northumberland and Durham, as proved by Borings and Sinkings." *Presented by the Council of the North of England Institution of Mining and Mechanical Engineers.*

Photographs of Members of the Institution. *From* Messrs. MAULL & FOX, *Piccadilly, W.*

The following gentlemen (having been duly recommended by the Council) were unanimously elected Members of this Institution:—Mr. J. McNeal Allan, Chief Draughtsman to Messrs. R. & W. Hawthorn, Leslie & Co., Newcastle-on-Tyne; Mr. James Brown, Assistant Manager, Engine Works, Astilleras del Nervion, Bilbao; Mr. William Barnes, of Messrs. C. Howson & Co., Liverpool; Colonel Vincenzo Bernardi, Chief Engineer, Italian Navy; Mr. G. P. Cooper, Principal Surveyor to Lloyd's Register, Cornhill; Mr. W. C. Carter, Consulting Engineer, Queen Victoria Street, E.C.; Mr. Edwin Clarke, Steam Launch Builder, Stroud, Gloucester; Mr. Clyde B. Coltart, Member of the firm of Messrs. Martin-Davey & Coltart, Naval Architects, Liverpool; Mr. James Donald, Draughtsman to Dr. Elgar, 113, Cannon-street, E.C.; Mr. George Dykes, Ship Surveyor to Lloyd's Register, Hamburg; Mr. J. A. Griffiths, Deputy Superintendent Engineer, Union S.S. Co., Southampton; Mr. Maxwell Hill, Naval Architect, Newcastle-on-Tyne; Mr. J. Alex. Houston, Manager and Owner of the Rowhedge, East Donyland, Wood and Iron Works; Mr. John Hudson, Jun., Chief Draughtsman to Messrs. J. Stewart & Son, Blackwall; Mr. Peter Jackson, Consulting Engineer and Marine Surveyor, Glasgow; Mr. C. P. Lemon, Constructor, Admiralty, Whitehall; Mr. F. Kraft, Engineer of the Department of Marine Engines, Société Cockerill, at Seraing, Belgium; Mons. A. J. A. Lagane, Director of the Naval Construction Works of the Forges et Chantiers de la Méditerranée at La Seyne; Mr. W. McLaren, Superintendent Engineer to Messrs. R. P. Houston & Co., Liverpool; Mr. S. W. Furze Morrish, of the Department of the Controller of the Navy, Admiralty, Whitehall; Mr. R. Horne Muir, Shipyard Manager to Messrs. Wigham Richardson & Co., Newcastle-on-Tyne; Mr. Charles B. Nichol, Inspecting Officer to Sir E. J. Reed, Westminster; Mr. W. H. Norman, Manager to the Commercial Docks, Calcutta; Mr. A. E. Freath Norris, of Greenwich; Mr. David Pollock, Naval Architect, Glasgow; Mr. G. J. Rickard, Manager and Naval Designer to the Société Cockerill, Seraing, Belgium; Mr. Alex. Rutherford, Yacht and Launch Builder, Birkenhead; Mr. Graham Robertson, Marine Surveyor to the Government of Bengal; Mr. Jas. Stewart, Superintendent to Messrs. Adam & Co., Shipowners, Newcastle-on-Tyne; Mr. Jas. Sellar, Manager to the New Harbour Dock Co., Limited, Singapore, Straits Settlements; Mr. E. Sharer, General Manager to the Fairfield Shipbuilding Company, Govan; Mr. W. H. Swainston, Partner in the firm of Messrs. W. Esplen, Son & Swainston, Consulting Engineers, Billiter Street, E.C.; Mr. Charles Thomson, Superintendent of River Service, Metropolitan Asylum Board; Mr. E. H. Tennyson d'Eyncourt, Assistant Constructor to Sir W. G. Armstrong, Mitchell & Co., Newcastle-on-Tyne; Mr. Felix Von Kodolitsch, Manager of the Arsenal of the Austrian Steamship Company, Trieste; Mr. J. Denholm Young, Chief Draughtsman to the North Eastern Marine Company, Limited, Sunderland; Mr. John Walker, General Manager to Messrs. R. Stephenson & Co., Limited, Newcastle-on-Tyne.

The following gentlemen were elected Associates:—Mr. J. W. Attridge, Rear-Admiral Bowden-Smith, Admiral of the Fleet Sir J. E. Commerell, G.C.B., V.C., Mr. C. F. Dickinson, Mr. D. W. Fitzgerald, Mr. W. Fenwick, Mr. Felix Gross, Mr. August Hartmann, Mr. R. A. Hadfield, Mr. J. E. Jackson, Capt. H. Lloyd, R.N., Sir J. L. Mackay, K.C.I.E., Mr. H. R. F. Plater, Mr. F. G. Panizzi Preston, Mr. E. A. J. Pearce, Mr. J. Sampson Starnes, Captain Z. Rogestvensky, Naval Attaché to the Imperial Russian Embassy, Mr. A. McLean Wait, Mr. A. Westmacott.

Since the issuing of Volume XXXIV. the Institution has sustained the loss of the following Members and Associates:—Mr. A. E. Allen, Mr. W. Andrews, Mr. Rustomjee Ardaseer, Mr. R. J. Cross, Mr. J. Dhunjabhoy, Mr. J. C. R. Gemmell, Mr. G. F. Penny, Mr. Cornelius Thompson, Members; Sir J. Anderson, Mr. W. E. Blackburn, Mr. F. C. Hide, Mr. Jas. Spence, Mr. H. Tatham, Associates.

The Secretary next read the following list of names of the retiring members, and the new names nominated by the Council, to fill up the vacancies for the Ordinary and Associate Members of Council for the ensuing year. Retiring Members of Council:—Mr. James Dunn, Mr. A. J. Durston, Mr. R. H. Humphreys, Mr. F. C. Marshall, Mr. J. Rodger Thomson. New candidates nominated for Members of Council:—Mr. Sidney Barnaby, Mr. R. R. Bevis, Mr. Alfred Morcom, Mr. J. Price, Mr. T. C. Read, Mr. T. Soper, Mr. H. G. Spence. Retiring Associate Member of Council:—Mr. T. H. Ismay. New Candidates nominated for Associate Members of Council:—Mr. Dixon Kemp, Mr. James Riley, Captain Eardley-Wilmot, R.N.

The **Chairman** (Admiral the Right Hon. Sir J. Dalrymple-Hay, K.C.B., D.C.L., F.R.S., Vice-President) next put to the Meeting the following list, containing the names of the President, Vice-Presidents and Treasurer, for the ensuing year, and which was unanimously adopted:—President—the Right Hon. Lord Brassey, K.C.B.; Past President and Vice-President—the Right Hon. the Earl of Ravensworth; Vice-Presidents—H.R.H. the Duke of Saxe-Coburg and Gotha, K.G., K.T., K.P., G.C.B., G.C.S.I., G.C.M.G., G.C.I.E., Admiral of the Fleet; the Right Hon. the Earl of Northbrook, G.C.S.I.; the Right Hon. Earl Spencer, K.G.; the Right Hon. Lord Armstrong, C.B., D.C.L., F.R.S.; the Right Hon. Lord George Hamilton, M.P.; the Right Hon. Lord John Hay, G.C.B. (Admiral of the Fleet); Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Sir Nathaniel Barnaby, K.C.B.; Sir Frederick Bramwell, Bart., D.C.L., F.R.S.; Sir Alexander Milne, Bart., G.C.B., Admiral of the Fleet; Sir Frederick W. E. Nicolson, Bart., C.B., Admiral; Sir James Ramsden; Sir Edward J. Reed, K.C.B., M.P., F.R.S.; Sir James Wright, C.B.; F. K. Barnes, Esq.; Peter Denny, Esq., LL.D., F.R.S.E.; Dr. F. Elgar, F.R.S.E.; Benjamin Martell, Esq.; Henry Morgan, Esq.; George W. Rendel, Esq.; J. I. Thornycroft, Esq., F.R.S.; W. H. Tindall, Esq.; W. H. White, Esq., C.B., LL.D., F.R.S.; Treasurer—Henry Morgan, Esq.

The **Chairman** then nominated Professor J. H. Biles and Mr. McIntyre as Scrutineers to examine the voting papers.

The **Chairman** (Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): I beg to move the adoption of the new Rule referred to in the Report of Council, viz.:—

25. Trustees.—There shall be four Trustees, two of whom shall be the President and Treasurer of the Institution for the time being. The remaining two shall be appointed by, and hold office at the pleasure of the Council. In the names of these Trustees, under the direction of the Council of the Institution, all securities shall be taken and investments made, the whole of such property being notwithstanding subject to the disposition of the Council, and the order of the Council in writing, signed by the Chairman of the Meeting and countersigned by the Secretary, shall be obligatory upon and full authority for the Trustees.

To be inserted after Rule 24.

Mr. **Morgan** (Vice-President and Treasurer): I beg to second the Resolution.

The **Chairman**: I beg to move the adoption of the New Trust Deed, which is framed in accordance with the Rule which has just been adopted.

Mr. **Martell** (Vice-President): I beg to second the Resolution.

The Trust Deed, which is as follows, was unanimously adopted:—

To all to whom these Presents shall come the Right Honourable Thomas Lord Brassey K.C.B. of 24 Park Lane in the County of London Henry Morgan of 31 Macaulay Road Clapham Common in the County of Surrey Esquire and Sir Nathaniel Barnaby K.C.B. of Moray House Belmont Hill Lewisham in the County of Kent and John Corry of Rosenheim Park Hill Road Croydon in the County of Surrey Esquire send greeting

Whereas the Institution of Naval Architects (hereinafter called "the Institution") was established in the year 1860 to promote the improvement of ships and of all that specially appertains to them And whereas the Institution consists of four classes namely (1) Members consisting exclusively of Naval Architects and Marine Engineers conversant with Naval Architecture (2) Associates consisting of persons who are qualified either by profession or occupation or by scientific or other attainments to discuss with Naval Architects the qualities of a ship or the construction manufacture or arrangement of some part or parts of a ship or her equipment (3) Honorary Members consisting of persons who are eligible as

Members and upon whom the Council may see fit to confer an honorary distinction and (4) Honorary Associates consisting of persons who have contributed to the improvement of ships or their equipment, and upon whom the Council may see fit to confer an honorary distinction AND WHEREAS the Officers of the Institution consist of a President Vice-Presidents Members of Council Associate Members of Council (not exceeding in number one-third the number of Members of Council) a Treasurer two Auditors of Accounts and a Secretary or Secretaries AND WHEREAS a General Meeting of the Members and Associates of the Institution is held annually and at this Annual General Meeting the Members of Council Associate Members of Council Treasurer and Auditors for the ensuing year are elected AND WHEREAS the Direction and Management of the Institution is vested in the Council for the time being the Associate Members voting with the Members of Council in all cases except in the decision of questions directly affecting the forms of ships and the construction of their hulls AND WHEREAS the funds property and effects of the Institution now consist of the particulars mentioned in the first and second Schedules hereto AND WHEREAS at an Annual General Meeting of the Members and Associates of the Institution held on the 14th day of March 1894 at the Hall of the Society of Arts John Street Adelphi W.C. it was unanimously resolved on the recommendation of the Council that the funds property and effects of the Institution should thenceforth be placed in the joint names of four Trustees two of whom shall be the President and the Treasurer for the time being during their tenure of Office as such President and Treasurer respectively of the Institution the remaining two of whom shall be appointed by and hold Office at the pleasure of the Council of the Institution of Naval Architects such Office of Trusteeship to be held by them or other the Trustees or Trustee to be appointed as hereinafter provided upon the trusts hereinafter declared AND WHEREAS the said THOMAS LORD BRASSEY is now the President and the said HENRY MORGAN is now the Treasurer of the Institution and the said NATHANIEL BARNABY and JOHN CORRY are the two persons appointed as aforesaid to fill the Office of Trustees together with the said THOMAS LORD BRASSEY and HENRY MORGAN AND WHEREAS the funds property and effects mentioned in the Schedules hereto have been duly transferred into the names of or otherwise delivered over to the said THOMAS LORD BRASSEY HENRY MORGAN NATHANIEL BARNABY and JOHN CORRY in pursuance of the said Resolution NOW THESE PRESENTS WITNESS that it is hereby agreed and declared as follows:—

(1) The said THOMAS LORD BRASSEY HENRY MORGAN NATHANIEL BARNABY and JOHN CORRY and the survivors and survivor of them and the executors or administrators of such survivors or survivor or other the Trustees or Trustee for the time being of these present (hereinafter called the Trustees or Trustee) shall stand possessed of the funds property and effects mentioned in the Schedules hereto and also of all other moneys investments and property now belonging to or hereafter acquired by the Institution which at any time hereafter shall be transferred to the Trustees or Trustee or placed under their or his control IN TRUST for the Institution and to be disposed of in such manner as the Council of the Institution shall from time to time direct

(2) Any moneys in the hands of the Trustees or Trustee requiring to be invested shall unless otherwise directed by the Council be invested by the Trustees or Trustee in or upon any of the investments by law authorised for the investment of trust funds

(3) A Minute of any resolution of the Council signed by the Chairman of the Meeting of the Council at which such resolution was passed and countersigned by the Secretary of the Institution shall be conclusive evidence of such resolution having been duly passed and shall be a complete authority to the Trustees or Trustee for all acts matters or things done by the Trustees or Trustee in pursuance thereof

(4) The power to appoint new Trustees or a new Trustee of these presents from time to time as occasion may arise shall be vested in the Council of the Institution and the Council shall have full discretionary power to remove any Trustees or Trustee (other than the said President or Treasurer for the time being) from that office and to appoint any other persons or person in their or his place and the trust moneys investments property and effects of the Institution shall at all times be transferred to and be vested in and remain and be under the control of the Trustees or Trustee so appointed

(5) In case of any casual vacancy in the office of Trustee arising by reason of the death or resignation of the President or Treasurer prior to any Annual General Meeting the Council of the Institution may appoint any person to act as Trustee until the next Annual General Meeting such person so appointed to hold the office as Trustee up to and until the next Annual General Meeting

IN WITNESS Whereof the said parties to these presents have hereunto set our hands and seals this day of 1894

The First Schedule above referred to

£402 0s. 2d. Two and Three-quarter per Cent. Consols
£800 0s. 0s. ,, ,, ,, ,,
£627 8s. 2d. ,, ,, ,, ,,
£522 3s. 5d. ,, ,, ,, ,,
£1,017 15s. 3d. ,, ,, ,, ,,
£750 0s. 0d. Three per Cent. India Stock

The Second Schedule above referred to

Furniture assets and effects of and belonging to the Institution of Naval Architects in and about the premises situate for the time being at 5 Adelphi Terrace in the County of London

Mr. W. H. White, C.B., LL.D., F.R.S. (Vice-President): I beg to move that the Meeting give power to the Council to appoint an Honorary Solicitor to the Institution.

Mr. Martell (Vice-President): I have much pleasure in seconding the Resolution.

The Resolution having been put by the Chairman to the Meeting was unanimously adopted.

The Chairman (the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President) then proceeded to deliver the following Opening Address:—Gentlemen, it is now my duty to move the adoption of the report which has just been read by our Secretary. The Council have desired me to submit it to you in the absence of our President, Lord Brassey. He has been engaged in the public service in India, presiding over the Royal Commission appointed to inquire into the Opium Question. He has not been able to return to this country in time to take part in our present proceedings. He has written to express his regret for his unavoidable absence, a regret which we all share. The report which you have heard is of a satisfactory character. Our funds are sufficient for our modest requirements. Our Treasurer, Mr. Morgan, following in the steps of Mr. Samuda and Mr. Green, has taken ample care of them; and thanks to the use of this Hall, so freely accorded by the Society of Arts, our meetings here are not the cause of any large expenditure. The Summer Meeting at Cardiff was a great success. Several members joined the Institution in consequence of our visit to that port. The hospitality of our hosts there, and the warmth of welcome, leave a grateful recollection of friendships formed, and of knowledge gained, by all those who were so fortunate as to attend the Meeting. An invitation has been extended to us by the authorities of Southampton, to hold a Summer Meeting at that port. The Council have gladly accepted it, and anticipate a similar success to that which has been recorded at Cardiff.

Let me now express the deep regret which we all feel for those of our colleagues who have died since our last meeting in this Hall. In the last volume of our Transactions interesting notices are published of the excellent colleagues whom we lost in Vice-Amiral Paris, who died on April 8; of Rear-Admiral Long, who died on April 24; of Mr. E. A. Cowper, who died on May 9; and of Mr. Henry Laird, who died on May 26. I trust I may be permitted to add a few words to express the esteem in which they were held by all who had the honour of their acquaintance. Vice-Amiral Paris had been our Associate since 1862, and had taken great interest in our proceedings. Six papers by him are recorded in our Transactions, and all full of varied information. This able and courteous French seaman joined that navy in 1822. He had three times circumnavigated the globe. He served in the Crimean war, and was one of the captains of the three French armour-clads which assisted in the capture of Kinburn, the first occasion on which armour-clad ships took part in a naval engagement. He early studied the use of the marine steam engine, having become a pupil of Mr. William Fawcett for that purpose. He was at the head of the French Hydrographic Office for several years, and had in 1863 the honour to be elected a member of the French Institute, and of the Bureau des Longitudes. Later he was Conservator of the Museum at the Louvre. He was a copious author on professional subjects. He and his son, Lieutenant Paris, were collaborateurs in many scientific inquiries, and I may be permitted to observe that our colleague, Mr. White, in his "Manual of Naval Architecture" (Notes on Deep Sea Waves, pp. 189, 193, 209), says: "Of French observers, the most laborious and distinguished is Lieutenant Paris, whose able memoir on Rolling (*Révue Maritime*, vol. xxxi.) is highly commended." Alas! he was cut off in his prime, and left his eminent father to mourn his loss. It is sad to think that the father's last days were clouded over by the death of his accomplished son, and that Lieutenant Paris' future services are lost to the great French Navy, of which both were such distinguished ornaments. You will remember that on March 22 last year our opening paper was read by Rear-Admiral Long. His intelligence and the great interest he took in our proceedings recommended him for the Council, to which you elected him at that meeting. On April 25 he died of a fall from his horse, and his early death deprived the Navy and the country of a young Admiral of whom there were the highest expectations. He was followed on May 9 by Mr. E. A. Cowper, an early Associate of our Institution. His scientific knowledge was of great advantage in our discussions. He was an early advocate of the compound engine, and an inventor of many useful improvements of the marine steam engine. He had filled the office of President of the Institution of Mechanical Engineers in 1881-82, and was a Founder of the Iron and Steel Institute. On May 26 we lost a friend and colleague whose name is known wherever British shipping shows our national colours. Mr. Henry Laird, who was a Member of Council, and had been a Member of the Institution for nearly twenty years, was cut off in his prime by the prevailing epidemic. To the large experience he had enjoyed in the great Birkenhead yard, he had added the training which he had received when studying in the works of the Messageries Impériales at Ciotat. His father, Mr. John Laird, and uncle, Mr. McGregor Laird, had been the first to avail themselves largely of iron for shipbuilding, and I well remember when I was a young officer serving on the Bight of Benin, in 1834, meeting one of the steamers which had been built at Birkenhead, and in which Mr. McGregor Laird investigated the mouths and course of the Niger. Since that time (1832) every improvement has been readily adopted by the Messrs. Laird, and none of us cross to Ireland without thanking them for our speedy transit in the splendid vessels with which they bridge the Irish Channel. To the death of one other Associate you will expect me to allude. When, by an inexplicable error, the great catastrophe befell the *Victoria*, and illustrated for all time the splendid discipline and stout courage of her officers and crew, our brave Associate, Sir George Tryon, died with those who perished at their posts, thus terminating a long and distinguished career. Wounded in the trenches before Sebastopol, Director of Transports in the Abyssinian War, Permanent Naval Secretary, 1882-84, Commander-in-Chief in Australia, Commanding the Naval Reserves, prominently skilful in the command of two Squadrons in our Autumn Manœuvres, he became Commander-in-Chief in the Mediterranean. The mournful story of his tragic death is known to all. An able officer, a skilful tactician, a vast store of practical knowledge has been lost to the profession and the country by his death.

I think without exaggeration it may be hoped that the great depression in trade, which has affected the shipbuilders as much as anyone, seems to be passing away. In Lloyd's Register

Shipbuilding Returns for December 31, 1893, which gives a fair and dispassionate review of the conditions of the ship-producing industries, I find that, omitting war-ships, there is a perceptible increase of the number of vessels under construction. 269 steam vessels, of 578,026 gross tons, were under construction on December 31, 1893, against 227 steam vessels, of 506,782 tons, on December 31, 1892. There is a slight falling off in the number of sailing ships—64 on December 31, 1893, against 79 on December 31, 1892; but the total shows 333 vessels, of 641,981 tons, in 1893, against 306 vessels, of 570,741 tons, in 1892, an increase of 27 vessels and 71,240 tons. Of these 333 vessels, 294 are building under the supervision of Lloyd's surveyors. During the last quarter, 107 steam vessels, of 212,182 tons, were commenced, and 12 sailing, of 21,729 tons; 101 steamers were launched, and 17 sailing vessels. Of the ships under construction, 207 steam vessels, of 470,061 tons, and 39 sailing vessels, of 48,134 tons, total 246, of 518,195 tons, are building for this country; and with an addition for our Colonies of 2 steam vessels, of 1,250 tons, 2 sailing, of 545 tons, total 4, of 1,795 tons, making 471,311 tons of steam vessels and 48,679 tons of sailing vessels for the British Empire. The total amount under construction is 269 steam vessels, of 578,026 tons; 64 sailing vessels, of 63,995 tons; or a total of 333, as stated above. This wave of industrial recovery has only as yet reached the Clyde, the Tyne, and the Wear, but we trust that other ports may soon share its benefits. Of this number 60,557 tons of steam vessels are building here for foreign countries, as well as 46,158 tons the nationality of which is not divulged, and it is interesting to see that these same countries which come to us to build are only building for themselves 90,370 tons of steam vessels; the great shipbuilding firm, Messrs. Cramp & Son, of Philadelphia, are building two large steamships for the Inman and International Line, of the same size as the *New York* and the *Paris*, and they are building, or about to build, two more, exceeding in dimensions and in horse-power the *Campania* and *Lucania*. All these it is intended to build under the supervision of Lloyd's Registry. Nor is this the only instance of the friendly rivalry of the United States of America. All of us must have admired the pluck of Lord Dunraven, who has endeavoured to bring away the America Cup from the best yachts of our cousins. All the skill in design of our colleague, Mr. George Lennox Watson, all the skill in building of the Messrs. Henderson, all the skill in seamanship of Lord Dunraven were in vain, and the *Vigilant* beat the *Valkyrie*, by a very small margin, it is true, but still by enough to save the Cup for America. I cannot attempt to discuss the merits of centre-board or no centre-board; but I say to this meeting we must look to our laurels, and see to it that success is not always on the other side of the Atlantic.

Last year H.M.S. *Howe*, having grounded at the entrance of Ferrol Harbour, was considered to be in peril of total loss. The Admiralty may be congratulated on her salvage, and on the fact that the *Howe* is now an efficient unit in the Mediterranean Squadron. The skill of the Swedish Salvage Company, who floated her, the perseverance and ability of Admiral E. Seymour and his officers, and the ready assistance of the Spanish authorities, have been becomingly acknowledged.

The Shipbuilding Programme of 1889 for the Navy is now practically complete. Of the seventy ships then projected, all but seven are completed, and those seven are of the smaller classes, and will be completed shortly. The great exertions of other nations to add to their navies has awakened a corresponding desire in this country not to be outnumbered by any probable combination. The Admiralty, by producing Return No. 465, has given us an accurate measure of the relations in which our numbers stand to those of some other European Powers. Our empire is so extensive that other navies than those mentioned have to be considered, if we desire to maintain our trade routes under all conditions free for the passage of our food supplies. I give here in a tabular form a list of the armour-clad battle-ships of the world, built and building :—

	ARMOUR-CLAD BATTLE-SHIPS.							Combinations of Two Powers.			
	Great Britain.	France.	Russia.	Germany.	Italy.	United States.	All but Great Britain.	France-Russia.	France-Germany.	France-Italy.	France-United States.
First Class	22	18	10	4	12	4	48	28	22	30	22
Second Class ...	12	13	8	7	4	—	32	21	20	17	13
Third Class... ...	11	6	—	11	5	2	24	6	17	11	8
Total	45	37	18	22	21	6	104	55	59	58	43
	In the Return No. 465 nine first-class cruisers may be classed as third-class battle-ships. I add them accordingly:—										
	9										
Giving	54	37	18	22	21	6	104	55	59	58	43

But, in addition to the countries named in Return 465, to which I have added the United States of America as also possessing first-class battle-ships, there must be considered other nations whose battleships of the third class are numerous, and some formidable. I need not remind you that, twice in recent years our flag in the Pacific was placed in jeopardy by being hoisted in an unarmoured frigate. On the first occasion the *Zealous* and on the second the *Triumph* were sent as flagships to the Pacific, but too late to enable the Commander-in-Chief on that station to carry out the orders of the Government, and to give protection to our trade in those seas. The battle-ships belonging to these countries are as follows:—Argentine, 1; Austria, 4; Brazil, 3; Chili, 3; China, 4; Denmark, 4; Greece, 5; Japan, 2; Netherlands, 7; Spain, 2; Turkey, 15; total, 50, making of sea-going battle-ships 154, against our 54, or 100 more than we have built or are building.

The following table shows the number of protected cruisers built and building for our own and other Governments:—

	ARMOURED CRUISERS.									Combinations of Two Powers.					
	Great Britain.	France.	Russia.	Germany.	Italy.	United States.	Austria.	Spain.	All but Great Britain.	France-Russia.	France-Germany.	France-Italy.	France-United States.	France-Austria.	France-Spain.
First Class ...	31	14	11	—	6	3	1	6	41	25	14	20	17	15	20
Second Class..	47	25	2	9	—	—	4	—	40	27	34	25	25	29	25
Third Class ...	51	31	3	19	—	—	7	—	60	34	50	31	31	38	31
Total ...	129	70	16	28	6	3	12	6	141	86	98	76	73	82	76
	9	{ Deducting the 9 from third-class battle-ship column.													
Giving ...	120	70	16	28	6	3	12	6	141	86	98	76	73	82	76

To make our survey complete here are the coast defence ships :—

Great Britain.	France.	Russia.	Germany.	Italy.	United States.	Spain.	Argentine.	Brazil.	Chili.	Denmark.	Netherlands.	Norway & Sweden.	Total.
16	{ 6+8 armoured gun-vessels = 14 }	15	13	4	19	1	3	3	1	4	16	12	105

It is necessary to take account of coast defence ships. For, if Great Britain is superior at sea, and establishes a blockade, coast defence ships must be counted upon as able to assist in breaking that blockade. It may be interesting to observe that the seaborne commerce of the world is carried in about 32,010 vessels, of 24,258,375 tons. Of these, the British Empire owns 11,859 vessels, of 12,788,282 tons; other nations, 20,151 vessels, of 11,470,093 tons. These other nations deem it right to have 154 battle-ships, 105 coast defenders, and 141 armoured cruisers, total 400, to protect their trade. The British Empire has 54 battle-ships, 16 coast defenders, and 120 armoured cruisers, total 190, for the protection of a much larger tonnage. Having rapidly glanced at the numbers and conditions of the navies of the world, I need not remind you of the spirit in which the nation has emphasised the necessity for an addition to the Navy, and the prospect of employment for all the various trades and professions connected with shipbuilding to be derived from that necessity. I know that this Institution, possessing so many persons skilled in naval construction, will be ready to co-operate with the able Naval Architects who serve the country at the Admiralty in devising means to make our new armour-clad ships superior, if possible, to those existing, in unsinkableness and in speed. It also affords some expectation that our magnificent private dockyards may find ample employment in the not distant future.

The papers on the Programme of Proceedings are of an interesting and instructive character. The first to be read to-day is by our colleague, Mr. White. No one has at his command such a fund of information on the subject of the behaviour of our battle-ships, and I trust that the discussion on his paper may be full and critical, so as to remove any doubts as to the efficiency and sea-going qualities of these powerful ships, which are so essential to the safety of our Empire. On Thursday Mr. Ellis will give us much information on recent improvements in armour plates; a subject which in the last thirty years has made such wonderful progress. At the evening meeting on Thursday our colleagues Mr. Thornycroft and Mr. Milton, and also Mr. Howden, will explain the merits of water-tube boilers, and their arrangements, which now occupy such a large share of public attention. Other papers of great interest will be read during this Session, and it is worthy of note, as illustrating the wide interest taken in our proceedings, that no less than four papers are contributed by foreign members of the Institution—M. Bertin, Captain Jaques, Mr. Otto Schlick, one of our Gold Medallists, and Mr. D. Croll. I must apologise to the meeting for having detained them so long, and I now move the adoption of the Report.

The Report was then carried unanimously.

PRESENTATION OF GOLD MEDALS TO MR. GEORGE H. CALVERT (MEMBER) AND HERR OTTO SCHLICK (MEMBER).

The CHAIRMAN: Gentlemen, I much regret the absence of Mr. Calvert. An accident, from which he is still suffering, unfortunately prevents him giving us his valuable assistance in the business of this Session, and I wish he were here in person to receive the highest reward which we are able to bestow, namely, the gold medal of the Institution. The Institution will remember that last year Mr. Calvert contributed a paper upon "Wake Currents," and gave us the results of his investigation. On that occasion Mr. Froude observed: "Whether we consider the unique character of the investigation, or the magnitude and cost of the undertaking, and the patience and perseverance which were required to carry out such a series of experiments to a successful issue, this paper is one which reflects very great credit on the contributor." Both Mr. White and Professor Biles confirmed this judgment, and Lord Brassey, our President, from this place, said: "For such work a man deserves a good reward, and I think he finds his reward in the grateful appreciation of his work which has been expressed by such competent authorities on Naval Architecture." A paper so valuable could not be passed over by the Council, and I am sure their decision will be approved when I present to Mr. Calvert a gold medal of this Institution.

I am further empowered by the Council to convey to Herr Otto Schlick (Member) a gold medal of this Institution, for his paper on "An Apparatus for Measuring and Registering the Vibration of Steamers." Herr Otto Schlick has since 1884 devoted much time, thought, and experiment to this most useful investigation. The investigations of Mr. White and Mr. Yarrow have fully confirmed Herr Otto Schlick's conclusions and suggestions, and Mr. White observed: "I think Mr. Schlick not merely deserves the credit of being the first to put into a theoretical shape the laws which affect the vibration of steam vessels, but also the credit of being still in the van as an observer and suggester of the direction in which further experiments should be made." I have much pleasure, therefore, in giving to the inventor of the Pallograph the gold medal which the Council conceive to be his due.

The CHAIRMAN then presented one of the gold medals to Herr Otto Schlick.

Herr OTTO SCHLICK: Mr. Chairman and Gentlemen, you have done me a very great honour in presenting to me the Gold Medal of the Institution of Naval Architects. Allow me to express to you my sincerest thanks for this high distinction, a distinction which is all the more of priceless value to me as it emanates from an Institution in which the greatest technical capacities of the world are incorporated. I trust my limited command of the English language will be accepted by you as an excuse for my giving expression to my feelings of gratitude in such a simple and unpretending way. I tender you again my best thanks. (Cheers.)

Result of the Ballot for the Election of Members and Associate Members of Council.

After the reading of Monsieur Bertin's paper on Wednesday, March 14, the Scrutineers appointed to examine the ballot papers for the election of the new Council presented the following report:—

Society of Arts, John-street, Adelphi, London, W.C.,
March 14, 1892.

The Right Hon. Sir John Dalrymple Hay, *Chairman.*

Sir John Hay,—Having examined the ballot papers for the election of Members and Associate Members of Council, we find that the following have been elected as Members of Council:—

James Dunn.
A. J. Durston.
R. H. Humphrys.
F. C. Marshall.
J. Rodger Thomson.
T. C. Read.

And the following gentlemen have been elected as Associate Members of Council:—

T. H. Ismay.
James Riley.

We are, dear Sir,

Your obedient Servants,

J. H. BILES,
M. McINTYRE,

(Scrutineers).

THE QUALITIES AND PERFORMANCES OF RECENT FIRST-CLASS BATTLE-SHIPS.

By W. H. White, Esq., C.B., LL.D., F.R.S., Assistant-Controller of the Navy, and Director of Naval Construction; Vice-President.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 14th, 1894; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

Five years ago I read before this Institution a paper "On the Designs for the New Battle-ships" which were then about to be laid down under the provisions of the Naval Defence Act. Considerable public interest was shown in that paper, and in the discussion which followed, as was natural under the circumstances. Eight ships were to be built exceeding in dimensions any vessels previously constructed for the Royal Navy, and there were differences of opinion respecting the features of offence and defence embodied in the designs, as well as the policy of building vessels of such large dimensions and cost.

It is not my intention in the present communication to revive past controversies. The ships have been built, five of them are already in commission, one has been on active service since May, 1892, and the remaining three will be ready for service this month, when the five years end which were contemplated in the Act of 1889. My wish is to place before the Institution certain facts of professional interest in relation to the qualities and performances of the completed ships, and incidentally to compare the intentions of the designs with results obtained in the finished ships.

Seven of the ships are of the barbette type, with high freeboard throughout the length, carrying their 67-ton guns about 23 ft. above water. The *Royal Sovereign* is the typical vessel in this group which will be most frequently mentioned, as she was first completed, and has been nearly two years in commission. Two others of the class were built in the dockyards, and four by private firms. The machinery for the three dockyard ships was supplied by one firm. For the contract-built ships the firms supplied machinery as well as ships. One design and specification served for the seven vessels so far as hull and fittings were concerned. For propelling machinery there were four designs, all practically governed by the same conditions for weight, space, and development of power on the contractors' trials.

The eighth ship (the *Hood*) is of the turret type, with moderate freeboard at the ends, over which the heavy guns deliver their fire. Those guns are about 17 ft. above water. In the remaining features the *Hood* resembles the barbette ships, and her machinery was supplied by the same firm which undertook the corresponding work for the other dockyard-built ships.

Without further preface I will pass on to a statement of facts in regard to the ships as completed.

(1) DRAUGHT AND TRIM.

The designed mean draught with all authorised weights, and 900 tons of coal on board, was 27 ft. 6 in.; the designed trim was 1 ft. by the stern. A "Board margin," or unappropriated weight, of about 500 tons was included in the load, to be carried at the designed draught. During construction various additions were made to the hull, equipment, and machinery, amounting in the aggregate to about 250 tons, the corresponding weight, with Board approval, being taken out of the margin.

When the *Royal Sovereign* was completed, a careful investigation was made, and it was found that at the designed mean draught she could carry 1,100 tons of coal, with all other authorised weights on board. In other words, the intentions of the design were fully realised, and 1,100 tons of coal could be carried, instead of 900 tons, on the specified draught. The ship in this condition was also to her designed trim.

Similar results have been obtained in the sister ships built in the dockyards. As might be anticipated, there are some differences in weight between the sister ships built in different yards, and engined by different firms, but in no case is there any departure worth mentioning from the intentions of the design as regards draught and trim.

This is very satisfactory, having regard to the great sizes of the ships, and their many novel features. In the completed ships, certain additions have been made to the complements and consumable stores, as originally proposed. For example, the coal supply at normal draught was first fixed at 900 tons, with a bunker capacity of about 1,100 tons. The "wing spaces" abreast the bunkers proper were so constructed that they could be used as "reserve bunkers" if occasion arose, but it was not then contemplated to fill these spaces ordinarily. After experience in the *Royal Sovereign*, it has been decided to carry the full weight of coal when leaving port, so that about 1,450 tons of coal are available. Of course, the draught at starting is correspondingly increased.

Another alteration in practice subsequent to the design is the introduction of "reserves of feed-water" for the boilers. Certain compartments in the double bottom have been utilised for the purpose, and from 130 tons to 160 tons of fresh water are carried at starting. In addition, the vessels have powerful evaporating plant.

For each additional inch immersion in these ships at load draught, the increased displacement is about 55 tons, so that the extra coal and fresh water involves about 1 ft.

increase in draught. With their considerable freeboard and reserve of buoyancy, this is of no importance, and in their fully laden condition, with bunkers full, the defensive powers are greatly increased.

(2) STABILITY: METACENTRIC HEIGHT.

The determination of appropriate conditions of stability for these large ships was a matter of the most anxious consideration during the preparation of the designs.

One had to deal with circumstances in many ways unprecedented, particularly in regard to the loads of armour and armament, and the heights of the heavy guns and their protecting barbettes. It was recognised that these weights and their distribution would give the ships unusually large "moments of inertia," thus tending to long periods of oscillation, even if a good "metacentric height" was provided.

In regard to the metacentric height, it had to be kept in view that provision must be made, not merely for possible variations in stiffness occurring on service, and for sufficient "stiffness" when rapidly manœuvring, but for reductions in stiffness arising from damage in action. Here entered the consideration of the system of hull armour adopted, which gave a much greater *protected area* on the broadside—including the water-line belt and the lightly armoured citadel standing on the belt-deck—than had been possessed by many preceding classes in the Royal Navy, or was proposed for the most recent battle-ships in some foreign fleets.

An unduly large metacentric height was undesirable, of course, tending to lessen the period of oscillation, and to produce unsteadiness of platform under ordinary conditions at sea. A small metacentric height, while it would have lengthened the period and conduced to steadiness, might have involved a lack of stiffness for rapid manœuvring of the ships, or for training their heavy guns on one broadside. If reduction in metacentric height had been carried too far, there would have been an undue reduction in the margin for possible damage in action. In existing ships examples are to be found of the evils attaching to either of these extremes in metacentric heights.

Moreover, I had to deal with an "unappropriated weight" of over 500 tons, and it was quite uncertain in what vertical position this might finally be placed, but judging by past experience the probability was it would be added in *upper weights* of additional armour or armament, boats and equipment.

Finally, I decided to aim at a metacentric height of about 3½ ft. for the barbette ships, when in normal load condition, at the mean draught of 27½ ft. with 900 tons of coal on board. Past experience had shown that in ships of much less size and inertia, an excellent combination of stiffness and steadiness had been obtained by the adoption of metacentric heights varying from 2¾ ft. to 3½ ft. In the new ships, having regard to their greater size and inertia, it was obvious that with a metacentric height of 3½ ft., the period of oscillation should be at least as great as, and would possibly exceed, the corresponding periods for their predecessors whose reputation for steadiness was so great. The *Hercules*, *Sultan*, *Inconstant*, *Monarch*, and *Invincible* were amongst the vessels considered, as well as some foreign ships with equal reputations for steadiness at sea.

The loads of consumable stores in the new ships were so considerable that special care was necessary in disposing them, so that the variations in trim and stiffness produced by the consumption of these stores might be minimised. The range of draught between the deep-load condition, and the ordinary light condition, is 3 ft., corresponding to a change of nearly 2,000 tons in displacement. By suitable arrangements it was made possible for the ships to pass from the normal condition to the extreme light condition, with practically no change in metacentric height.

When the full weight of coal (1,450 tons) is carried, since the reserve wing bunkers are low down, the metacentric height is increased to about 3¾ ft. The addition of the reserve feed in the lower compartments of the double-bottom (made, as explained above, subsequently to the date of the design), involves a further increase in stiffness, bringing the metacentric height up to 4 ft., when wing bunkers, as well as ordinary bunkers, are full. This maximum stiffness may be decreased, of course, as coal and fresh water are consumed. It is interesting to add that it equals the metacentric height of the *Minotaur* class, which have good reputations for behaviour at sea, and are of much less inertia.

The practical constancy in stiffness obtained in the *Royal Sovereign* class, apart from reserve bunkers and feed-water, is in marked contrast to what was formerly common in armoured ships where the coal was carried low down. For example, in the *Hercules* the metacentric height varied from 1·9 ft., when light, to 2·7 ft., when fully laden, and in the *Devastation* the corresponding variation was from 2·5 ft. to 3·7 ft.

Inclining experiments were made on the *Royal Sovereign* and the *Ramillies* (contract built) to check the design calculations. In the *Royal Sovereign* the actual position of the centre of gravity was found to be ·15 ft. (1¾ in.) below the calculated position. In the *Ramillies*, owing to heavier machinery, it was about 4 in. below the calculated position. This close agreement between estimated and actual position was most satisfactory, and it was decided to be unnecessary to incline any more of the barbette ships. The turret ship *Hood* was also inclined with satisfactory results.

Members of the Institution will understand that the satisfactory solution of this problem was not an easy matter. On all sides there were limiting conditions. The features of armour, armament, freeboard, and height of guns decided upon for the class, practically regulated the distribution of the principal weights in a vertical sense, and governed the vertical position of the centre of gravity. The dimensions and forms of existing docks had to be considered: beam and draught could not be permitted to exceed certain maximum values. For manœuvring purposes the length had to be kept within reasonable limits. Stability had to be secured in association with a form adapted for high speed. This, I am happy to say, has been accomplished.

Some critics of war-ship designs entirely fail to recognise the part which stability plays in the selection of forms and proportions. They do not appreciate the radically different vertical distribution of weights in war-ships as compared with merchant ships. Consequently they suggest the adoption of cross sectional forms and proportions of beam to draught and depth which would utterly fail to provide sufficient stiffness in war-ships. Should effect ever be given to their views in actual ships, the result would be disastrous. There is, however, no risk in that direction, for closer scrutiny and exact calculation would disclose the danger.

There is usually behind these suggestions some idea of possible advantage to be gained in a particular direction. For example, a favourite view is that a flatter floor, sharper bilge, and nearly vertical side above the bilge, would give greater displacement, in proportion to wetted surface, than the rounder bilge usual in war-ships. This is quite true. Further, I have seen it stated that the alternative form would increase resistance to rolling, and give greater steadiness than the actual sectional form of our battle-ships. This is a matter of opinion. I will not enter upon its discussion now, but will only remark that, in my judgment, an altogether exaggerated value is attached in some quarters to the influence of sectional form in the central portions of the length upon rolling. One of the roundest forms of midship section ever adopted is that of the *Sultan*, and she has proved herself one of the steadiest ships afloat. Moreover, ease of rolling motion is a matter that must not be ignored, and in that respect the rounder form has distinct advantages. What is most important to note, however, is that such changes in cross sectional form lower the metacentre and diminish stability.

For purposes of information only, Fig. 1, Plate XXXI., has been drawn, showing the comparative forms of midship section in the *Royal Sovereign*, a large ocean steamer of high speed, and the *Sultan*.

(3) CURVES OF STATICAL STABILITY.

In Fig. 2, Plate XXXII., are given the curves of stability for the *Royal Sovereign* in various conditions. They are of an entirely satisfactory character. The maximum righting moment occurs at an inclination to the vertical of 37 degs.; the maximum value of the arm of the righting couple is $2\frac{1}{3}$ ft., and the range of stability is over 60 degs.

Apart from the heave and impulse of the sea, the only inclining forces to which these ships, which have no sails, can be subjected are those when the vessels are turning rapidly and those arising from wind pressure. Neither are of any practical importance. Turning trials show the ships to heel very little. If a wind having a velocity of seventy-five miles an hour acted directly on the whole broadside, the angle of steady heel would not exceed 4 degs., and would probably be less.

Figs. 3 and 4, Plate XXXII., contain curves of stability for two typical ships which have had long and successful experience at sea. These afford an interesting comparison with Fig. 2.

Fig. 3 shows the curves for the *Monarch* as she has hitherto served, with good sail power supplementing steam. It is interesting to note the diminution of stability in the light condition. Her sail equipment, of course, involved much more serious demands upon her stability than would have been made had sails been absent. But that matter was so fully discussed for the *Monarch* after the loss of the *Captain* that further remarks are unnecessary.

Fig. 4 shows the corresponding curves for the *Devastation* class of the Royal Navy. These vessels have no sails. Here the moderate freeboard, when fully laden, tends to lessened stability. As the ship lightens, although there is a loss of metacentric height, the gain in freeboard nearly counterbalances it.

Fig. 5, Plate XXXIII., has been constructed for the load conditions of the *Royal Sovereign*, *Monarch*, and *Devastation*, the ordinates representing righting moments (not arms of righting couples). Here the greater weight of the *Royal Sovereign* tells as compared with the other two ships.

Fig. 6, Plate XXXIII., has been constructed for the light conditions of the three ships, also to show righting moments.

As against external forces, such as wind pressure, Figs. 5 and 6 are useful means of comparison. Under wave impulse Figs. 2—4 are to be preferred.

(4) PERIOD OF OSCILLATION.

No rolling experiments in still water have yet been made on the *Royal Sovereign* class. From observations at sea, however, it appears that the period for a complete oscillation (double swing) is from 15 to 16 seconds. The time for a single swing—port to starboard, or *vice versâ*—is 7½ to 8 seconds. Variations in stiffness due to alterations in lading, of course, affect the period; but with normal weights, and 3½ ft. metacentric height, the period of oscillation is about 8 seconds. As above stated, this result was anticipated at the time the designs were prepared, and it brings the *Royal Sovereign* class, so far as period is concerned, into practical agreement with a number of ships which have great reputations for steadiness. Most of these ships have smaller metacentric heights than the *Royal Sovereign*, but they are also inferior in weight and moment of inertia.

Some persons, in discussing the behaviour of the *Royal Sovereign* class, have dwelt upon their relatively large metacentric heights, but failed to remark their great moments of inertia. Both are counted into the period of oscillation, and that is the best standard of comparison. The reasons for the selection of the metacentric height actually possessed by the *Royal Sovereign* class have been stated above.

(5) BILGE KEELS.

In this connection reference may be made to the reasons which led to the decision not to fit bilge keels to the *Royal Sovereign* class during construction. No one has more strenuously urged the utility of bilge keels than myself. But while it is undoubted that they can never do harm, and in many cases may do great good in limiting rolling, their influence varies under different circumstances. In small ships of quick period, and in ships of moderate weight and moment of inertia, they are likely to prove most beneficial. In slow-moving ships of great inertia the influence of bilge keels must clearly be less felt, and may be very small. That influence depends upon the area of the keels, their radial distance from the axis of rotation, and their rate of motion through the water, which rate is governed by the arc of oscillation and the period of the oscillation. Since, within considerable limits of oscillation, ships are practically isochronous in their motions, the mean rate of motion of bilge keels through the water varies with the arc of oscillation. In other words, fluid resistance to the motion of the bilge keels has a small value and moment about the axis of rotation in a slow-moving ship until considerable angles of oscillation are reached.

Moreover, with a given moment about the axis of rotation of fluid resistance to the motion of bilge keels, the check put upon the rolling of a ship to which they are attached depends upon the weight, the stiffness, and the moment of inertia of the ship. It may happen, therefore, in large slow-moving ships that the influence of the largest practicable bilge keels will be scarcely felt until considerable angles of rolling are reached.

This appeared to be the case in the *Royal Sovereign* class, and it was, therefore, decided not to fit bilge keels at the outset, until experience had been gained at sea with the ships. In thus deciding, the fact was kept in view that two vessels of exceptional steadiness, the *Hercules* and the *Sultan*, were practically without bilge keels, the side keels being very shallow in depth. Moreover, it was obvious that if bilge keels could be omitted it would greatly facilitate docking the ships.

As an experiment bilge keels have now been fitted to the *Repulse*, and she will be tried in company with other ships of the class. Provided that these trials are made under the same conditions of lading in all the ships, the results will be very valuable. Should the keels prove sensibly advantageous, they can easily be added to the sister ships.

It is unnecessary to repeat what has been said above with reference to the supposed influence of cross-sectional forms upon resistance to rolling. The analysis of a large number of rolling experiments on ships of very different cross-sectional form has shown that the portion of the resistance contributed by the midship parts of the length is small when compared with those portions of the resistance due to the deadwoods and flat surfaces, while surface disturbance greatly exceeds both of these factors.

One remark may be added. In recent years the battle-ships of the Royal Navy have, for the most part, been constructed with low ends. Hence moderate angles of rolling immerse the edges of the low decks, and greatly increase resistance to rolling. There can be no question but that this deck resistance is a valuable feature in limiting oscillation under many circumstances.

In high-freeboard vessels of the *Royal Sovereign* class there is no corresponding element of resistance to rolling. On the other hand, the high freeboard and great height of guns increases fighting efficiency, the power of maintaining speed in rough water, and comfort to all on board. Under circumstances when the low-freeboard ships have to be battened down, or when they can fight their guns with difficulty, the high-freeboard ships suffer from no similar drawbacks.

(6) Behaviour at Sea.

Experience at sea with the new battle-ships has been very limited, except in the case of the *Royal Sovereign*, which was commissioned in May, 1892, as flag-ship of the Channel Squadron. The sister ships, *Empress of India* and *Resolution*, were commissioned for service with that squadron in September and December last. The turret ship *Hood* joined the Mediterranean Fleet in June, 1893, and the *Ramillies* became the flag-ship on that station in October; but except on the passage out these ships have not had experience in the Atlantic. It is to the *Royal Sovereign*, therefore, that one must turn for information as to behaviour over any considerable period. Apart from long-continued experience under various conditions of wind and sea, no fair appreciation is possible of the true qualities of any ship or class. I propose, therefore, to briefly summarise the facts for the *Royal Sovereign*, and subsequently to deal with the case of the *Resolution*, which was so much before the public in January last.

It will be convenient here to recapitulate the broad conclusions in regard to the rolling of ships, which have been established by theoretical investigation, and confirmed by experiment and observation during the thirty-four years that have elapsed since the late Mr. W. Froude brought his new theory before this Institution.

First: The behaviour of a ship depends chiefly upon the ratio of her period of oscillation to the apparent period of the waves which produce rolling.

Second: The slope of the waves, their ratio of height to length, is an important factor in the rate of accumulation of rolling and its maximum amplitude.

Third: The resistance offered by water to the rolling motions of ships is most influential in limiting rolling, and any means available for increasing that resistance and the "rate of extinction" of rolling must be beneficial.

Fourth: For any ship the condition tending to produce the heaviest rolling is that when the waves pass her at a rate which synchronises with her natural period of oscillation in still water. Apart from the action of resistance, the successive impulses of a regular series of synchronising waves would increase the amplitude of the oscillations so rapidly that any ship must be capsized in a very short time.

Fifth: Every ship, no matter what her size and period of oscillation, is liable to this condition of synchronism. It may occur with a beam sea of period identical with her own, or it may result from the course and speed being such as to produce synchronism with waves of dissimilar period. In fact, allowing for the infinitely varied conditions of sea necessarily encountered, no ship can altogether escape from heavy rolling.

Sixth: Experience has confirmed the deduction from mathematical investigation that ships which are slowest in their still-water oscillations, as a rule, are steadiest at sea.

Seventh: For slow-moving ships, of long still-water periods, the condition of synchronism is sometimes reached in a long and very low swell, with practically no wind. This swell results from waves which have travelled long distances, from the storm region in which they were formed, and in transit have been greatly degraded in height, while retaining considerable length and period.

Eighth: When rolling is set up in ships by the passage of waves, it may be anticipated that the heavier ships, with greater moments of inertia, will accumulate the largest angles of oscillation.

This is readily understood, apart from mathematical demonstration. Each wave as it passes tends to increase the oscillation, and the increment is dependent upon the wave-slope, while it is little influenced by the size or weight of the ship, if the waves are of great length in proportion to the dimension of the ship (usually her breadth) presented to the wave advance. On the other hand, the effect of water-resistance in limiting oscillation depends, as previously explained, upon the relation of its moment about the axis of rotation to the righting moment and moment of inertia of the ship. That is to say, the moment of the water-resistance becomes relatively less as the weights and inertia of ships increase, and consequently in two ships of identical period exposed to the same waves (say, synchronising in period, or nearly so) the larger ship of greater inertia will reach larger angles of oscillation.

Bearing in mind these conclusions from long experience, we may pass to the summary of facts respecting the actual behaviour at sea of the *Royal Sovereign*.

During the first eight months the ship was on service there was no report in regard to her rolling, and the only statement in regard to her behaviour was to the effect that off the coast of Ireland, in the Atlantic swell, she had compared very favourably with vessels of the *Admiral* class.

In January, 1893, during a passage from Plymouth to Vigo, the ship encountered a long, low swell, which set her rolling; and in the cruise which followed, to Madeira and back, very similar conditions prevailed. The striking feature in this case, which naturally attracted great attention, was that so large a ship should be set rolling by what would ordinarily be treated as a smooth sea, when smaller ships of less period were practically unaffected. Careful observations were made of the character of the swell which produced these results. It was found that with lengths varying from 450 ft. to 700 ft. were associated heights varying from 6 ft. to 12 ft., and it became obvious that these waves were so related in period to the period of the *Royal Sovereign* that rolling necessarily resulted, while ships of less period remained steady. This was no new phenomenon, as I will explain hereafter.

The actual angles of rolling on this occasion were not considerable, as the following summary of observations will show:—

INCLINATIONS ON EACH SIDE OF THE VERTICAL.

	Mean. Degs.	Maximum. Degs.
January 18, 1893	4·6	9
„ 19, „	8·5	13·5
„ 20, „	2	4·5
February 11, „	8·5	16
„ 12, „	7	11

It will be understood, of course, that the maximum angles of inclination only occurred at intervals, the rolling passing through "phases"; mean inclinations are the fairer measures of average behaviour.

After this cruise under the conditions described no further reports of rolling were received until the end of December, 1893. The squadron was then proceeding from Gibraltar to Arosa Bay, and encountered a heavy swell, in perfectly fine weather with an otherwise smooth sea. The apparent period of the waves was found to vary from 13 secs. to 15 secs; the period of oscillation of the *Royal Sovereign* class (double-swing) being 15 secs. to 16 secs. The lengths were estimated at 650 ft. to 960 ft., and the heights at 10 ft. to 15 ft. In this case, therefore, there was a close approach to synchronism in the periods of the waves and the big ships, the *Empress of India* being in company; while the quicker-moving ships were more advantageously situated. In the following table are given a set of simultaneous observations for the ships of the squadron:—

INCLINATIONS ON EACH SIDE OF THE VERTICAL.

	Mean. Degs.	Maximum Degs.
Royal Sovereign	7	11·5
Empress of India	5·9	10·5
Immortalité	2·8	5
Narcissus	3	7
Bellona	6·2	13·2

The *Rodney* was in company, but did not take simultaneous observations on the occasion described in the table.

Taking all the observations made at various times during this day, and disregarding changes which may have occurred in the course and speeds of the ships, or changes in the state of the sea, the following summary represents the facts:—

MEAN INCLINATION ON EACH SIDE OF THE VERTICAL.

	Degs.
Royal Sovereign	6·8
Empress of India	9·4
Immortalité	3
Narcissus	3·3
Rodney	5·8
Bellona	6·1

In order to illustrate the general character of the motion of the large ships, the gradual increase in amplitude, attainment of a maximum inclination, and subsequent gradual decrease, Plate XXXVIII. has been prepared from a series of actual observations.

One feature in the accumulation of rolling under the trying conditions of synchronism is the apparent *suddenness* with which comparatively large angles of inclination may be accumulated. Here, again, theoretical investigation anticipates observation. Apart from the action of resistance, the passage of each synchronising wave should add an angle equal to about three times its maximum slope to the range of oscillation. In the long, low swell which synchronised with the *Royal Sovereign* class, the maximum slope was about 3 degs. only, corresponding to an increment in range, apart from resistance, of more than 9 degs. for each wave, apart from resistance. There would be four waves passing in a minute; and it is easy to understand, therefore, in how short a time considerable angles of rolling may be reached, especially in a slow-moving ship, where resistance acquires no great moment until there is a good swing.

When the *Royal Sovereign* and *Empress of India* were placed beam on to the swell, and a series of nearly regular waves of synchronising periods passed the ships, much larger inclinations were reached at times than are shown in the foregoing Tables. The maximum inclinations recorded under these very trying conditions were about 25 degs.

to 30 degs., which is undoubtedly heavy rolling, and has naturally been made the subject of adverse remarks.

It may be well to explain, therefore, that this kind of behaviour has been experienced long ago, under very similar circumstances, in vessels having unsurpassed reputations for average steadiness, and about the same periods of oscillation as the *Royal Sovereign* class. In this connection I will venture to quote a passage from my "Naval Architecture," published nearly twenty years ago.

"No feature in the behaviour of ships is better established than that heavy rolling results from equality, or approximate equality, of the period of the ship and the period of waves, even when the waves are very long in proportion to their height. Many facts might be cited in support of this statement, but a few must suffice. . . . Vessels of the *Prince Consort* class were made to roll very heavily by an almost imperceptible swell, the period of which just synchronised with that of the ships [for a double roll]. On one occasion the *Achilles*, a vessel having a great reputation for steadiness, rolled more heavily off Portland in a dead calm than she did off the coast of Ireland in very heavy weather. Mr. Froude reports a very similar circumstance as having occurred [in the Channel] during trials with the *Active*. And, lastly, during the cruise of the Combined Squadrons in 1871, when the *Monarch* far surpassed most of the ships present in steadiness in heavy weather, there was one occasion when, doubtless through the action of approximately synchronising periods, she rolled more heavily in a long swell than did the notoriously heavy rollers of the *Prince Consort* class."

The *Hercules*, as a rigged ship, was remarkable for average steadiness of platform. Yet on some occasions, in a swell very similar to that which set the *Royal Sovereign* class in motion, she rolled to angles of 25 degs. and 30 degs. on each side of the vertical. Similar experience has been obtained with the *Inconstant* and other vessels.

These instances are not quoted for the purpose of diminishing in the least degree the important influence upon fighting efficiency of steadiness of platform in war-ships. It is not a possibility, however, to secure absolute steadiness under all conditions of sea, for the reasons given above. The designer, therefore, must fall back on experience, and endeavour to secure *average* steadiness. His aim is to give to a new design about the same period of oscillation as was possessed by ships of proved good behaviour. In the design of the *Royal Sovereign* class, as already explained, it was intended to approximate to the period of ships like the *Hercules* and *Monarch*. This has been accomplished, and it is important to note that in the ships as they now go to sea, by additions of coal and feed-water, the stiffness has been increased, and period correspondingly quickened. With the weights on board originally contemplated as "normal," the period would be about 7 per cent. greater than in the deep-laden ships. As they now have periods of about 15 secs. when deeply laden, this would mean an increase of about one second in the time for a double swing.

This may be thought a refinement by some persons, but it is by no means the case that such differences in period do not affect behaviour. In fact, observations made in the *Royal Sovereign* class, with varying conditions of stowage of coal and feed-water, show such changes in stiffness and period to have quite appreciable effects.

Small changes in course and speed relatively to synchronising waves also produce marked results on rolling. As an illustration, I may take a recent observation made by the *Royal Sovereign*. With swell abeam, the mean inclination to the vertical was about 9 degs., and maximum (occasionally reached) 18 degs. With the swell two points before the beam, the mean inclination was about 5½ degs., and the maximum 10½ degs. With swell four points before the beam, the mean inclination was about 4 degs., and maximum 9½ degs.

Further reports on observations of rolling were made after the passage of the Channel Squadron from Vigo to Madeira in January last. There is no new feature requiring detailed notice. Throughout there was a long, low swell, or a confused sea. On the whole the *Royal Sovereign* class rolled less than in the December cruise, the wave-periods not approaching so closely to synchronism. An analysis of the figures shows that the mean inclinations to the vertical averaged about 6 degs. for the class. Inclinations exceeding 15 degs. are not reported for the *Empress of India* during the period of observations, and are only twice mentioned for the *Royal Sovereign*, and three times for the *Resolution*. On one occasion the *Resolution* reached an inclination of about 31 degs.; and the *Royal Sovereign* on one occasion reached 21 degs. These were altogether exceptional rolls, and must have resulted from some special condition of the sea at the time, although no details appear in the reports.

All the reports on the class speak of the rolling motion of the ships as remarkably easy, free from jerks, and with quick recovery from extreme inclinations. This was anticipated from their form, period of oscillation, and conditions of stability.

Summing up the facts, so far as they are in my possession, it appears that during the period of her service, now approaching two years, the *Royal Sovereign* has, on the whole, proved herself steady and well-behaved at sea. The heaviest rolling of the class has occurred under the conditions of a long, low swell synchronising, or approximately synchronising, with their period of oscillation. In this respect the class resembles the *Hercules*, *Monarch*, and other ships of remarkable average steadiness and about equal period. Under such circumstances, the great inertia of the *Royal Sovereign* class, inevitable with their offensive and defensive arrangements, occasionally tends to produce considerable angles of inclination. A very moderate change of course produces considerable reduction in rolling.

Unsteadiness of platform under these conditions is clearly a drawback. There is no question of danger arising, however, as is explained hereafter. The edge of upper deck has been only just awash when the rolling has been heaviest in a long swell. Experiments are about to be made with bilge keels in one of the vessels, in order to determine whether the increase in resistance thus obtained will sensibly diminish rolling.

All past experience shows that ships having periods of 15 secs. to 16 secs. for a double swing are, as a rule, exceptionally steady at sea. The *Royal Sovereign* class have about that period, and there is nothing whatever in their under-water form or stability to make their behaviour differ from that of their equally slow-moving predecessors. Their greater inertia is the new and inevitable condition of the designs. Further experience is required to determine the relative steadiness of the class under average conditions of sea.

In concluding this section, I desire to place on record our great indebtedness to the naval officers serving in the *Royal Sovereign* class for the valuable observations they have made and recorded. Captain Hammill, of the *Royal Sovereign*, deserves special thanks for the information he has afforded, as well as for many valuable suggestions. Having to go beyond precedent necessarily involves new conditions. Whatever care or skill may have been bestowed on a design, nothing but actual experience can show whether or no it is successful. Much as we have learnt respecting the behaviour of ships, there are still many obscure points, and in elucidating these naval architects must depend upon naval officers for facts as to the conditions of sea and the performances of ships.

(7) BEHAVIOUR OF THE "RESOLUTION" IN DECEMBER, 1893.

The case of the *Resolution* is quite distinct from that of the other ships of the class, and it has been so prominently before the public that I propose to state the facts briefly. It will be understood that a full discussion of the incident is not intended, nor indeed is it possible, for one holding my official position to attempt it, for reasons that will be obvious.

The *Resolution*, a newly commissioned ship, left Plymouth at 2 p.m. on December 18th last to join the Channel Squadron at Gibraltar. On December 23rd, at 9 a.m., she arrived at Queenstown.

According to the newspaper accounts, the ship had been seriously strained in structure by heavy rolling, reaching to angles of 30 degs. or 40 degs. from the vertical. Dangerous leaks had been developed, and she could only be kept afloat by continued pumping. Considerable repairs were said to be required, and it was alleged that she was in such a state that she could hardly proceed without risk as far as Plymouth or Portsmouth before being taken in hand. Graphic accounts followed of the terrible weather which had been encountered, of the unsatisfactory behaviour of the ship, the great discomforts suffered by all on board, and the immense quantities of water which were said to have passed down into engine-rooms and stokeholds. In short, the impression was produced, and possibly still remains in many minds, that the *Resolution* had a narrow escape from disaster, and her behaviour was considered the more unsatisfactory seeing that the torpedo gunboat *Gleaner*, which was in her company, had proceeded to her destination, while the big ship put back.

Now for the facts. It has been stated by the representative of the Admiralty in the House of Commons that the captain of the *Resolution*, in the exercise of his undoubted discretion, put back to Queenstown because he considered it the wiser course, having regard to the possible continuance of bad weather, and the quantity of coal remaining on board.

The ship proceeded to Devonport, and a careful survey was made by the officers of Devonport Dockyard, who had nothing whatever to do with the construction or fitting out of the *Resolution*. This survey established the entire absence of any working or weakness in her structure. Various fittings on or above the upper deck and outside the ship were damaged or washed away by the sea. The bridges, which are merely light superstructures at a considerable height above the shelter deck, showed some small signs of movement, but nothing of any importance. There were no serious leaks anywhere. One or two places were found where small fittings had been attached to the sides, and the rivets were not absolutely watertight. A few local defects in deck planks had permitted trivial leaks to occur here and there. Some small leakage also occurred at gun ports, deck pipes, and other openings provided with covers that had been thoroughly tested during construction, but were apparently not so well secured as they might have been when the storm was encountered. In dealing with such fittings, experience counts for much, and a newly commissioned ship is always at a disadvantage. Other fittings which were in place need not have been there under the circumstances, arrangements having been made for stowing them in safe positions at sea, or when bad weather was anticipated. The covers to the forward barbette gun-wells were washed away by the sea, not because they were not strong enough, but because they were not properly secured; and this circumstance led to the entry of water through the barbette.

The best possible evidence, to those conversant in such matters, of the trivial and unimportant character of the defects arising from this experience of the *Resolution* is found in the fact that, they were all made good—including repairs to damaged fittings and renewals of fittings lost—for the sum of £440.

There is no evidence that large quantities of water, much less dangerous quantities, passed into the interior. Before the hatches were battened down amidships a sea broke on board, and some water found its way down to the main deck and into the engine-room, but this did not recur after the battening down. Discomfort there was, no doubt, during the three days the ship was battling with the storm; but that is a common experience, and not peculiar to war-ships. It has come to my knowledge that two large passenger steamers which were crossing the Bay about the same time had a very similar experience, but they continued their voyages, and I have not seen any comments in the Press in regard to their behaviour. The storm was undoubtedly severe, and the sea was exceptionally high and steep for a considerable time.

After passing Ushant early on the morning of the 19th, the *Resolution* had a swell on the beam, which caused her to roll considerably. The wind, which was south at starting, veered during that morning to west, and then to north-west. She was kept on her course for seven or eight hours, until about 7 p.m. Two exceptionally heavy rolls then occurred, and the sea broke over the upper deck amidships. The hatches were not battened down at the time, and water passed through them on to the main deck and into the engine-room, as above described. After this happened the ship was brought head to sea, gear secured, and battening down completed. She then resumed her course; but, as she again began to roll considerably, she was once more brought head to sea and there kept steaming slowly. This happened about 9 p.m. on December 19th.

The swell increased and the wind freshened during the night. By 8 a.m. on December 20th it was a whole gale, with tremendous squalls. Measurements of the waves were made that day with all the care possible under the circumstances. Accurate measurement, especially of length, was hardly possible. The wave heights were obtained by horizon observations, and are probably more nearly correct. Heights of 42 ft. were observed from hollow to crest, and lengths of 300 ft. from crest to crest. The exceptional steepness of these waves will appear from the fact that extensive observations have fixed the average height of large Atlantic storm waves at one-twentieth of the length, so that waves 42 ft. high would be over 800 ft. long. Similar observations give 15 ft. as the average height for waves 300 ft. long. No doubt in this instance, as in many others where the wind has veered during a long-continued storm, there were independent series of waves running in different directions and superposed on one another, which would account for the height and steepness of the waves observed.

The ship was kept head to sea until 4 p.m. on December 21st, when the swell had begun to drop somewhat, but was still from the north-west. Measurements of waves that morning showed heights of 26 ft. to 30 ft., and lengths estimated at 280 ft.—still a very steep and heavy swell. A northerly course was then shaped; and, as the swell decreased gradually during the night, on the morning of the 22nd the ship proceeded to Queenstown. On arrival she had over 450 tons of coal on board, having left Plymouth with about 790 tons.

There are two stages to be considered in this narrative. First, that during which the ship was exposed for some hours to a swell abeam, described as moderate, but said to produce occasional heavy rolling. This resembles the case above discussed for the *Royal Sovereign* class; and in his report the captain of the *Resolution* expressed the opinion that the cause of rolling was approximate synchronism between the period of the ship and that of the waves.

The second stage is that where the ship was kept head to the sea. Her behaviour under these circumstances is reported to have been most satisfactory. She was very buoyant, rode well over the very heavy sea, and pitched easily. At times she rolled considerably, which is not remarkable when the state of the sea and its confused character are taken into account.

It is reported also that under these conditions the oscillations were quite different from those which occurred when the swell was abeam. In the latter case the rolling gradually increased, reached a maximum, and then gradually diminished—completing a "phase," in fact, like that represented in Plate XXXVIII. Head to sea the ship is stated to have "lurched" at once, or nearly so, to her maximum inclination, and then to have gradually lessened her swing in succeeding oscillations. This is what would be anticipated from the position she occupied in relation to the short steep sea, and the pitching and 'scending motions impressed upon her. Under these circumstances there would necessarily be great variations in the distribution of the buoyancy as compared with still water, and considerable temporary reductions in transverse stability, which would account for the occasional heavy lurching. Moreover, there must have been very severe longitudinal bending moments on the structure, and it is most satisfactory to find that there was no indication whatever of working or weakness.

Another fact of great importance must be stated. There is no trustworthy evidence of the angles through which the *Resolution* rolled on this occasion. The only observations recorded were made with a short, quick-moving pendulum placed in the chart-house, at a height of 35 ft. to 40 ft. above water. I need not dwell upon the possible errors of pendulums so placed in a ship rolling among waves. Cases are on record where the indications of pendulums, similarly placed in ships of about the same period, have been *twice the true angles* of oscillation, observed simultaneously by trustworthy methods. In fact, no experienced naval officer trusts pendulum observations, spirit levels, or gravitational instruments of any kind for use at sea.

One cannot fix precisely what was the actual error of the pendulum in the *Resolution.* But it is certain that its movements placed at such a height must have grossly exaggerated the rolling of the ship. When angles of inclination of 30 degs. or 40 degs. are said to have been indicated by, or estimated from, the movements of the pendulum, the actual angles must have been much less, and may have been only half what was shown on the scale.

It is important to note also that, even had these great angles of inclination been reached, there would have been no reason for apprehension of danger to the ship. The curves of stability (Fig. 2, Plate XXXII.) show that the maximum righting moment occurs at an inclination to the vertical of 37 degs., and that instability is not reached until the inclination exceeds 60 degs. There is a popular impression, no doubt, although an absolutely erroneous one, that if a ship is inclined past her angle of maximum stability, she will capsize. To this Institution I need not explain that even in a ship with large sail power, and exposed to squalls of wind, there may be no danger in angles of inclination much exceeding that at which the righting moment reaches its maximum. But when, as in the case of the *Resolution*, there are no sails, and the inclining force of the wind on the broadside is relatively so small, there is a much greater margin of safety.

In Plate XXXIV. a cross section of the *Resolution* is given for an inclination, in still water, of 40 degs. to the vertical. At this inclination the righting moment, for all practical purposes, may be considered as maintaining its maximum, and has a value of more than 30,000 foot tons. This is the greatest angle of roll which, by pendulum or estimate, has been attributed to the *Resolution*. For the reasons just stated it is practically certain it was never approached. Had it been approached the upper deck must have been invaded by the sea to a much greater extent than actually happened.

Among waves, the *rise of the sea*, as well as the rolling of the ship, necessarily influences the amount of water which comes on to the deck. This fundamental truth is often overlooked, and in some discussions on the *Resolution's* behaviour, this has been done. Simply to illustrate the well-known fact Plates XXXV. and XXXVI. have been prepared. The latter shows the *Resolution* beam-on to trochoidal waves of the heights and lengths said to have been observed on December 20th, but to which she was then kept bow-on. The maximum slope of the waves is 26 degs., and an inclination to the vertical of 8 degs. would then immerse the top of the bulwarks. In this position the corresponding angle on the curve of stability for measuring the righting moment would, of course, be 34 degs.

Plate XXXV. shows the *Resolution* beam-on to an Atlantic storm wave 600 ft. long and 30 ft. high, the maximum slope being 9 degs. Here an angle of inclination to the vertical of 25 degs. would bring the top of the bulwarks awash.

In practice, of course, waves have not the regular forms shown on the diagrams, nor are successive waves of identical size and height. The "rise of the sea" on occasional waves in a series often considerably exceeds the average rise, and in a confused sea formed by superposed series these variations in height are very striking. Even with my limited opportunities for studying wave-phenomena, this has been much impressed on my mind, and experienced naval officers have frequently drawn attention to the same fact when the assumptions made in the mathematical theory of rolling have been explained to them.

Plate XXXVII. has been constructed on the hypothesis of two superposed series of waves, one 600 ft. in length by 20 ft. in height, and the other 300 ft. by 20 ft. in height. At certain times the ship on such a compound wave, if broadside on, might immerse her bulwarks at an inclination of 18 degs. If end on, the wave-crests passing rapidly, might also rise considerably above the bulwarks, and come on to the upper deck.

The presence of water in considerable quantities, at times, on the upper deck of the *Resolution* cannot, therefore, be regarded as any proof that the ship approached the angles of inclination indicated by the pendulum; much more moderate angles, under the circumstances described, would have produced this result.

It is undoubted that the ship at times rolled considerably, and that the *Gleaner*, although of small dimensions, made better weather of it when beam-on to the swell first encountered. The *Gleaner* is said to have "risen over the beam swell and sea like a cork," which is what would be anticipated from the fact that she is a quick-moving ship, her period being only one-third to one-fourth that of the *Resolution*. On the swell which synchronised with the movements of the latter and accumulated rolling, the *Gleaner* could move so quickly as practically to accompany the waves. Everyone knows that under such circumstances the smaller ship is likely to have an advantage; but it is equally true that under most conditions the larger and slower-moving ship will be better behaved than the smaller, and more capable of maintaining her speed.

The *Resolution* was, in fact, put to a severe test at the very commencement of her service, when those on board had not grown familiar with the vessel, and particularly with the fittings provided for use in rough weather. She was not fully prepared when the sea first broke on board, and the washing away of certain fittings which were not well secured, or which were left in place instead of being stowed, permitted water to pass below. This involved discomfort, but not danger; and the statements to the contrary are unfounded. So are the accounts that were published in regard to the straining and leaks produced by the rolling. As to the extent of the rolling, there is no exact information, but there was undoubted exaggeration in the published reports.

(8) PERFORMANCES UNDER STEAM.

In the design it was proposed to develop 9,000 H.P. on the natural draught contractor's trial of eight hours, the corresponding speed being about 16 knots; and on the four hours' forced draught trial to develop 13,000 H.P., the corresponding speed being 17½ knots.

The *Royal Sovereign*, being the first completed ship of the class, was chosen for the purpose of comparing estimates with actual performances. She was brought to her designed load-line, and was practically ready for service when the trials were made. On the eight hours' trial the mean indicated horse-power was 9,661, with ·39 in. air pressure in stokeholds; the revolutions averaged 97 per minute. During the trial four runs were made on the measured mile at Stokes Bay. The mean number of revolutions per minute on these runs was 99, the mean power 9,780 H.P., and the mean speed 16·77 knots. On this basis, the mean speed for the eight hours was 16·43 knots, including the turns made as the ship ran her trial.

It may be worth mentioning that the speed by log on this trial was 16·37 knots, showing a fair agreement with actual performance. Of course, this agreement was accidental, since it is fully recognised that many circumstances seriously affect the indications of the log. But it is the custom of the Service to have the log running when ships are under weigh, and to record their indications. Not unfrequently in published accounts of trials one sees the log-speeds given without any notation of the mode of speed measurement; and in some instances I have observed detailed criticisms of relative performances based on log-speed records which were altogether untrustworthy. A far better method of approximating to speeds when making long runs is, undoubtedly, to determine the curves of revolutions for speeds by progressive trials, and to use these results, instead of any log yet available.

On the forced-draught trial, the *Royal Sovereign* was run up Channel and back in deep water, and over a known distance. For three hours' continuous steaming the mean revolutions were 106·3, the mean development was 13,360 H.P., with 1·6 in. air pressure in stokeholds, and the speed (by revolutions) was 18 knots. I may add that this result was checked by a comparison of the "co-efficients of propulsion" obtained from the model experiments, at 16¾ and 18 knots.

It will be seen, therefore, that the anticipations of the design were fully realised in regard to the speeds corresponding to the specified powers, and that the actual development was above the specified both for natural and for forced draught.

As all the ships are of identical form, and the screws of the same type and dimensions, nothing was to be gained by repeating the trials for speed, and incurring the expense of ballasting in order to bring them down to their designed load-lines. It was decided, therefore, that the contractors' trials on the remaining ships should be limited to the development of power under the specified conditions, care being taken to immerse the screws sufficiently. The ships were run at draughts and displacements lighter than their completed draughts, varying from 24 ft. 1 in. mean draught and 12,100 tons displacement up to 26 ft. 11 in. mean draught and 13,500 tons. The *Royal Sovereign* was tried at 27 ft. 6 in. draught and about 14,200 tons displacement.

On the natural draught trial of eight hours' continuous steaming the developments varied from 9,180 to 9,600 H.P., the air pressures in stokeholds varying from ·2 in. to ·5 in. of water. The specification provided for 9,000 H.P. with ·5 in. air pressure.

In the later ships it was decided not to push the forced draught trials so far as had been done in the *Royal Sovereign*, but to limit the development to 11,000 H.P. With this limitation it was possible to set the valves so as to favour economy in the use of steam at ordinary working speeds, and to increase the efficiency under general service conditions, when the air pressure in the stokeholds would be not more than ·5 in. With ordinary coal and stoking the specified natural draught power (9,000 H.P.) would not be exceeded, and not often reached, so that 11,000 H.P. gave a good margin in the engine department. The steam-producing power of the boilers, of course, remained unchanged.

The mean development on the four hours' trials varied from 11,300 to 11,600 H.P. The air pressure varied from ·35 to 1 in.

No trustworthy observations of speed were made, but the logs were run as usual. Attempts have been made by some persons to analyse and compare the results, on the assumption that the speeds were correctly measured. All these attempts simply represent so much waste work.

In my paper of 1889 I explained that the greater length of these ships would favour economy of power at the higher speeds, as compared with what had been accomplished in vessels previously built. This has been fully realised on trial, and the following figures are of interest:—

The *Trafalgar*, 345 ft. in length, and of 12,000 tons displacement at the trial draught (27½ ft. mean), required 8,440 H.P. for 16·22 knots, and 12,900 H.P. for 17·28 knots. The *Howe*, 325 ft. in length, 9,600 tons displacement at the mean draught of 26 ft. 8 in., required 8,230 H.P. for 15·9 knots, and 11,600 H.P. for 16·9 knots. The *Royal Sovereign*, 380 ft. in length, and about 14,200 tons displacement on the same mean draught as the *Trafalgar*, required 9,780 H.P. for 16·77 knots, and 13,360 H.P. for 18 knots.

Much might be said in further illustration of the point, which was discussed at length five years ago, but these figures must suffice at present.

From personal observations made during the trials of these ships, I can testify that at the higher speeds, even in smooth water, the greater freeboard of the *Royal Sovereign* class is a source of sensible economy in propulsion. Against the high bow the waves can maintain themselves when once formed, whereas in the vessels of low freeboard a wall of water is gradually raised above the upper deck level, until it reaches such a height that it falls over upon the deck, and has to be re-created. In a moderate sea the conditions are still more favourable to the ships with high bows, and the maintenance of speed in rough water is greatly superior.

We are accustomed to adverse criticism of measured-mile performances, which are of great value for many purposes, although no one supposes them to represent what can be done on long-distance steaming. Fortunately it is now possible to refer to a thorough test of the *Royal Sovereign* on a trial made from Plymouth to Gibraltar in October last. The run extended over 72 hours, and was made in fair weather, except for a few hours towards the end, when head winds and some sea were encountered. The mean speed for the 72 hours was fifteen knots; the mean power was 8,180—90 per cent. of the specified power. This is an excellent result, most creditable to the engineer officers and their staff. As regards the speed, it is proper to note that the ship started with a considerable load of coal and stores, drawing about 28½ ft., and having a displacement of about 14,900 tons. Her consumption of coal for steaming was 484 tons, and for all purposes about 500 tons. Hence her mean displacement for the run was about 14,650 tons. At this speed, therefore, the maximum coal supply (1,450 tons) would suffice to cross the Atlantic at a speed of 15 knots. This is probably an unrivalled performance for a battle-ship. The rate of coal consumption was 1·84 lbs. per I.H.P. per hour.

It is interesting to compare this performance on a long run at sea with that of some other battle-ships when tried on the measured mile for short periods and with everything at its best, as an indication of what has been accomplished in the direction of economical propulsion.

	Length.	Mean Draught.		Displacement.	I.H.P.	Speed in Knots.	
	Ft.	Ft.	In.	Tons.			
Royal Sovereign	380	28	2	14,650	8,180	15	Run to Gibraltar.
Alexandra	325	26	1½	9,430	8,615	15	Measured mile trials.
Dreadnought	325	26	10	11,000	7,927	14·24	
Hercules	325	24	8	8,676	8,529	14·69	

At cruising speeds also the *Royal Sovereign* has done well. When steaming at a speed of 7·6 knots per hour, the expenditure of one ton of coal suffices to drive her enormous weight (over 14,000 tons) more than 7 knots, less than 1,000 H.P. being indicated. For 10 knots speed about 2,500 H.P. is required, and an expenditure of one ton of coal would drive the ship about 4½ knots in fair weather with bottom clean.

Trials have been made as to the most economical mode of propulsion at very low speeds, with the result that it has been found preferable even at speeds of 5½ to 6½ knots per hour, to keep both engines at work rather than to work one engine only and use the helm to keep a course.

This is a suggestive experiment, taken in connection with the economy anticipated in some quarters by adopting triple screws, in order to work only the central engine at low speeds.

Similar trials made in other twin-screw ships have given confirmatory results.

(9) MANŒUVRING POWERS.

The vessels of the *Royal Sovereign* class have proved very handy for their dimensions, comparing favourably with many ships of less size and weight. They are perfectly under control, answering all movements of the helm even at low speeds. One remarkable proof of their handiness is to be found in the fact that vessels of the class have proceeded under their own steam alone, without the assistance of tugs, from Plymouth Sound into the Hamoaze, a passage involving very awkward turns in limited space and a strong tideway. Turning trials have been made with several of the ships, some fully laden, and others light. It need hardly be said that differences of draught and trim affect performance.

Taking the sea-going condition, it appears that the tactical diameter is about five times the length, or about 1,900 ft. This tactical diameter is practically constant for all speeds. The time of turning varies, therefore, nearly inversely as the speed.

At 12 knots the course can be reversed in about 3·4 minutes; at higher speeds in proportionately less time.

The actual space required for turning is practically the same as that required by a number of battle-ships from 40 to 50 ft. shorter, and 2,000 to 3,500 tons less displacement, and taking the ratio of tactical diameter to length, the big ships compare favourably with any battle-ship of recent construction and high speed; notwithstanding their great inertia due to the weights and positions of the barbettes and heavy guns.

RELATIVE SIZE AND COST OF "ROYAL SOVEREIGN" CLASS.

In my paper of 1889 I explained that the comparatively large dimensions and displacements of the *Royal Sovereign* class, resulted from the fact that they were designed to carry great weights of armour, armament, coals, and equipment, at high speeds. As compared with first-class battle-ships recently built, or now building, for foreign navies, they are of large displacement-tonnage, and somewhat greater draught. As these foreign ships are intended to have about the same speed, while in armour and armament they are designed to meet our ships on fairly equal terms, it has been assumed in some discussions of the subject that our ships are unnecessarily large for their intended service.

To this Institution it is unnecessary to explain how fallacious a standard of measurement is displacement tonnage, apart from a full statement of what is included therein. One requires to know not merely what numbers and weight of guns are carried, what are the thicknesses of armour and areas protected, but also what are the weights of ammunition, coal, stores, and equipment included in the nominal displacement. In other words, what is the total load carried at the maximum estimated speed.

Fortunately, I have been able to make such a comparison between the details of the designs of the *Royal Sovereign* class and those of some foreign battle-ships of the same date of nearly equal length, and of about 12,000 tons displacement. Without going into particulars I can state broadly that the *total load* in our ships reckoned in the displacement, and carried at the maximum speeds, exceeds that of the foreign designs by about 1,600 tons. This excess is almost entirely made up on the items of coal, ammunition, stores, and equipment.

Everyone familiar with ship designing knows how an addition to the load, with constant speed, leads to a much greater increase than itself to the displacement. But apart from this it will be seen that if the *Royal Sovereign* carried 1,600 tons less than she does—that is, had an equal load with that carried by the foreign ship—she would be about 12,500 tons displacement, and would draw about 2½ ft. less than she does. Of course at this lighter draught she would have a greater speed also.

This is only a typical case. In the Royal Navy the established policy is to give to our ships greater sea-keeping power, more coal, more ammunition, more stores. Hence, with equal skill in design, equal weights of armour, equal numbers and weights of guns, and equal speed, our ships must be of greater displacements.

Thanks to our superior economy in construction, the costs of our ships compare favourably with those of foreign ships. The Dockyard-built *Royal Sovereigns* cost about £770,000, exclusive of establishment charges and armaments. The corresponding costs for foreign ships of recent construction are from £950,000 to £1,000,000.

"CENTURION" AND "BARFLEUR."

The *Centurion* and *Barfleur*, also built under the Naval Defence Act, may be briefly mentioned before concluding. These ships are designed specially for service as flag-ships on distant stations, and their draught limited, so that they can pass through the Suez Canal. They are wood sheathed and coppered. Their length is 360 feet, displacement about 10,500 tons, maximum speed about 18½ knots. On trial they have both proved excellent steamers. Their nett cost (exclusive of armaments) is about £550,000.

In them we have an illustration of the price paid in reduced offensive and defensive power, when first cost is diminished. The *Royal Sovereign* and *Centurion* may be treated as about equal in speed, manœuvring capability, freeboard, coal endurance, and the power of maintaining speed at sea. But to effect a saving of 30 per cent. in cost, it is necessary to reduce the calibres of the four heavy guns from 13·5 in. to 10 in., and of the secondary armament from 6 in. to 4·7 in. The maximum thickness of armour on the belt has to be made 12 in. instead of 18 in., and that on the barbettes 9 in. instead of 17 in.

As the designer of both classes, I can say that the work on the *Centurion* was as carefully thought out as that on the *Royal Sovereign.* The ships have been built in the same Dockyard, and under similar conditions. The comparison is, therefore, fair and complete. And the broad result is that, however well adapted the *Centurion* may be for her special service, and capable as she undoubtedly is of meeting on equal terms ships of larger size, but earlier construction, she is distinctly inferior to foreign ships of the first class now building in offence and defence. Her heaviest guns cannot perforate the armour on the hulls and heavy gun emplacements of those ships. Their heavy guns can readily perforate her defence.

Seven *Centurions* can be built for the cost of five *Royal Sovereigns.* I leave to others the discussion of the question whether such a gain in numbers is any adequate compensation for loss in individual power.

DISCUSSION.

Mr. W. Laird (Member) : Sir John Hay and Gentlemen, although I know that many gentlemen may wish to speak on the very able and interesting paper which we have just heard from Mr. White, I think you might be interested to hear a few words on my practical experience at sea in one of these new first-class battleships : I mean the *Royal Oak.* Before saying what I wish to say—and I will not occupy you very long—I desire to thank our Chairman for the kind words that he has used in alluding to the death of my brother, Mr. Henry Laird, a Member of the Council of this Institution, whose loss is felt very widely among those with whom he was associated in many ways. I would also thank the Chairman for having spoken in such complimentary terms of the work done by my father in the early days of iron shipbuilding, and also of the enterprise of my uncle, MacGregor Laird, in making the early attempt—certainly the first in a steam vessel—to explore the great river Niger, and who, after many years, was able to induce the Government to establish a line of mail steamers to run down the West Coast of Africa, which has been developed into one of the first services of the day. Now to revert to the *Royal Oak.* On her completion in October, I felt anxious to further enlarge my experience of sea-going by a trip round in a vessel having a larger displacement, considerably, than any of those I had been previously on board of. When we left the Mersey the weather was very unsettled, but we hoped it was improving. Instead of that it became worse, and by the time we got to Holyhead, it was blowing very strongly, with a heavy sea. The ship was under the command of the Hon. Alexander Bethell, and the officers and crew were from the steam reserve at Portsmouth. As we proceeded down Channel the weather became worse, and when we were crossing the Bristol Channel there was a whole gale blowing from the S.W. with a very heavy sea, at first on the starboard bow, and afterwards more on the beam. Throughout this experience of two days the ship behaved in a most satisfactory way, and we made good our passage to Portsmouth without any trouble of any kind, and arrived there up to time on Sunday. In the same ship I was present at the steam trials, and recently at the gunnery trials, and on neither of these occasions was the weather just what we would have chosen, if we had had the choice of it; but there was nothing that caused the least trouble or anxiety in the behaviour of the ship. In the gunnery trials particularly, although there was a considerable swell on, there was nothing to prevent the working of the guns, and taking the necessary aim and firing with deliberation. I quite admit, and we must all admit, that the *Royal Oak* and her sister ships may come into conditions of sea and wind in which they will roll considerably; but is it not true that we constantly, during the winter months, have reports from our well-tried Atlantic liners that they do occasionally meet with certain seas or successions of bad weather which try them just as much as they try, or would try, a ship of the *Royal Oak* or *Royal Sovereign* class? Neither one or other is exempt from the accidental combination of wind and waves. I feel myself, from considerable experience at sea, that if the *Royal Oak* and her sister ships do roll, they roll easily, which, after all, is one very essential element in ships carrying guns, so as to enable them to fight their battles under all conditions of weather, and when this is attained with conditions of absolute ultimate safety, it is indeed a great achievement. The question has been alluded to in the newspapers, and it is just touched upon in Mr. White's very interesting paper, and that is, whether a small class of ships with small displacement, of course costing rather less, would be equally efficient for our purpose. Now I admit, in fact I have had experience in doing it, that small ships may be built for certain services, and many services are such that the larger ships would not suit them, and the funds at the disposal of those who want them would not pay for them; but in the consideration of this subject to-day I am not dealing with the wide question of all ships necessary for the Navy, but I am dealing with the best ships for our line of battle, that is our first line of defence, and I do not see myself where the displacement of the *Royal Oak* is to be curtailed without sacrificing some of her good qualities. Can we take away from her armament and large supply of ammunition, which weigh nearly 2,000 tons; can we reduce her protective armour and protective deck, or take away from her coal supply, which gives her such an enormous range of action at low speed, and even at high speed a very considerable distance may be run? If you consider all these are essential, and then allowing sufficient weight for the structure of the ship and the machinery I do not see where you are going to reduce the displacement. I do hope those who have to deal with these things will not be led aside from providing, at any rate, a sufficient number of these magnificent ships to form our first line of battle, whatever they may think necessary and prudent to do for our second line of defence. What we have to remember as Englishmen is this—That the sea owns but one mistress; England has held that proud position for ninety years. It is now not only a matter of pride, but a matter of absolute necessity that she should maintain it, and if proper support and encouragement is given to those who have to do with the designing and with providing funds for these great ships, and other ships too, I have no doubt that we shall continue to occupy a position which will ensure safety for our commerce, and increase the greatness of England.

Admiral E. **Field**, M.P. (Visitor): Sir John Hay, it is too bad to call on me, because I never came into the room with any intention of taking part in this discussion. I came here to be instructed and informed, and I have received a vast amount of information, and a vast amount of instruction from our talented friend, the most talented naval architect the British Navy has ever had. I have listened to his paper with great interest, and there are one or two points which, as you command me to say a word or two, I will point out to the meeting. There is this on page 160. The learned gentleman says: "Whatever care or skill may have been bestowed on a design, nothing but actual experience can show whether or not it is successful." Then he says: "Much as we have learnt respecting the behaviour of ships, there are still many obscure points, and in elucidating these, naval architects must depend upon naval officers for facts as to the conditions of sea and the performances of ships." That is a point I would say one word upon. Some few years ago, I did, at the instigation of a gallant officer now gone to his rest, Sir Alfred Ryder, venture to ask our late Government if they would direct, as the French do, that certain naval architects, who were proficient in their profession, should be sent to sea in a certain number of our ironclads to watch the behaviour of these ships, and themselves gain practical experience as well as theoretical knowledge. I ventured to suggest that that should be done in our service. I was told that Mr. White intended to make a passage in a ship to gain a certain amount of experience. Mr. White is too valuable a man to be allowed to go to sea, except for a cruise for the good of his health, and for the shaking up of his liver, which I know he requires from time to time. That is no reason why some future Mr. White, who may be treading on his heels some twenty years hence, should not have that experience, and it would be very valuable if Mr. White could go so far as to suggest to the Admiralty some gentleman of promise, pick him out specially for the duty, and send him in a flagship, so that he may notice with his own mind and sight the behaviour of these great leviathans when subjected to serious wave disturbance. Sir Alfred Ryder pressed that point on me strongly, and I ventured to press it on our Admiralty and Government at the time. I am told some naval architects, at present low down in the office, are sent, from time to time, to gather instruction. That is not the kind of instruction we want in a naval architect's office; we want a gentleman of skill and knowledge to report with regard to the behaviour of these vessels who could be at Mr. White's elbow to tell him what this, that, and the other ship did. Now, I will pass from that. There is something else I am disappointed in also. I have a great respect for the learned gentleman who has read us this valuable paper. I know what will happen when Parliament comes to thresh out another naval programme. There are a great many clever Members of Parliament in the House—clever as regards brain power, with plenty of assurance, able to grapple with every question that ever arises, whether it be military or naval or civil, it matters not—certain Members of Parliament who feel, rightly or wrongly, that they are perfectly capable of dealing with every question under the sun. I know what will happen when a naval programme is launched on the floor of the House. We shall have certain prominent clever men, but without nautical experience of any kind, getting up and echoing Lord Brassey's letter published in *The Times* some time ago, urging strongly that what the Navy wants now is more *Centurions* and more *Barfleurs*, that you must not put all your eggs into one basket; but, as Mr. White says here, we may have seven *Centurions* in lieu of five *Royal Sovereigns*. I came here to-day to obtain information so as to be armed with knowledge, and to be put into possession of some strong argument, so as to be able to grapple with that idea when it is put forward and supported, as it is sure to be. There is the money side of the question, and we have those who speak in the interests of taxpayers, saying that the money required to carry out the programme of building these colossal ships is so gigantic in amount, that it takes their breath away. There are the Illingworths and the Pictons, and the gentlemen of that school, who will fight against this expenditure, tooth and nail, and the Government is eminently squeezable, as all Governments are, and may yield to this pressure, unless it is fortified by strong opinions and arguments. They are not going to make this a party question.

I came here to-day hoping that I should receive some strong argument from this paper, and the discussion upon it, to beat down what I may call the Brassey view of this matter? There is an argument—it only occupies half a page—and the chief part of it is summed up in one paragraph about the *Centurion*, and what she can do. They save 30 per cent. in cost, and that is an enormously powerful argument to your ordinary politician who has to take care of his seat, and wishes to get hold of votes; but Mr. White goes on to show that "it is necessary to reduce the calibres of the four heavy guns from 13·5 in. to 10 in."—that is a statement.

Mr. W. H. White: That is a fact.

Admiral E. Field, M.P.: The answer to that is: Has Mr. White considered the recent invention of the wire gun—would it be necessary with wire guns to reduce the calibre in that way? I am a little sceptical on that point. Then he says it is also necessary to reduce "the secondary armament from 6 in. to 4·7 in." Am I justified in holding on to that, and believing that to be an absolute fact, bearing in mind that the wire gun will solve some of these difficulties? Then Mr. White says: "The maximum thickness of armour on the belt has to be made 12 in. instead of 18 in. (I must bow to his authority), "and that on the barbettes 9 in. instead of 17 in." No doubt that is correct, because he would not put it forward if it were not. But this is where I am disappointed. I wanted to be told, and I have not been told, that the great advantage of the 14,000-ton ship over the 10,000-ton ship is this, that England, in having these 14,000-ton ships, would be having a larger coal endurance in these ships than they could ever possess in ships of the *Centurion* class. I am sorry the problem has not tended a little more in this direction. I have been talking to experts in the House of Commons—one or two of them are here, Sir Edward Harland is one of them—who believe in big ships, mainly because of their coal endurance, and my point is this, that England will be always operating thousands of miles away from her base, while the French and other nations may be only a few hundred miles from their base. It is of cardinal importance for us that our ships should be so constructed as to enable them to carry a sufficient coal supply under those conditions. Therefore, as I say, I am a little disappointed that something more has not been made of the superior coal endurance, which I hope exists, and I believe does exist, when we bear in mind the description which is given of the *Royal Sovereign* class with regard to the carrying of extra coal—something like 1,400 tons of coal, as compared with the ordinary normal coal supply. I do not see that the *Centurion* class has that advantage. I may possibly be comforted later on by Mr. White telling me that I am right in supposing the *Royal Sovereign* can carry an extra coal supply to make her more capable of operating an extra distance from her base than the *Centurion* class could be. I do not know that there is any other point which strikes me, except to say that, I am grateful to Mr. White for having made it so clear that the hue and cry raised by clever politicians, ignorant of nautical affairs, in the House of Commons, asking questions about the behaviour of the *Resolution*, is totally without justification. One man (I should like to sit on him) actually went so far as to ask whether they would not order a Court of Enquiry into the conduct of the captain of that ship. God help the service if a captain is not to have a free discretion in the handling of his vessel, and to determine whether it is right for him to put back into port, or not, when there is any feeling of anxiety on board, or on the part of the officers accompanying him, with regard to whether the ship is leaking or not leaking. I say (although that is not before the meeting) that the captain of the *Resolution* is second to none in ability and talent, and it was a scandalous thing to raise such a hue and cry as to the exercise of his discretion in putting back into port. It was a grand thing to ascertain that the ship was all right, and that there was no ground for alarm—the officers and the men put to sea again in a better condition, each trusting in the ship, whereas under the first condition they were launched into a heavy gale of wind in twenty-four hours with the men and officers all strange to one another, and under those conditions she might have met with some serious disaster, and then it would have been said the Admiralty were to blame for sending her to sea, without giving her a few days in the Channel first of all, to see that everything was all right. Therefore, I am grateful to Mr. White for having thoroughly exposed the hollowness of the outcry raised against that ship and her behaviour, and for the admirable paper he has given us on that part of the question. I have not the capacity—I do not feel competent—to say anything on the purely scientific problems set forth in the paper. Those are questions for naval architects. I had no intention of speaking to-day; I only came for the sake of instruction, and with the hope, as a humble and modest sailor sitting at the feet of Mr. White, that I might be able to drink in some of his learning and ability, so as to be able to meet the arguments which will be brought forward in the House by clever men, but men without a particle of nautical experience or knowledge.

Rear-Admiral G. **Digby Morant** (Associate Member of Council): Sir John Hay and Gentlemen, I wish, first, to express my thanks to Mr. White for the very able paper he has written, and, as I think, we must admit, he has by it cleared the character of the *Resolution* and her consorts. The things I more particularly wish to speak upon are confirming various paragraphs with regard to the behaviour of ships in rough seas, which Mr. White has mentioned in this paper at page 158—a ship that I had the honour to command in the Channel some twelve years ago, the *Achilles*. I started from Plymouth in company with the *Minotaur* and *Northumberland* for Arosa Bay, in January, I think it was, and before we started there had been a continuance of south-west varying to north-west gales for some weeks. When we got into the Bay we had a very troubled, heavy cross sea, and the three ships rolled very heavily. The *Northumberland* was on my beam, and I could see her performances. Probably the angles were taken with the same instrument as was used in the *Resolution*, viz., a pendulum. The *Northumberland* signalled to the Admiral that she was rolling 40 degs. out of the vertical each way. That continued throughout the day. The *Minotaur* made the signal that she was rolling 36 degs. each way, and my ship was rolling 32 degs. each way. We were battened down, as we were taking green seas over both gangways, each roll. I think that those three ships were considered able and stable ships in all their long lives, and I believe they are considered so st ll. It shows that the best ships will, in bad weather, roll. On another cruise in the same squadron—the *Agincourt*, *Neptune*, *Northumberland*, and my ship, the *Achilles*—were going from Vigo to Gibraltar. We came out of Vigo in the evening. Neither my ship, the *Agincourt*, nor the *Northumberland* were rolling at all. There was literally nothing to make us think that there was an Atlantic swell. The *Neptune*, however, rolled so heavily, that her turret guns broke adrift, and they had to choke the guns with hammocks before they could secure them. That is a point that Mr. White has made about the different periods ships have, and the seas combining with those periods. In confirmation of Mr. White's remarks about the great running seas that are sometimes observed in bad weather, which would, no doubt, influence a ship's behaviour at sea, I was in a very heavy gale off the west coast of Ireland, when the Calf Lighthouse was washed away—in fact, I saw it just before this occurred. There I saw seas running in quite different directions from the prevailing wind and sea. I saw seas that ran and broke, covering acres of water with their foam. If a ship happens to get on the side of one of those waves, there is no question she will roll very heavily, in the same way as Mr. White mentioned about the *Resolution*, viz., that when she was head to sea, she occasionally gave a great roll. I have seen that frequently in the many gales of wind I have been in, when lying-to, head to sea, or nearly head to sea—if you get on the crest of one of the waves, the ship will lurch. There is no question about that. I do not think I have anything more to say. I wished to confirm these remarks of Mr. White, as far as my experience, which has been pretty considerable now for a great many years, goes.

Admiral H. Boyes (Associate): Mr. Chairman and Gentlemen, I rise now as an officer of some experience, although not, perhaps, recently, to say a few words in corroboration of what Mr. White has put before us in this very able paper. It has been my lot to command ships of all descriptions —beginning with a 10-gun brig, then corvettes, frigates, and lastly the then largest ironclads, the *Warrior* and *Agincourt*; I began on a 10-ton gun brig. In the Channel Fleet in 1867-9 we had nine ironclads—they were called ironclads in those days—all cruising together in the Bay of Biscay for experimental purposes, one of which was to test the rolling propensities of individual ships. I then commanded the *Warrior*. It was not in gales that the ships made the worst weather of it, but in light winds, when there was a bit of a swell on; and as each ship would meet a sea just fitting her, she would start to roll, beginning almost at nothing, and going on until she got a heavy roll up to 18 degs. or 20 degs. That was especially the case in the *Warrior*. With regard to the matter of synchronising, a ship may go on for months and years without meeting waves by which she would be affected in that way. Sometimes a ship would go through half a commission without any severe rolling or straining; and occasionally you would see a ship start to roll, the sea would meet her as she commenced, and then another sea would give her another tap at the right moment, until at last she got up a very extensive roll, going on for a quarter of an hour or twenty minutes. It was the same way with most of the ships of the squadron. The *Achilles* was the steadiest. It was my duty to take the Bermuda Dock across the Atlantic. I had under me the *Warrior*, the *Black Prince*, the *Terrible*, the *Lapwing*, and another vessel. The object was to drag this thing across the Atlantic. The anxious question was the expenditure of coal. An account of coal was signalled daily. I put a limit of coal to be expended by every ship in the squadron for the following twenty-four hours. It was very curious to notice when we were in line, extending over half a mile in length, all attached to each other, sometimes with three ahead and one astern of the dock, one vessel would suddenly take a start to roll, and the others would be steady. The *Black Prince*, the *Warrior*, and the *Terrible* (paddle frigate) came under these conditions. Even the dock itself, nearly 400 ft. long and 120 ft. broad, occasionally got up an oscillation that went up to 12 degs. or 14 degs., and would go on swinging for some ten minutes or quarter of an hour, and then would not be affected, perhaps for many days, or possibly not at all. A most pertinent remark in Mr. White's paper is at page 158 (in which I perfectly concur), viz.: "It is not a possibility to secure absolute steadiness under all conditions of sea. The designer therefore must fall back on experience, and endeavour to secure average steadiness." In reference to the case of the *Resolution*, lately returning to England after experiencing a gale in the Bay of Biscay, in my opinion (formed only on newspaper reports) the ship was never in any danger; her return was a matter of prudence, and not of necessity. The repairs to the upper deck fittings could be more quickly and more economically made good in England. I believe that if her captain could have anticipated the exaggerations and false reports that were circulated about the ship, he would have gone on instead of turning back, which was quite as feasible.

Captain C. C. P. FitzGerald, R.N. (Associate): Mr. Chairman and Gentlemen, I will commence by congratulating Mr. White on his very able paper, which I cannot help looking at somewhat in the nature of an apology for the *Resolution*. The paper is devoted to showing that the *Resolution* did not do any more than she was expected to do on that memorable occasion in the Bay of Biscay. It may not have been a surprise to her designer, but it was somewhat of a surprise to those who commanded the *Resolution* that she rolled as she did. It is quite clear you cannot do away with rolling altogether, but we sailors who have to go to sea in the ships look upon it as one of the primary conditions of shipbuilding to get the steadiest gun platform it is possible to get; and I do not think, with all respect to those new ships which were discussed some three or four years ago, with all their attributes of armour and armament, speed, and so on, that this rolling was altogether expected. Nothing was said about it at that time. I cannot help thinking that the rolling came somewhat as a surprise, and was more than it was expected to be. Mr. White in his paper has mentioned the *Hercules* as being a remarkably steady ship, and so she was, up to a certain point. I was First Lieutenant of her on her first commission. I think we were something like eighteen months in commission before she ever rolled, and then she found her period, and got synchronous waves, and started off rolling violently. I am not going into the scientific part of the question as to metacentric height, &c., because that is quite outside the scope of my ability, but the behaviour of these new ships we may discuss; and whatever the metacentric height may be, it is evident they do roll in an excessive degree, and not only in the case of the *Resolution*, but in all the class. It is rather a remarkable coincidence that I met a man, as I was coming here to-day, who has a son in the *Empress of India*, and I am told she started off rolling suddenly and without warning the other day. They had been firing, and were picking up the target, and the officers got all their gear down—pictures and things of that sort—and put them on the deck for safety. She started off rolling, and she filled up the cabins in about five minutes, and nobody expected it at all. There is something remarkable about this. The principle the constructor should go on is to reduce rolling as much as possible; and if he cannot do this without bilge keels, I sincerely hope he will put them on. We are told that the bilge keel is only supposed to arrest rolling in a slight degree. That may be so, but it is a remarkable fact that they are going to put them on now, and did not do so at first. I can strongly congratulate the constructors on going to the experimental stage in this matter. Bilge keels were not put on at first, but have now been put on as an afterthought—at any rate, if they had been considered necessary in the first place, they would have been put on.

Mr. W. H. WHITE: I do not think you can have read the passage in the paper.

Captain FITZGERALD: I did read it. I quite gathered that they were not forgotten, but they were not put on. That was the principal thing. Mr. White explained to me the other day that the bilge keel does not come into action in a ship with very large moment until she rolls, or is about to roll heavily—that is to say, it does not stop moderate or small rolling, because the moment of the ship is so large that the resistance of a bilge keel is not effective until the roll is about to become excessive, but it would act strongly to prevent violent rolling. That is exactly what we want, and I cannot help thinking that experiments will show that the bilge keels will stop these ships from rolling somewhat more than the scientific calculations indicate. I am strongly in favour of the experimental process, because whatever calculations may tell you, there is just the chance that old Father Neptune has something up his sleeve which he has not disclosed, and which Mr. White and his colleagues will find out by experiment. There was a remark made which struck me as being somewhat jaunty, if I might say so, about the bridges: "The bridges, which were merely light superstructures at a considerable height above the deck, showed some small signs of movement." That is not a very light matter when you consider that the bridge is the position in which the navigating officers stand, and that the compass is there, and the whole navigation of the ship is conducted there, and if the bridge began to make some slight movement, I think you would feel a little bit uncomfortable. I do not think that is a very light matter. I hope they will make bridges which will not show any signs of moving in future ships. I think, while discussing this subject, and pointing out minor defects in these ships—not throwing a shadow of a doubt on their stability, but rather on their steadiness as gun platforms, which is a very different matter, we should remember the many good qualities they possess, and I for one, as a naval officer, can heartily congratulate Mr. White on these marvellous productions. A brother officer of mine, who lately read an able paper at Malta about the bulkheads of the *Victoria*, made a remark in concluding his paper which I should like to repeat and endorse. He said:—"The gradual evolution of the design of the most efficient fighting ship is a matter of slow growth, the product of the unceasing study of many minds, and nothing would be more fatal than to discourage the keenest criticism"—I am sure Mr. White will admit that (Mr. White: "Hear, hear"); he is always most generous in so doing—"but, at the same time, in justice to the distinguished men to whom we owe our progress in naval architecture, it is only fair to remember that, while we call attention to what we consider their mistakes, we pass by unnoticed the immense mass of improvements which have resulted in real progress." I thoroughly endorse these remarks.

Mr. J. I. Thornycroft, F.R.S. (Vice-President): Mr. Chairman and Gentlemen, I would like to make a few remarks on this subject, because it has been asked—and Admiral Field has put it very plainly—why are these ships so large? I think Mr. White in his paper has very clearly stated many reasons why they should be so large, and also he has shown us that they are not really larger than many foreign ships. One most important thing that Mr. White told us five years ago was that by making these ships so large there was greater economy of propulsion, that a higher speed could be got from the larger ship without increase of power. For long radius of action the size of these ships is most important, because their economy of propulsion is greater, and because they are able to carry more coal, and in every way perhaps be better, although they have the disadvantage, as has been remarked, of costing more money. Now, there is another reason why these ships should be made large. On the wall we have a diagram illustrating the rolling of the *Royal Sovereign*, and on that diagram it may be noticed that each successive roll takes place at a regular period of fifteen seconds, that is, just four rolls a minute in the ship or thereabouts. I have noticed on the coast for many years, when I have been there, the period at which the waves broke on the shore, and I can say that in about twenty years I have only noticed waves breaking on the shore with so slow a period as that about three or four times. We have the testimony of the Admirals who have spoken that a ship may be eighteen months without rolling. It comes to this, that if the ship has this long period of rolling, and is to be of sufficient stability, she must be large. You cannot make a small ship of sufficient safety with a very slow period of rolling. I think Mr. White has put this so clearly that it is almost superfluous to add anything, but adverse criticism has been so plainly put forward on this subject, and the defects of some of our ships at sea have been so plainly spoken of, that I think I should say what I can on this subject. With regard to the diagrams before us, we see also that the increment of rolling of the ship is very slow. There are exceptional waves, no doubt, when a ship suddenly takes a lurch, but it has also been noticed that these synchronous waves are usually waves not of a very steep character, but their peculiarity is that they are uniform in character, and the rolling of the ship gradually increases. If we had waves of equal regularity of very great steepness, as I have sometimes observed, then these vessels would be unsafe. What Mr. White tells us is matter of observation and experiment, and it is not necessary for Mr. White to go to sea when he can have perfect records taken of what takes place. I think the fact, that officers should be surprised at the rolling of their ships, merely indicates that this is a question which should be more discussed. If it were discussed they might ultimately gain knowledge that would enable them to avoid this rolling with greater certainty. It is said that by altering the course of the ship rolling can be prevented. It is also evident before they begin to roll how the course should be altered, and I hope gallant officers will excuse me for making any remarks in this direction. I have made a number of experiments at sea, in which my object has been, to make the vessel roll, and by altering the course I have increased the rolling very greatly in the way Mr. White has so plainly put before us. In my experiments with a ship with great resistance to rolling—that is, not great stability, but great extinguishing power—we could not get a greater roll than 23° or 24°, and that is pretty uncomfortable. In ships with large moments, as pointed out, the rolling takes place to a much greater angle with facility. With regard to bilge keels I think Mr. White has made out his case perfectly. I think there is great doubt as to the advantage of putting on bilge keels, which always handicap a ship, and which must take something from her performance, for the sake of avoiding rolling which takes place at rare periods. I think the rolling ought to be avoided by other means.

Mr. B. MARTELL (Vice-President): Sir John Hay and Gentlemen, I have naturally waited to hear all that naval officers had to say on this subject, because I think it comes more within their province than it does mine, situated as I am, and having particularly to do with the Mercantile Marine, but I cannot help saying that we are greatly indebted to Mr. White for reading this paper. In the first place, it will do a great deal to allay the apprehensions that have been excited in the mind of the public with reference to the safety of our modern men of war; and, in the next place, Mr. White being in some respects on his trial, has, in my opinion, most satisfactorily cleared himself, and we shall give him a verdict of not guilty. Now I think, sir, it is a very great pity that some naval officers are so fond of rushing into print on naval architectural matters. I say this feelingly, because I know that expressions are given utterance to and statements are made as to the performances and duties of public men engaged in this profession, when, if the persons who make them were to take a little trouble and go to those men, the heads of Departments, they would be very glad to give them information, which in many instances would satisfy them; but instead of doing so they rush into print, and disturb the public mind very much with some of their statements and opinions. This has been the case particularly with reference to what must be in your minds with regard to the performance of the *Resolution*. I consider it is a matter of great congratulation indeed to think that Mr. White has so brought these matters before us as to show that, in the first place, there was no question whatever as to the sufficient strength of that ship, and, in the next place, there need not have been any apprehension with reference to her safety as regards her stability. When we look at those curves of stability, I can only say I wish we could produce similar curves for all merchant ships; and more particularly I say that when I look at the upper one, and see that the curves of ordinary load conditions and ordinary light conditions almost conform to each other. Now, with 3 ft., I think Mr. White stated, of difference, there must have been a great deal of careful consideration and knowledge required to bring about such a result as that, and I think it is a matter of great congratulation to the Admiralty Department, and to Mr. White in particular, that he has been able to show us that these ships, as regards their margin of stability and steadiness under ordinary conditions, commend themselves so much to our satisfaction and approval. With regard to the *Resolution* it is not for me to speak, because it is a matter more for naval officers, but seeing that the ship returned, and that at the time she had 450 tons of coal on board, and that it only cost £400 to make her fit to go to sea again, I think we should find a good many officers in the Mercantile Marine who would have prosecuted their voyage instead of returning to Queenstown. We not only have these statements from Mr. White, of which we can judge, but we also have the general consensus of opinion of naval officers—Admirals of great experience—as to their approval of the statements he has made, and it is very gratifying to find that the experience of naval officers conforms so nearly to the scientific results brought forward by Mr. White. That the theory adduced with regard to the rolling of these large ships when the waves are synchronous with the vessel conforms with practical experience is a matter of great satisfaction, because it confirms us in our appreciation of and belief in the theory that has been brought forward by Mr. White to explain the excessive rolling that takes place sometimes, and which sometimes will occur in all ships of this kind, and which naval officers must prepare themselves to encounter. With regard to Captain FitzGerald's remarks, we are all so well acquainted with his humour that, directly he gets up to say something we all expect to laugh. He always does say something instructive, but he says it in the most interesting manner. With regard to the bridge-house, that he humorously made some remarks about, there is a vast difference between what you would call a slight movement in a house of that kind, situated where that is, and actual danger accruing from its being swept away. There is no such danger as that. In merchant ships we frequently see slight movements, and many passengers listen and hear them when they are lying in their berths, the creaking of the bulkheads and such like, but there is no danger with regard to that, and I cannot understand from Mr. White that there was any danger there, but merely a "slight movement" of an unimportant character. If you are going to build bridges of that kind sufficiently strong to obviate the slightest indication of straining, you will have to go to a much greater extent than was suggested by Captain FitzGerald. That is my experience. With regard to the bilge keels proposed to be fitted on these ships that Mr. White has alluded to, we all understand from his explanation that it was positively a question of discussion between themselves; it was no afterthought, whether they should fit these bilge keels or not, seeing that many similar ships really performed very well without them, and they thought, if any undue rolling occurred, that then it could be very easily done, with very little expense. We may have different opinions about the effect of bilge keels in diminishing rolling. I think, from my experience, it would have been better to have fitted them in the first place, because I have seen the great advantage of doing this in some large merchant ships. At the same time, the manner in which the Admiralty are accustomed to fit their bilge keels—making them very strong—in the form of the section of a triangle, and fastening them on to the ship with tap rivets, so that, in the event of any disturbance of the bilge keel no water can get into the ship, obviates all danger accruing from collisions, &c., under any circumstances. With regard to the opinions of some persons, we have heard a great deal in decrying these large ships, in terms of opprobrium, as *monsters*. I do not think they need designate these large warships by such a name, because we have building, and have recently had under our consideration, ships to be built 600 ft. long, whereas the largest ship here of the *Powerful* class will only be 500 ft. long. There is no doubt in my mind that so long as foreign Governments build large ships of this size, that we are bound to build similar-sized ships to compete with them, or larger ships. When Mr. White has so clearly shown the great advantage that is to be gained, and the comparative saving that is effected by making our ships larger, and when he has instanced the case of the *Centurion*, and showed what armour she had, and what was the calibre of her guns and armament, and compared it with a ship that would be 2,000 tons or 3,000 tons more displacement, the comparative advantage economically of building large ships is seen. That showed that the advantage was all on the side of the larger ship, and this is more particularly the case when we in this country can build a ship (no matter whether she be a mercantile ship or a warship) which, if built in France, would cost one-third more, at least, than if built in this country. So that there is a great advantage, both economically and likewise politically, in building warships of sufficient size to enable them to compete with similar-sized ships of foreign Governments. I hope, therefore, we shall not hear so much of this cry with regard to monster ships, and shall go on building these large ships so long as other Governments continue doing so. I do not think I have anything more to say than to congratulate my friend Mr. White on the very able paper he has read, and the appropriate time at which he has read it, and no doubt it will do a great deal to allay the apprehensions existing in the public mind with reference to the safety and behaviour of these ships at sea.

Mr. **Edwin** N. **Henwood** (Visitor): Sir John Hay, I wish to ask one or two questions with reference to the paper read by Mr. White. He states that there is a difference between the load draught of water and when the coals are consumed of 3 ft. In such case I would ask him to say whether provision is made for maintaining the vessel in her fighting condition in the event of going into action? Because if she had to go into action with her coals consumed, being then 3 ft. higher out of water than when at the load-line, if rolling very slightly she would expose the bottom plating much more readily than when at the load-line. The next question is this:—In view of the great advantage that would accrue to warships from the use of a fuel which may be called the "concentrated-essence-of-coal," whether it would not be to the advantage of H.M.'s Navy to have the system of oil-fuel adopted, so as to enable these vessels to carry a supply which would last over three times that which is now obtainable with coal supply, and, further, would relieve a large number of men from a very objectionable employment, and enable them to be used as a fighting complement?

Professor J. H. **Biles** (Member of Council): Sir John Hay, Ladies and Gentlemen, the point I wanted to speak on in connection with this paper is one which perhaps may be of some interest to the members of this Institution. It is the relative period of rolling of large armoured ships of this kind as compared with large Atlantic liners. These large Atlantic liners go across from one side to the other, year in and year out, without deviating appreciably from their course, and they meet all kinds of seas, so that the period of rolling is of interest in such vessels because they very seldom deviate from their course; in fact, it is generally looked upon as a point of honour to keep to the course as long as possible. I think you may take it that most of the larger sizes (not the very largest), from 6,000 to 8,000 gross tons, have a rolling period of from thirteen to fifteen seconds, which, curiously enough, is about the same period as the *Resolution*. The metacentric heights of course are different, and the moments of inertia of the vessels are different, but there is a sufficiently close approximation to the period of rolling to make the comparison almost a correct one. Now those who have crossed in Atlantic liners must be familiar with the fact that often for days together these vessels will steam in a beam sea where the rolling has an extreme angle of 30° (quite as much as 30°), varying of course, going through the phases shown by Mr. White's diagrams, but certainly every five minutes or so rolling to such angles as 30°. The ships continue on their course, the officers are in no way alarmed by such experiences, and they do not come to any trouble.

Mr. W. H. **White**: You mean on each side of the vertical?

Professor J. H. **Biles**: On each side of the vertical. I do not mean to say that they are constantly rolling to 30°, but they do roll at an extreme angle to 30° on each side of the vertical. I have myself seen them do that, and I have measured the angle, not with a clinometer, but with relation to the horizon. I may mention one interesting fact which came under my notice not long since, of a vessel of about 12,000 tons displacement, a merchant vessel, leaving port (an absolutely new vessel), with a green crew, with a metacentric height of 3½ ft., with a rolling period probably of about 12 seconds. The vessel went across the Atlantic, and encountered some of the worst gales which we had this winter, and arrived after a long passage with a record of having very excessive rolling. That vessel was loaded in a way that conduced to the rolling: she carried out a cargo that only half filled her, and which was in the bottom of the vessel. That same vessel returned with a full cargo with a metacentric height probably of not more than 1 ft. or 1½ ft. The extreme of period I am acquainted with on the Atlantic is in a ship of the displacement of 15,000 tons at starting, which is reduced to 13,000 when all the coal is burnt out, and it is twenty seconds. That ship, although she has a very long period, can roll to a very great angle when the sea happens to suit, and it more frequently suits in a ship of that kind when it is a long sea coming in on the quarter. So that even if it were possible in the case of a battle-ship to reduce the metacentric height to so small an amount as 1 ft., and thereby cause the period to be considerably increased, there is an absolute certainty that the vessel would, on occasion, fall in with seas that would cause her to roll to angles that would be called excessive. So that it seems to be quite impossible to design any ship which shall not at some time fall in with conditions of sea which will cause her to roll excessively. I am not quite sure (I thought Mr. Thornycroft was going to say something on that point) that it is not possible to design an apparatus to prevent a ship from rolling, almost under any conditions of sea, to an excessive angle, but that has not been done on a large scale. If Mr. Thornycroft's admirable apparatus could have been tried in one of these large ships or vessels of smaller size, we might have been in a position to say it would be possible to send a ship to sea with an apparatus on board of her which would ensure that, whatever conditions of sea she fell in with, she would not roll excessively. I want to make one explanation further. In speaking of the period of rolling I mean the period of the double oscillation. Mr. White's figures, I think—I am not quite sure—were given for the single oscillation. The double oscillation that I spoke of in connection with these large ships is from 13 to 15 seconds, which would of course correspond to 6½ to 7½ seconds for the single oscillation. The inclination I spoke of was on each side of the vertical.

Mr. W. H. **White**, C.B., LL.D., F.R.S. (Vice-President): Sir John Hay and Gentlemen, I came here to-day with a very definite object. That object was not to make an apology such as my friend Captain FitzGerald supposes I have made. If I have done so, it has been done by pure accident. I did not intend to apologise. I am not aware of anything to apologise for, nor did I consider I was on my trial, as my friend Mr. Martell suggested; and while I value very highly the many kind things that have been said of me personally, coming from the gentlemen who have spoken, yet I came here, believe me, with the simplest possible motive a man can have, namely, to tell you the truth so far as I know it about these ships: nothing more nor anything less. I have told you the actual story of their design. Believe me that I have not discovered what the ships are as completed, and then said that I intended them to be so. I have not altered one single fact or figure from what appears in the official records of the Admiralty at the date of the design. I have compared those facts and figures with actual results. When I tell you that the centre of gravity of the 14,200 tons weight in the *Royal Sovereign* is within 1¾ in. of where I placed it by calculation, that is the truth; and when I tell you that bilge keels were seriously debated at the time of the design, that is also the truth, and there is no "after-thought" about it. They were deliberately left off the ships with the distinct intention that, if experience showed them to be desirable, they could be put on. I must, therefore, call upon my friend Captain FitzGerald to withdraw the word "after-thought" in view of this explanation.

Captain C. C. P. **FitzGerald**, R.N.: With your kind indulgence, I will explain that my point was this:—I said bilge keels were not put on, I did not say that they were forgotten. I did not want to contradict Mr. White. I say that something has happened which was not expected to happen, and now bilge keels are going to be put on. It remains to be explained how and why. Something has since happened in these ships which their designers did not anticipate, and in consequence of the practical experience since gained, bilge keels are going to be put on.

Mr. W. H. White, C.B., LL.D., F.R.S. (Vice-President): This statement of Captain FitzGerald's in its amended form I consider as disagreeable as it was in its past form. It is not correct to say that anything has happened which the designers did not suppose would happen. If Captain FitzGerald will have the goodness at his leisure to read my paper, and to weigh the several statements which are therein made, he will see clearly that the pith of my remarks is this:—Designers of ships have to base their work in relation to steadiness upon past experience and recorded data. By general consent, the element of the design which the naval architect can influence, and which has most effect upon behaviour under average conditions of sea, is the *period*. In the *Royal Sovereign* class, in adjusting the metacentric height in connection with the weights which had to be carried in definite positions, I hoped and aimed to attain about the same period as that possessed by steady ships such as the *Monarch* and the *Hercules*. These are the simple facts. Twenty years ago I wrote the passage which I quoted to-day, explaining why ships like the *Monarch* and *Hercules* occasionally rolled very heavily. Is it in reason, therefore, or can it be admitted for a moment, that Captain FitzGerald has any justification for asserting that a time would not come when the *Royal Sovereign* class would roll, just as the *Monarch* and *Hercules* had done? This point I leave to the meeting to decide. The facts are stated in the paper, and speak for themselves. This reply and refutation is made with the greatest good feeling on my part. Captain FitzGerald and I are excellent friends, and I am happy to think that a little passage of arms like the present does not in the least affect our good fellowship. However, I want to point this out. Captain FitzGerald is a practical seaman of large experience, and yet he asserts that constructors "should stop ships from rolling." I want to know if the "penny in the slot" principle is to be carried as far as that. We have heard of "Britannia ruling the waves," but naval architects never presumed so far. I say in the paper, and I repeat it, that all experience, all records, and all past knowledge show that no ships can be built which under certain conditions of sea will not roll. Moreover, I recall attention to the fact that the *Hercules* and *Sultan* had not bilge keels in the modern sense, but were simply fitted with shallow side keels. These ships have passed through years of experience with admirable results on the whole, although at times they have rolled violently. So there was no reason whatever for apprehending that in the *Royal Sovereign* class there would be any great advantage gained by putting on the deepest keels which the ships could carry consistently with their convenient docking. Captain FitzGerald says bilge keels are to be fitted now. They are to be fitted as an experiment in one ship. Fully confident as I am of the merits of scientific method and analysis, I do not contend that the calculations which we can make, on the basis of recorded experiments, on the effects of bilge keels in the *Royal Sovereign* class are to be preferred to the full-scale experiment about to be made on a ship of the class. I am anxious that there should be no misunderstanding on this point, and therefore have dealt with it at some length. Now I want to go a step further. In the paper I have told you as much as I know, or anybody knows, about the actual behaviour of these ships. The facts reported have been summarised, and the broad conclusions have been stated. They may be recapitulated. The *Royal Sovereign* herself has been at sea nearly two years. During the first eight months there was not any suggestion of her being what sailors call a "roller." Then she made a passage during which she encountered a long, low swell and was set rolling. The thing was so different from past experience in the ship that what was really very moderate rolling attracted a good deal of attention, especially as it was set up in an almost smooth sea and in calm weather. The only rolling of the *Royal Sovereign* class of any amount worth mentioning in the two years—I am excluding always the passage of the *Resolution*—has been under those special conditions of sea, and at or about the same season of the year in the same waters. I say again, if you want to ascertain the *average* performance of a ship you must try her under different conditions of sea. If the *Royal Sovereign* were exposed to the action of the same sea which caused her to roll, she would necessarily do exactly the same. But that is no proof that the period of oscillation designedly given to the *Royal Sovereign* class was undesirable, nor does it contradict that great body of past experience which shows their period of oscillation, on the whole, to conduce to average steadiness at sea. Having studied these matters continuously for nearly thirty years, I am convinced that past experience does point to the conclusion that ships having long periods are usually steadiest in a leeway. The observations of Admiral Morant, Admiral Boyes, and others confirm this view, and I think Captain FitzGerald's experience in the *Hercules* also confirms it. Many points mentioned incidentally in the discussion need not, I think, be dealt with. I may refer, however, to Mr. Henwood's remarks about the effect of lightening. My experience with ships is that there is no difficulty in bringing them to a deeper draught. The tendency is rather for them to go that way. Mr. Henwood, as a naval architect, is surely aware that every large warship in the service has provision for admitting a considerable weight of water to the double bottom at the discretion of the captain. The draught and stiffness of the ships are therefore largely under control as coal and stores are consumed. In relation to oil fuel, I do not propose to be tempted into a discussion on the present occasion. I have my own opinions, and know what has happened up to date in relation to that subject. Admiral Field referred to the policy of sending naval architects to sea. He spoke in somewhat slighting terms of the sort of naval architects we send to sea. Let me tell the Admiral, and I am sure he will be charmed to hear it, that the observations of rolling which we have been discussing here to-day were mostly made by young naval architects working under the direction of the officers of the ships. There is nothing to prevent the existing system being carried further, and more naval architects gaining experience at sea, except expense. Personally I should like to spend the next three years at sea, especially in view of what one reads in the newspapers as likely to happen in the way of new construction. Unfortunately the regulations of the public service in this country do not provide for the employment of a sufficient number of competent naval architects on my staff, to allow us to dispense with the services of any of them even for the time necessary to go to sea. When I have gone to sea, although I have benefited, or have been supposed to benefit, in point of health, that advantage has been a good deal discounted by the fact that my table was covered with a mass of papers on my return. Passing to the remarks made respecting the relative value of ships of different sizes, I need hardly say that my conception of the work of the naval architect is, that he should put into the shape of the ship, qualities which the responsible authorities decide to be necessary. The naval architect may have his own views, and possibly may exercise more or less influence on the decisions reached; but that is not the main point. No matter where the suggestions may come from, there is a responsible authority in this country, the Board of Admiralty, which decides finally what qualities of speed, armour, armament, and coal endurance should be embodied in every ship built. It is my duty as Director of Naval Construction to try to produce ships which shall be capable of floating, steaming, and being fairly steady at sea, while complying with the stipulated conditions. In the *Centurion* the problem was to produce a ship capable of going through the Suez Canal; well designed for such services as she would have to perform on distant stations, with large coal supply, with high speed, and copper sheathed. That ship was made no larger than she needed to be, for the required speed, thickness and extent of armour, numbers and weight of guns, and other features. The *Centurion* has wing spaces for coal the same as the *Royal Sovereign*. In coal endurance, speed, manœuvring, and power of maintaining speed at sea the *Centurion* is practically the same as the *Royal Sovereign*. Admiral Field said that he was deprived of his best argument in favour of the larger ships, if their coal supply did not exceed that of the *Centurion*. There is no such deprivation. Let me comfort the Admiral. As a matter of fact the *Royal Sovereign* class and the *Centurion* are, amongst existing battle-ships, practically unrivalled in coal endurance, although practically equal as between themselves. There is a great tendency to talk of the faults of our own ships, and to treat them as if they were going to fight or chase one another. They are not built for that purpose, but for acting against foreign ships in case of war. As regards the wire gun, I quite agree with Admiral Field. Things move on. There is no stagnation in ordnance any more than in armour. But the system of wire construction does not belong to the 12 in. calibre in particular. The Admiral will see that if a 12 in. gun can be made on that principle a 13½ in. or a 10 in. gun can also be made of wire construction. We must distinguish between calibre and construction. At the date of the design of these two classes, the *Royal Sovereign* and the *Centurion*, we had not wire guns available. In order to economise on displacement and cost it was necessary in the *Centurion* to pass from 13½ in. guns of 67 tons weight to 10 in. guns for the heavy armament. The secondary armament was reduced from 6 in. to 4·7 in. quick-firing guns. On the belt the armour instead of being 18 in. thick was made 12 in. thick. On the barbettes the armour had to be reduced from 17 in. to 9 in. These were serious changes. The concluding words of my paper are these: "I leave to others the discussion of the question whether such a gain in numbers is any adequate compensation for loss in individual power." If economy is put in the first place, and a larger number of ships obtained for a given expenditure, then of course we can go much further than *Centurions*. We can in fact produce a vast number of small ships. Mr. Thornycroft would probably favour the putting of that sum of money into torpedo vessels, and we could get a great many of such vessels. But it might happen when you had this large number of vessels that they could not do the work of larger ships. Fortunately, the authority which has to decide what shall be done has before it all these conditions; and the public feels confidence in the Board of Admiralty. On its naval side, there are officers of long experience and high standing, and with the means they have at hand their decision in regard to new types of ships is not likely to be seriously challenged. If we, the naval architects, can play our part fairly well, and produce vessels which shall be speedy, powerful, and well behaved, then I trust the defence of the Empire will not in any way suffer.

The Chairman (Admiral the Right Hon. Sir J. Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): Gentlemen, I am sure you will desire me to convey the thanks of the meeting to Mr. White for the excellent paper which we have heard, which has originated a discussion which must be of great value to the country, a discussion which I think will give a feeling of security to the public mind with regard to the condition of those ships, some of which, without much knowledge, have been detracted from in the public Press. Speaking from this Chair, I must say that I wish our President, Lord Brassey, had been here, because a most interesting letter from him recently appeared in *The Times*, in which he deprecates the building of these very large ships. I think if he had heard Mr. White's paper, with the open mind he possesses, and the great knowledge he has of these matters, possibly he might have reconsidered his decision. So long as we find France and Russia, and Italy

and the United States, building these large ships for their defensive purposes, so long is it necessary for us to have large ships, each one of which should be able to meet and resist one of those vessels. I am quite sure this paper will do much to cool the atmosphere with regard to the large ships constructed by the Admiralty. I do hope they will not give up building them, although I trust they will build small ones for other purposes. I convey the thanks of the meeting to Mr. White for his paper.

ON THE AMPLITUDE OF ROLLING ON A NON-SYNCHRONOUS WAVE.

By Monsieur E. BERTIN, Directeur de l'Ecole d'Application Maritime, Member.

[Communicated to the Thirty-fifth Session of the Institute of Naval Architects, March 14th, 1894; Admiral the Right Hon. Sir JOHN DALRYMPLE HAY, Bart., K.C.B., D.C.L, F.R.S., Vice-President, in the Chair.]

I DO not think that I do any wrong to the various authors who have treated the question of rolling on a non-synchronous wave when I say that the calculations which have been hitherto attempted have not greatly advanced the question. Naturally I make no exception in favour of what I have hitherto accomplished myself; but, at the same time, I risk a new attempt, in the hope of being more successful. I propose to show how the problem is susceptible of graphical solutions, which, if not very easy to obtain, are at least pretty simple and easy to understand.

In order to facilitate the comprehension of the subject, and to indicate the exact signification of the symbols, I will first remind my readers of the value of the maximum amplitude, Φ_M, of rolling on a synchronous wave :—

$$\Phi_M = K\sqrt{E\Theta} = K\sqrt{\frac{\Theta}{N}}. \qquad (1)$$

N (of which E, the co-efficient of "clisity,"* is simply the reciprocal) is the co-efficient of decrease of the artificial rolling in calm water, which, when we know by experience the law of this decrease, can be calculated by the empirical equation—

$$\delta\phi = N\phi^2. \qquad (2)$$

Θ is the inclination of the waves at the point of inflection, after the corrections have been made which are rendered necessary by the fact that the ship is not the infinitely small floating body to which the simple formula would apply. K is a co-efficient which takes account of all that is unknown; it is probably constant and greater than unity. A very simple calculation permits us to give it, as a first approximation, the value—

$$\sqrt{\frac{\pi}{2}}$$

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* For the meaning of the word "clisity," see "Naval Science: Notes on Waves and Rolling," by E. Bertin, vol. iii. page 334: "The fault of being liable to reach a large angle of roll may receive the name 'clisity.'"

It is very easy to establish or to prove formula (1). It has in its favour the very suitable agreement between the values of Φ_x, to which it leads, and the maximum amplitude of the rolling as observed.

The amplitude on non-synchronous waves ought evidently to depend on the co-efficient N, which is theoretically proportional to the ratio of the moment of resistance, M, to the moment of inertia of the ship, $\Sigma\, m\, r^2$, and which, consequently, is suitable for expressing the influence of the passive resistances.

This amplitude depends also, in a high degree, on the ratio which the period of the waves 2 T bears to the period of the rolling 2 T_n. It can easily be explained, by means of the influence of this ratio, expressed as a factor of the form

$$1 - \frac{T}{T_n}, \qquad (3)$$

how it is that the rolling of a vessel A, which is less on certain waves than that of a vessel B, will on other waves be ten to fifteen times as great as that of the latter; a fact which always creates astonishment, although it is well known by experience.

The factor (3) is inversely proportional to the number of double rolls $2\,m$, or to the number of simple rolls $4\ m$, which makes up the complete series of oscillations, at the end of which the difference between the periods $2\,T_n - 2\,T$ having been repeated $2\,m$ times, its accumulation is equal to $2\ T_n$, and the agreement between the movements falls back to the same point as at the start. In fact the equality

$$(2\,T_n - 2\,T) \times 2\,m = 2\,T_n$$

gives

$$2\,m = \frac{1}{1 - \frac{T}{T_n}} \qquad (4)$$

It is possible to say, then, that the amplitude Φ on a non-synchronous wave depends on N or E, and on *m;* that is to say, upon the "clisity" and the agreement between the two periods.

The attempts which have been made to express it mathematically have generally consisted in the integration of the differential equation of the rolling. In order to render the integration possible, very variable co-efficients are assumed as being constant. Moreover, the passive resistance is neglected, or else inadmissible assumptions are made about it which falsify the effect of the "clisity." I was led to attempt a graphic method of solution by the difficulties of obtaining exact results algebraically, and of establishing, for example, by help of the calculus, in what manner the number of rolls forming an increasing or decreasing series depends upon the passive resistance, and, consequently, upon N, and at the same time upon the ratio of the two periods.

In what follows I will only proceed upon considerations analogous to those which have served to establish Formula 1. The facts, however, to which they must be applied are more complex. I take for granted, as is usually done, that the period of a roll T_n is constant, no matter what its amplitude may be, although the law of isochronism is not always so exact as the first observers of rolling considered it to be. This is the only fundamental hypothesis necessary in order to establish the calculations which follow.

We must remember what are the modes of agreement between the waves and the rolls, which produce in some cases an increase and in others a decrease of the amplitudes.

The question of the passive resistance being reserved for consideration later on, the passage of a wave tends to increase the amplitude when the axis of the ship and the normal to the surface of the water turn in the same sense during the return to the position of equilibrium, and in the opposite sense during the departure from this position. The passage of the wave tends to diminish the amplitude when the axis and the normal turn in opposite directions during the return to the position of equilibrium, and in the same sense during the departure from this position.

Let us denote by ψ the amplitudes which would be attained in a non-resisting medium; their maximum will be denoted by Ψ.

Let us take, for simplicity, as the point of origin of time, the instant when, in a series of increasing rolls, the conditions are most favourable for an increase of the amplitude—that is to say, the middle of the series. The vessel is, for example, in the position *a* (Fig. 1, Plate XXXIX.), on the summit of a wave, at the moment at which it commences its return swing in the direction of the rotation of the normal, in such a manner as to commence the following departure swing in passing over the point of inflexion at which the direction of the rotation of the normal changes its sense. The first oscillation thus accomplished will be followed by a series of others in which, as the two periods $2\,T$ and $2\,T_n$ differ from one another, the initial accord will be realised less and less, and consequently the conditions will be less and less favourable for increasing the amplitudes.

In order to take account more accurately of the manner in which the coincidences of the two periods succeed each other, we must trace the curves of the angles described by the ship and the normal, at the same time following a rather complicated rule for the signs. For abscissæ let us take the times, and for ordinates the angles described by the ship from the commencement of the return swing to the end of the roll, and those described by the normal from the summit to the hollow of the wave, and from the hollow to the summit. In order that the angles described by the normal—in opposite senses from summit to hollow or from hollow to summit—may be added to, instead of subtracted from the ordinates, the rule of the signs must be reversed at the points of inflexion. So we shall count as positive the totality of the angle described by the normal from *a* to *b* and *c*, and as negative the totality of the angle described from *c* to *d* and *a*. The angles described by the ship are always marked off with their proper sign. By means of this convention the agreement between the periods tends to increase the amplitude of the rolls during the intervals of time that the two curves are on the same side of the axis of abscissæ, and tends to diminish the amplitude when the two curves are on opposite sides of the axis.

In Fig. 2, Plate XXXIX., and in the whole study of the question which follows, it is pre-supposed that T_n is greater than T. The case in which T is greater than T_n is treated in the same manner.

If we call the effects which tend to increase the amplitude positive, and those tending to decrease it negative, we see at once, on Fig. 2, starting from the point O, that there are:—During the first roll a positive effect during the interval T, and a negative effect during $T_n - T$; this is the condition corresponding to the maximum of $\delta \psi$. During the second roll there is a positive effect during $T - (T_n - T) = 2T - T_n$, and a negative effect during $2(T_n - T)$, and, in the same, during the rest of the series. During the n^{th} roll there is a positive effect during $T - (n - 1)(T_n - T)$, that is to say, during $nT - (n - 1)T_n$, and a negative effect during $n(T_n - T)$.

We thus find that the resultant effect becomes equal to zero, and that the amplitude has consequently attained its maximum when, for *n* we have the value *m*, obtained by the equation

$$mT - (m - 1)T_n = m(T_n - T),$$

whence

$$m = \tfrac{1}{2}\frac{T_n}{T_n - T} = \tfrac{1}{2}\frac{1}{1 - \frac{T}{T_n}};$$

this number *m* represents only the second half of the series of increasing rolls; the total series is got by the equation

$$2m = \frac{1}{1 - \frac{T}{T_n}} \qquad (4)$$

and the complete series, leading back to the initial conditions, is

$$4m = 2\frac{1}{1 - \frac{T}{T_n}} \qquad (4a)$$

We thus find by another method the value of the number 2 *m* of the rolls, as pointed out at the commencement of the paper; always, be it well understood, without taking any account of the passive resistances.

Let us now consider the successive values of the increases of amplitude, $\delta_0\psi$, $\delta_1\psi$, $\delta_2\psi$ . . . . . $\delta_n\psi$ produced by the different waves, or, rather, this relation to the maximum amplitude $\Delta\psi$, which would be caused by a synchronous swell, and which is only approximately attained on one or two waves of the non-synchronous swell.

I will suppose that if during one roll T_n the effect of a wave is positive during the fraction q of T_n, and negative during the fraction $1 - q$, the total effect $\delta\psi$ will bear to the maximum $\Delta\psi$ the ratio that the difference $q - (1 - q) = 2q - 1$ bears to unity. Thus the value of $\Delta\psi$ being given by the well-known formula in the theory of rolling on a synchronous swell,

$$\Delta\psi = K^2\Theta, \qquad (5)$$

where K has the same meaning as in (1); we get for $\delta\psi$ the expression

$$\delta\psi = (2q - 1)K^2\Theta. \qquad (6)$$

Let us remark immediately that this proportionality of $\delta\psi$ to $\Delta\psi$ is by no means necessary. If later we find for the ratio a more exact expression than $(2q-1)$, either an algebraical expression or one simply expressed by a curve of a function of q, nothing would prevent us from adopting it; the curves which follow would not thereby be rendered more complicated.

The fraction q, for the rolls which commence at the origin of time on Fig. 2, has just been found, by the help of that figure, to be precisely equal to $n\frac{T}{T_n} - (n - 1)$. Its successive values are

$$\frac{T}{T_n}, \quad \frac{2T - T_n}{T_n}, \quad \frac{3T - 2T_n}{T_n} \quad . \; . \; . \; . \quad \frac{nT - (n-1)T_n}{T_n},$$

otherwise expressed thus:

$$\frac{T}{T_n}, \quad 2\frac{T}{T_n} - 1, \quad 3\frac{T}{T_n} - 2 \quad . \; . \; . \; . \; . \quad n\frac{T}{T_n} - (n - 1),$$

from which we deduce for the successive values of $2q - 1$, that is to say, of $2n\frac{T}{T_n} - (2n - 1)$, which enter into formula (6)

$$2\frac{T}{T_n} - 1, \quad 4\frac{T}{T_n} - 3, \quad 6\frac{T}{T_n} - 5 \quad . \; . \; . \; . \; . \; . \quad 2n\frac{T}{T_n} - (2n - 1),$$

until the value of $n = m$.

These values form the terms of a series. Their sum is easily got, and, if we double it, in order to add the effect of the waves which have passed before the origin of time, in Fig. 2, to the effect of those which have passed after it, we get the maximum amplitude of the rolling which would be reached on a non-synchronous swell and in a non-resisting medium.

We have

$$\Sigma\,(2 + 4 + 6 + \ldots\ldots + 2\,m)\,\frac{\mathrm{T}}{\mathrm{T}_n} - \Sigma\,(1 + 3 + 5 + \ldots\ldots + (2\,m - 1) = m\,(m + 1)\,\frac{\mathrm{T}}{\mathrm{T}_n} - m^2.$$

Replacing $\frac{\mathrm{T}}{\mathrm{T}_n}$ by its value in terms of m, drawn from equation (4) by

$$\frac{\mathrm{T}}{\mathrm{T}_n} = \frac{2\,m - 1}{2\,m},$$

we obtain

$$\Sigma\,(2\,q - 1) = \tfrac{1}{2}\,(m - 1);$$

and doubling this, in order to express the effect of $2\,m$ rolls, we get

$$\Psi = \mathrm{K}^2\,\Theta\,(m - 1). \qquad (7)$$

The only interest of this expression for the amplitude attained in a non-resisting liquid, like that of all others of a similar character, is one of pure curiosity; the advantage pertains to it over the others of having been arrived at in a very elementary manner, and it applies neither better nor worse than they do to the true rolling.

If in formula (7) we vary the co-efficient m from 1 to 5, which causes the factor $(m + 1)$ to vary from 0 to 4, we can see on the following table that the values corresponding to the ratio $\frac{\mathrm{T}_n}{\mathrm{T}}$, for which ψ passes through very different values, are all comprised between very restricted limits, which are easily attained in practice.

m.	$m - 1$.	$\frac{\mathrm{T}_n}{\mathrm{T}}$.
1·0	0·0	2·00
1·2	0·2	1·71
1·4	0·4	1·55
1·6	0·6	1·45
1·8	0·8	1·38
2·0	1·0	1·33
3·0	2·0	1·20
4·0	3·0	1·14
5·0	4·0	1·11

For $T = 5$ secs. it is only necessary for T_n to vary from 7·75 secs. to 5·55 secs., in order that $m - 1$ should vary from 0·4 to 4 (that is to say, from 1 to 10) while $\frac{T_n}{T}$ varies from 1·55 to 1·11. When $\frac{T_n}{T}$ passes from 1·71 to 1·11, Ψ varies from 1 to 20. Without attributing more importance to these numbers than they merit, we can see at least that they explain the very great differences of the amplitudes of the rolling of vessels which differ from each other but slightly when steaming on the same swell.

In considering the true rolling in a resisting medium, we will limit ourselves to the consideration of a particular case, viz., that of a vessel having 8 seconds for the half period of rolling, placed on waves of 7·2 seconds, which gives

$$m = \frac{1}{2}\,\frac{8}{0 \cdot 8} = 5.$$

For this case equation (7) gives (K^2 being made equal to $\frac{\pi}{2} = 1{\cdot}6$),

$$\Psi = 1{\cdot}6 \times 4\,\Theta = 6{\cdot}4\,\Theta.$$

Thus, for $\Theta = 10°$, we would have $\Psi = 64°$, and for $K^2\,\Theta = 10°$, $\Psi = 40°$.

Let us first assume for this particular case the results relating to rolling in a non-resisting medium, considering not only the maximum amplitude Ψ, but also the amplitude ψ, for each successive roll. Each amplitude ψ is equal to the sum of $\delta\psi$, corresponding to the rolls preceding the one under consideration from the instant that ψ equalled zero. We know how to calculate the values of $\delta\psi$ from equation (6).

We will suppose $K^2\,\Theta = 10°$.

We will trace the curve of the values of $\delta\psi$ and of ψ corresponding to the different rolls which follow one another, fixing the origin of time not, as in Fig. 2, on the roll, which gives the maximum positive effect, and, consequently, $\delta\psi = \Delta\psi$; but, on the roll commencing an increasing series, with $\delta\psi$ equal to zero; and we will suppose ψ, as well as $\delta\psi$ equal to zero at the origin.

Thus, in Fig. 3, Plate XXXIX., the point of the axis of abscissæ, starting from which the values of n are to count, is not the origin O, but the point 5.

Since we have supposed

$$\frac{T}{T_n} = 0{\cdot}9,$$

the successive values of $2q - 1$ are

For the roll 5	$2 \times 0{\cdot}9 - 1 = 0{\cdot}8$
„ rolls 6 and 4	$4 \times 0{\cdot}9 - 3 = 0{\cdot}6$
„ „ 7 and 3	$6 \times 0{\cdot}9 - 5 = 0{\cdot}4$
„ „ 8 and 2	$8 \times 0{\cdot}9 - 7 = 0{\cdot}2$
„ „ 0 and 9	0

The successive values of $(2q - 1) K^2 \Theta$ are then, starting from the origin—

	0°	2°	4°	6°	8°	8°	6°	4°	2°	0°
For the rolls ...	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10.

The curve which represents them (Fig. 3) is composed of the two straight lines A A.

This is evidently only an approximation. If one knew the true values of $\delta \psi$, they would rather form, I think, an undulating curve, having its ordinates equal to zero at the points 0 and 10, and its maximum ordinate at the point 5, after the manner of the curve *a a*. We can study this point later on, but, from the practical point of view, the straight lines A A are quite sufficient for the present.

Let us now add together the successive ordinates of the broken line A A—

$\delta_0 \psi$ 0
$\delta_0 \psi + \delta_1 \psi$ 2
$\delta_0 \psi + \delta_1 \psi + \delta_2 \psi$ 4
. . . .
$\delta_0 \psi + \delta_1 \psi$ . . . . . . $+ \delta_n \psi$,

and let us set up from the points 0, 1, 2, 3, ... *n* the ordinates thus obtained, which at first go on increasing—

0° 2° 6° 12° 20° 28° 34° 38° 40°

until we reach the maximum $\Psi = 40°$, and thence go on diminishing—

40° 38° 34° 28° 20° 12° 6° 2° 0°.

Taking these sums as ordinates, we obtain B B, the curve of amplitudes ψ successively attained in a non-resisting medium (Fig. 3).

We have now to deduce from this curve the unknown amplitudes ϕ in a resisting medium, knowing that the effect of the resistance is carried on from one roll to another in a diminution of the amplitude $\delta \phi$ given by equation (2) of the artificial rolls in calm water—

$$\delta \phi = N \phi^2. \qquad (2)$$

The values of N indicated by experience are generally comprised within the limits 0·008 and 0·012. Let us adopt the mean value, 0·01.

The curve of $\delta \phi$, on Fig. 2, may be obtained by successive trials conducing to more and more approximate curves. The condition to be satisfied is the following:—

Let C C be the curve of $\delta \phi$, which we have got to determine, and which we will suppose to be known. Let us get the sum of the ordinates—

$\delta_0 \phi$
$\delta_0 \phi + \delta_1 \phi$
. . . .
$\delta_0 \phi + \delta_1 \phi + \ldots \ldots \delta_n \phi$;

and let us set up these ordinates at the points 0, 1, 2, ... n, exactly as we did before, in order to deduce B the curve of rolls ψ from the curve A (broken line) of $\delta\psi$. The new curve D D thus obtained represents a series of what we may call negative amplitudes of a roll ϕn which does not exist, but the amplitudes of which, representing the cumulative effect of the resistances, starting from the origin, must be cut off from the amplitudes ψ, in order to give the true amplitudes ϕ.

Thus the curve C, and consequently the curve D, being supposed to be exact, the difference M N between the ordinate of B and the ordinate of D for any given roll having the number n represents the true amplitude ϕ of the roll n. If we take at the same point n the ordinate P Q of the curve C, we ought to have, according to equation (2)—

$$\overline{MN} = 0{\cdot}01\,\overline{PQ}^2.$$

When this condition is not satisfied, the curve C must be corrected by increasing its ordinates if the values of M N, which we have just found, are too great, and by diminishing them if the values are too small. The operation must be repeated until condition (2) is satisfied with sufficient accuracy. The point of intersection of the two curves B and D determines the abscissa, for which the amplitude ϕ equals zero, and consequently the true number of rolls included in a complete series of increasing and decreasing oscillations. This number is always less than $2\,m$, and may be much less. Consequently the true number of rolls which composes the first half of the series, that during which the amplitude ϕ goes on increasing, is equally diminished.

Thus, the influence of the passive resistances makes itself felt in two ways, and twice in the same sense, in diminishing the maximum amplitude, Φ, of the rolls compared to the maximum amplitude Ψ, which would be attained in a non-resisting medium; on the one hand it diminishes the sum $\Sigma\,\delta\psi$ constituting the angle Ψ by a quantity equal to the sum $\Sigma\,\delta\phi$ corresponding to the same number of rolls; on the other hand, it even diminishes the number of the differences $\delta\psi$, which enters into the sum $\Sigma\,\delta\psi$, and, consequently, enters into Ψ. There is a certain amount of interest about this point to which I draw attention, because the old theories give no prominence to it, or even are founded on hypotheses in flagrant contradiction with it.

When the two curves B and D have been obtained, nothing is easier than to trace E, the curve of amplitude ϕ, on which one can follow the law, according to which the rolls succeed each other, better than by consulting the distances M N between the curves B and D.

Starting from the point where the curve E intersects the axis of abscissæ, a new series of rolls, characterised by a new curve E^1 commences. The two series starting from dissimilar initial conditions, the two curves E and E^1 are necessarily unlike. Thus the passive resistances cause the mode of concordance between the wave and the roll at the commencement of each series to vary from series to series; they thus introduce a cause of irregularity which prevents the rolls from being repeated in uniformly periodic series, even on a regular sea. Moreover, the origin and the extremity of the curve E E differ completely from one another. The irregularity of the series is a fact proved by observation, but it is right to say, in order to explain this phenomenon, that other causes contribute towards producing it, besides that which the consideration of the effect of the passive resistances has just revealed.

Fig. 3 has been obtained with the aid of the trials which have just been described, and which in practice take nearly half the day's work of a skilful draughtsman, for each case considered.

The value ot $\frac{T}{T_n}$ is 0·9 in the figure; the value $K^2\Theta$ is 10°; the co-efficient N has received the three successive values of 0·008, 0·010, and 0·012, which according to formula (1), correspond with the three following values of the maximum semi-amplitude Φ_M on a synchronous swell.

N	Φ_M
	Degs.
0·008	35·4
0·010	31·6
0·012	28·9

The variable amplitude* of the rolls, on the given non-synchronous swell, is given in Table A, according to the curves E.

The three curves of rolling with resistance differ very much from the three curves of rolling without resistance; but they differ little amongst themselves. The effect of the co-efficient of decrease N is notably lessened by that of the co-efficient of agreement *m*.

The indicated maxima Φ for the rolls with resistance are very much the same as those observed in the usual conditions of the sea.

The three maxima Φ, which are respectively 22·7°, 21°, and 19·9°, differ only by 2·8°, while for the roll Φ_M the difference between the least and the greatest attained is nearly 6·5°.

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* Amplitude is here the angle described from the position of equilibrium; more exactly, it is the semi-amplitude of a roll.

TABLE A.

Number of Rolls.	Semi-Amplitudes of the Successive Rolls.			
	ψ without Resistance.	φ with Resistance.		
		N = 0·008.	N = 0·010.	N = 0·012.
	Degs.	Degs.	Degs.	Degs.
No. 1	0	0	0	0
„ 2	2	1·85	1·80	1·7
„ 3	6	5·6	5·4	5·2
„ 4	12	10·6	10·3	10·0
„ 5	20	16·4	15·8	15·3
„ 6	28	20·8	19·6	18·7
„ 7	34	22·7	21·0	19·9
„ 8	38	22·5	20·7	19·3
„ 9	40	21·0	19·0	17·6
„ 10	40	18·2	16·2	15·0
„ 11	38	14·3	12·4	11·2
„ 12	34	9·5	7·6	6·6
„ 13	28	3·5	1·9	0·9
„ 14	20	„	„	„
„ 15	12	„	„	„
„ 16	6	„	„	„
„ 17	2	„	„	„
„ 18	0	„	„	„

The number of rolls for a complete increasing and decreasing series has been reduced from 18 to 13, counting the last amplitude as *nil*, as the succeeding one was negative. The change of value of N has a certain influence on this number, but not a sufficient influence to make it vary by one unit under the conditions we have considered;

in order to reduce the total number of rolls of a complete series to 12, we should require, according to Fig. 3, to attribute a value to N which it would only have if bilge keels of very large surface were used.

If, instead of keeping, for N, to the small variations which are found to exist in ships very nearly similar to each other, we had taken extreme cases; such, for instance, as the value 0·04 observed on the *Elorn*, fitted with bilge keels, and the extraordinarily low value 0·004 observed on the *Sultan*, then the co-efficient N would have exercised a pronounced influence on the whole law of the motion. The total number of rolls in the first case would have been only 12; it would have been 14 in the second case. At the same time, the two maxima of Φ would have been respectively 12·8° and 27·8°. Fig. 3 only gives the extremity of the two curves D, corresponding to the two extreme cases.

We should have had to draw Fig. 3 for several properly chosen values of the co-efficient of agreement m; and, moreover, we should have had to cause $K^2 \Theta$ to vary, and in order to do this it would not have been sufficient to change the scale of the ordinates. We should thus obtain pretty easily a collection of data relating to non-synchronous rolling, complete enough to correspond with the actual state of the experimental data which we possess on the subject of $N . m$ and $K^2 \Theta$.

VOTE OF THANKS ON MONS. BERTIN'S PAPER.

Mr. W. H. White, C.B., LL.D., F.R.S. (Vice-President): As has always been our custom, I should like to formally move a vote of thanks of the Institution to Monsieur Bertin for this communication. It is one of a series we have had from him; and, I am sure, we all feel they have been of exceedingly high value. I have much pleasure in moving that the thanks of the Institution be formally voted to Monsieur Bertin for his very valuable paper. (Carried unanimously.)

THE STRESSES ON A SHIP DUE TO ROLLING.

By Professor A. G. GREENHILL, F.R.S.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 14th, 1894; Admiral the Right Hon. Sir JOHN DALRYMPLE HAY, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

THIS paper is intended as a sequel to the paper on "The Shifting of Cargoes" (Transactions of the Institution of Naval Architects, 1887, Vol. XXVIII.), by the late Professor Philip Jenkins; it resumes the subject where it was left by Professor Jenkins, who investigated the maximum effect which takes place at the extreme angle of a roll, and it extends his theory to the effect at any intermediate part of the oscillation, and to the case in which the angle of maximum righting moment may be less than a right angle.

The question of the rolling of ships has excited much public discussion of late, from the attention directed to some prominent instances of recent occurrence. The following investigation will show the difficulty of the exact measurement of the rolling, even by observers on deck or on the bridge. This difficulty is, of course, much increased for observers below decks, who judge by their own physical sensations, checked to some extent by the oscillations of a pendulum or of a swinging lamp. These oscillations vary very much with the position of the pendulum.

The subject is discussed analytically in Chapter xxxvii., Tome ii., of Pollard and Dudebout's "Théorie du Navire"; but it is hoped that the geometrical considerations of the present paper will put the theory in a more abbreviated form.

(1) For the purposes of this investigation the ship may be supposed to roll about a horizontal longitudinal axis through G, the centre of gravity (Fig. 1, Plate XL.)

On the assumption that the metacentre M is a fixed point in the ship, the angle of maximum righting moment is a right angle; and at any inclination θ from the upright position, the righting moment is

$$W \,.\, GZ = W \,.\, GM \sin\theta \text{ (ft.-tons)}$$

if the ship is of W tons displacement; so that if the moment of inertia of the ship about the axis of rotation is $W K^2$ (tons-ft.²), and if the stirring of the water is neglected, the ship will oscillate like a simple pendulum of length

$$G L = \frac{K^2}{G M} \text{ (feet)},$$

swinging through an equal angle 2α from side to side.

The length of the seconds pendulum is about 3·266 feet; so that if the time of a single roll is t seconds, then

$$G L = 3{\cdot}266 \times t^2;$$

thus if t is 5 seconds, $G L = 81{\cdot}25$ feet.

At the inclination θ from the upright, the angular acceleration will be—

$$\frac{d^2\theta}{d t^2} = -\frac{g}{G L} \sin\theta = -\frac{g}{G K}; \qquad (1)$$

if L K is drawn at right angles to G L to meet the horizontal through G in K (Fig. 1); while the angular velocity ω is, from the Principle of Energy, given by—

$$\tfrac{1}{2} G L \,.\, \omega^2 = g\,(\cos\theta - \cos\alpha). \qquad (2)$$

(2) If P Q represents a short plumb-line fastened at a point P of the ship, and carrying a plumb-bob weighing w lb., the plumb-line P Q at any part of the roll will assume the direction of the resultant of the force of gravity, w pounds, on P, and of the reversed effective force of w lb. at P; and the tension T of the plumb-line will be equal to this resultant.

Denoting this reversed effective force by F pounds, making an angle ϕ suppose with G P, then F can be resolved into the two components—

$$F \cos\phi = \frac{w}{g}\,\omega^2 \,.\, G P, \text{ the } \textit{centrifugal force}, \text{ acting along } G P;$$

$$F \sin\phi = -\frac{w}{g}\frac{d^2\theta}{d t^2} \,.\, G P = w \sin\theta \,\frac{G P}{G L}, \text{ the } \textit{tangential} \text{ force, across } G P.$$

Taking a parallel axis through I vertically above G, at a height

$$\frac{g}{\omega^2} = \frac{G L}{2\,(\cos\theta - \cos\alpha)} \text{ feet},$$

the resultant of gravity, w pounds, and of the centrifugal force,

$$\frac{w}{g}\,\omega^2 . G P = w \frac{G P}{G I} \text{ pounds},$$

will be a force $w \frac{I P}{G I}$ pounds, acting along I P.

Draw P R at right angles to G P of length G P tan ϕ, so that the angle P G R $= \phi$; then the tangential effective force on w lb. at P is

$$\frac{w}{g}\omega^2 . \mathrm{G\,P} \tan\phi = w\frac{\mathrm{P\,R}}{\mathrm{G\,I}} \text{ pounds};$$

so that the resultant of gravity and the total reversed effective force on w lb. at P is a force

$$\mathrm{T} = w\frac{\mathrm{I\,R}}{\mathrm{G\,I}} \text{ pounds}, \qquad (3)$$

in the direction I R; and, therefore, the plumb-line, P Q, will assume a direction parallel to I R, if the thread P Q is so short that the natural free oscillations of the plummet are quick and die out rapidly.

(3) Now, since

$$\tan\phi = -\frac{1}{\omega^2}\frac{d^2\theta}{d\,t^2} = \frac{g}{\omega^4}\left(-\frac{1}{g}\frac{d^2\theta}{d\,t^2}\right) = \frac{\mathrm{G\ I}}{\mathrm{G\ K}},$$

therefore the angle I K G $= \phi$; and if G J is drawn perpendicular to I K, the triangles G J I and G P R are similar, as also the triangles G R I and G P J, homologous sides being inclined at an angle ϕ.

The tension of the plumb-line is thus

$$\mathrm{T} = w\frac{\mathrm{I\,R}}{\mathrm{G\,I}} = w\frac{\mathrm{J\,P}}{\mathrm{G\,J}} \text{ pounds}, \qquad (4)$$

in a direction making an angle ϕ with J P; and thus the rolling of the ship converts the steady vertical lines of force of gravity on *terra firma* into variable equiangular spirals, having at any instant a common pole J and the same radial angle—

$$\phi = \tan^{-1}\frac{\sin\theta}{2(\cos\theta - \cos\alpha)}, \qquad (5)$$

α denoting the extreme angle of a roll, and θ any intermediate inclination from the upright.

(4) If a tumbler or bucket of water, or a mercurial horizon, is held at P, the free surface, if small enough for the waves on it to die out rapidly, will be perpendicular to the direction of the plumb-line P Q; and these free surfaces will form portions of cylindrical surfaces, the cross section of which will be equiangular spirals orthogonal to the first system.

A marine barometer, or a swinging lamp, suspended in gimbals at P, will hang in the direction P Q; and the mercury column, if sufficiently mobile, would stand at a height x, instead of the true height h, when registering the atmospheric pressure σh, σ denoting the density of mercury, where

$$\sigma h = \sigma x \frac{\mathrm{J\,P}}{\mathrm{G\,J}},$$

so that

$$x = h\,\frac{\mathrm{G\,J}}{\mathrm{J\,P}}; \qquad (6)$$

and, to prevent this so-called *pumping* action, the tube of the marine barometer must be contracted to a fine bore for a part of its length; or else the barometer must be suspended at G.

(5) If a box of sand is held at P, the sand will slip when the angle between P Q and the normal to the surface of the sand exceeds ϵ the angle of repose of the sand; in this manner Professor Jenkins analysed the tendency of the cargo to slip at any point, when it was not stowed close up to the beams.

According to Professor Jenkins this tendency to shift is a maximum at the end of a roll, the condition to which he confined his attention; and now $\phi = \frac{1}{2}\pi$, and J coincides with K.

The plumb-line P Q now sets itself at right angles to P K, and the free surface of the water in the tumbler or bucket, and of the mercury in the mercurial horizon, is a plane passing through K; while a grain cargo will slip at P if the angle between its surface and P K is less than ϵ, the angle of repose.

Thus, if a bucket is taken up the mast to a point A, the water will be spilt at the end of a roll through an angle 2α, which would require a steady inclination ϵ (the angle of repose of the sand) given by

$$\tan\epsilon = \frac{\mathrm{A\,L}}{\mathrm{K\,L}} = \frac{\mathrm{A\,L}}{\mathrm{G\,L}}\tan\alpha \qquad (7)$$

A tumbler placed at L will never spill, so that L, or as near as it can be reached, is therefore the steadiest part of the ship; this can be verified experimentally by a heavy pendulum representing the ship provided with platforms in which small tumblers of water or of sand may be placed.

Thus, if a tumbler of water is placed on a platform at the axis of suspension G, the surface will preserve its horizontal direction in space; and a short plumb-line, or lamp, suspended at G will hang vertically. The pendulum for measuring the oscillations of a ship should therefore be suspended as near as possible to the axis about which the ship may be supposed to roll.

At the end of a roll the tension of the plumb-line P Q is

$$\mathrm{T} = w\,\frac{\mathrm{K\,P}}{\mathrm{G\,K}} \text{ pounds.} \qquad (8)$$

Thus a yard, weighing P tons, attached to the mast at A, will at the end of a roll call up a stress of

$$\mathrm{P}\,\frac{\mathrm{A\,K}}{\mathrm{G\,K}}\ \text{tons},$$

in a direction at right angles to A K.

As the ship swings through the upright position, J coincides with I, and $\phi = 0$. The plumb-lines now all point to I, and the free surfaces of liquid in different parts of the ship are circular cylinders, about a common horizontal axis through I; this is the theory employed in the design of water-wheels to determine the amount of water spilt out of a bucket at any part of its revolution.

(6) It is interesting to discuss the curves traced out by I, J, and K, both in space and relatively to the ship.

In space (Fig. 1) K describes a horizontal line G K, and I describes a vertical line G I; and it will be found that I K touches an ellipse, with centre C at a height

$$\mathrm{G\,C} = \tfrac{1}{2}\,\mathrm{G\,L}\ \mathrm{cosec}\,\alpha\cot\alpha = \tfrac{1}{2}\,\mathrm{G\,K}_\alpha\cot\alpha,$$

so that C lies on the straight line bisecting $\mathrm{L}_\alpha\,\mathrm{K}_\alpha$ at right angles; the locus of J is therefore the *pedal* of this ellipse with respect to G.

For if G H (in Fig. 1) is taken equal to $\tfrac{1}{2}$ G K cosec α, and if the angle G I H is denoted by θ', then—

$$\tan\theta' = \tfrac{1}{2}\,\mathrm{cosec}\,\alpha\cot\phi = \frac{\cos\theta - \cos\alpha}{\sin\alpha\sin\theta},$$

$$\sin\theta' = \frac{\cos\theta - \cos\alpha}{1 - \cos\alpha\cos\theta},\quad \cos\theta' = \frac{\sin\alpha\sin\theta}{1 - \cos\alpha\cos\theta};$$

and therefore the length of the perpendicular from C on I H is

$$\mathrm{C\,I}\sin\theta' = (\mathrm{G\,I} - \mathrm{G\,C})\sin\theta'$$

$$= \left(\frac{\mathrm{G\,L}}{2\cos\theta - 2\cos\alpha} - \frac{\mathrm{G\,L}\cos\alpha}{2\sin^2\alpha}\right)\frac{\cos\theta - \cos\alpha}{1 - \cos\alpha\cos\theta} = \frac{\mathrm{G\,L}}{2\sin^2\alpha},$$

a constant; so that I H touches a circle, centre C and radius $\tfrac{1}{2}$ G L $\mathrm{cosec}^2\,\alpha$; and therefore I K touches an ellipse of semi-axes

$$\mathrm{C\,I}_0 = \tfrac{1}{2}\,\mathrm{G\,L}\ \mathrm{cosec}^2\,\alpha \text{ and } 2\,\mathrm{C\,I}_0\sin\alpha = \mathrm{G\,L}\ \mathrm{cosec}\,\alpha = \mathrm{G\,K}_\alpha.$$

Thus, if the ship swings through 60°, $\alpha = 30°$, and this ellipse is a circle.

In the ship (Fig. 2, Plate XLI.,) K describes the straight line L K at right angles to G L, and I describes a hyperbola of excentricity sec α, with a focus at G, directrix at a height $\frac{1}{2}$ G L above G, and centre at C′ at a height G C′ = $\frac{1}{2}$ G L cosec α.

If J′ is taken in G J, such that

$$G J' = G L^2 \div G J,$$

a third proportional to G J and G L, then it will be found that J′ lies on the foot of the perpendicular from L on the tangent to the circle with centre O, where

$$G O = 2 G L,$$

this circle subtending an angle 2 α at G.

The locus of J in the ship is therefore the inverse with respect to G of the *pedal* of this circle with respect to L.

The demonstration of these theorems is easily constructed.

(7) If the vanishing angle of stability of the ship is found to be 180° ÷ n, instead of 180°, then, on the assumption that the curve of statical stability is still a *sinusoid*, equations (1) and (2) must be replaced by

$$\frac{d^2 \theta}{d t^2} = - \frac{g}{G L} \frac{\sin n \theta}{n} \tag{9}$$

$$\tfrac{1}{2} G L \,.\, n^2 \omega^2 = g (\cos n \theta - \cos n \alpha), \tag{10}$$

so that the oscillations of the ship now synchronise with a pendulum of equivalent length O L, swinging through n times the angle of oscillation of the ship.

Figs. 1 and 2 will still serve to represent the interior stresses due to the rolling of the ship, provided G K is stretched n times and G I is stretched n^2 times, so that tan ϕ is increased n times, while the corresponding angle of inclination of the ship from the upright is taken as one-nth of the angle A G I.

Suppose, for instance, that $n = 3$, so that the angle of vanishing stability of the ship is 60°, then, if the ship rolls to an extreme inclination of 30° from the upright, $\alpha = 30°$ and $3 \alpha = 90°$; so that K_α, the position of J or K when $\theta = \alpha$, is now on G K, at a distance G $K_\alpha = 3$ G I.

The general effect is to drive J away to a greater distance, and in a direction more nearly horizontal; and at the same time to increase the angle ϕ, so that the motion of the ship is, on the whole, easier, and the sensation on board is more like that on *terra firma*.

The metacentric evolute is now a hypocycloid, with n cusps, and the C.G. of the ship is at the centre of the hypocycloid; the metacentre M, for the upright position, being at the upper end of a cusp.

(8) If the C.G. is lowered by a change of ballasting through a distance a feet, the righting arm G Z is given in length by an expression of the form

$$a \sin \theta + \frac{b}{n} \sin n\theta ;$$

so that the equations of oscillation become

$$\frac{K^2}{g} \frac{d^2\theta}{dt^2} = -a \sin \theta - \frac{b}{n} \sin n\theta \qquad (11)$$

$$\frac{1}{2} \frac{K^2}{g} \omega^2 = a (\cos \theta - \cos \alpha) + \frac{b}{n^2} (\cos n\theta - \cos n\alpha) \qquad (12),$$

and the rolling stresses in the interior are obtained by a superposition of the two states of (3) and (7).

It is found conducive to steadiness and stiffness to put M at the lower end of a cusp; and now the equations of oscillation become

$$\frac{K^2}{g} \frac{d^2\theta}{dt^2} = - \mathrm{G\,Z} = -a \sin \theta + \frac{b}{n} \sin n\theta \qquad (13)$$

$$\frac{1}{2} \frac{K^2}{g} \omega^2 = a (\cos \theta - \cos \alpha) - \frac{b}{n} (\cos n\theta - \cos n\alpha) \qquad (14),$$

so that the rolling stresses of (7) can be deducted from those of (3).

Even with G a little above M, when $a < b$, and the ship is initially unstable, and lolls slightly to one side or the other, the steadiness is still further increased.

I am informed by a passenger, who crossed from America last year in one of the largest Transatlantic steamers, that there was a slight permanent list to one side or other for the greater part of the voyage, and that the steadiness of the vessel was very remarkable.

DISCUSSION.

Mr. J. J. Ellis (Member): Sir John Hay and Gentlemen, there is very little I have to say on this paper. It is one of considerable interest, and more so as it seems to have a special bearing on the paper which preceded it. At first sight, the title of the paper may not appear to be quite clear; but, as I understand it, Professor Greenhill here makes an investigation of the effect (both in magnitude and direction) of the rolling of the vessel on a plumb bob of known weight suspended freely at a known position in the ship. This is, of course, a measure of the stresses produced by the rolling on the material of the vessel at that part. In the paper read this morning, and in the discussion which followed, particular attention was drawn to the difficulty of accurately measuring a ship's rolling, especially when the pendulum is suspended at a point high up in the vessel. The first page of the present paper calls attention to the same fact, and very much of what is stated in the paper shows, or tends to show, how much error may creep in. Instead of a simple pendulum, suspended in a position considerably above the centre of gravity of the vessel, giving correct indications of rolling, it has been known to give indications which amounted to twice as much as the actual roll of the vessel. The pendulum for measuring rolling should, therefore, be suspended as nearly as possible at the centre of gravity of the vessel; the greater the departure from that position in a vertical direction the more inaccurate are the results obtained. But not only for rolling does this hold true, it is also the case with the much more common experiment of inclining a ship for stability. If this experiment has to be conducted on a day with any wind, it is a matter of common experience, especially if the vessel is "tender," that considerable difficulty is often met with in obtaining accurate readings; the pendulum oscillates to such a degree that it requires extreme care to obtain results at all reliable. This is due to a bad choice of vertical position for the suspension of the plumb bobs; they are often suspended at a considerable distance above the centre of gravity of the vessel. The proper point (vertically) for the suspension of the plumb bobs, when inclining a vessel, is as nearly as possible at the centre of gravity of the ship. The last dozen lines of the paper contain a remark with which we are all familiar in a general sense, namely, that a small metacentric height—sometimes even a negative metacentric height of small amount—is conducive to easy motion of a vessel at sea. The paper, as a whole, is one well worthy of study, and will form a valuable addition to the Transactions of the Institution.

Mr. J. MACFARLANE GRAY (Member of Council): The writer of the paper has complimented us in a way that we scarcely deserve. By reading the paper to us he has led us to believe that he considered we were all able to follow the reasoning, keeping pace with the utterances. We have implicit faith in Professor Greenhill, but we must read and consider such a paper at home. I can see it is one of great value, and, knowing Professor Greenhill as I do, I said to a gentleman who was leaving: "Stay; remember that if you were to count the mathematicians in the world, beginning at the highest, counting them on your fingers, before you got once over your fingers you would have Greenhill, and that man is going to read this paper to us." There is also another valuable paper communicated now by the same author to be taken as read. We owe Professor Greenhill our sincere thanks for having prepared these papers for us, and for the many others which he has read at this Institution. It has been suggested to me what an advantage it would be to have someone to boil down the mathematics of each session's papers, and at the end of every volume to have it served up in the form of a popular lecture. What a godsend this would be to many of us—and it could be done.

Mr. W. H. WHITE, C.B., LL.D., F.R.S. (Vice-President): Sir John Hay and Gentlemen, I had the opportunity before coming to the meeting of reading this paper and the companion paper which Professor Greenhill has contributed to our proceedings, which will not be read. Mr. Macfarlane Gray has done no more than justice to Professor Greenhill's great mathematical ability, and to the services which he has rendered to this Institution on previous occasions. In these two papers Professor Greenhill, I understand, does not propose, in any important points, to go beyond what has been done before; but, in geometrical methods, to give us a very convenient and graphic representation of matters affecting the qualities of ships, the stresses on ships' structure, and the indications of pendulums. He has put these matters in a form which is not merely beautiful in itself, but is much more easily followed than mathematical expressions. When this paper comes to be read it will be seen that Professor Greenhill points out most clearly the causes of error in any gravitational instrument used in a ship for indicating the oscillations of the ship herself. The other paper, as a piece of pure geometry, I think is admirable. On Leclert's Theorem, I may be permitted to say that I take very great personal interest in it, having been one of the first to apply Leclert's Theorem to ordinary ship diagrams and calculations. At the Naval College we did, as class exercises, much work of that kind, not in any way anticipating Professor Greenhill's work, but extending and applying Leclert's beautiful Theorem to various features of ship calculation. I agree with Mr. Macfarlane Gray that both contributions are to be read rather than discussed, but at the same time I am sure the meeting will desire to recognise the value of the contributions coming from Professor Greenhill, and which will appear in our Transactions. Many of the members may not have the mathematical power to follow these papers. Those who have the necessary knowledge, and who aim at mastering the science as well as the practice of shipbuilding, will heartily endorse everything that has been said about our obligations to the writer of these papers.

Professor A. G. **Greenhill**, F.R.S. (Visitor): Sir John Hay and Gentlemen, I am glad of an opportunity of expressing my thanks for the very valuable criticisms that have been made, because I felt some timidity in coming before this Institution as a mere amateur. Mr. Macfarlane Gray made some very complimentary remarks when he said that I was complimentary in putting such a paper before the meeting. I think Mr. Macfarlane Gray has been equally complimentary on other occasions. As to the paper on Leclert's Theorem, I should like to explain that I would not venture to claim any originality in the results. I wished merely to present the Theorem in a manner which, to my mind, seemed a simple way of presenting it. There was one remark in the preceding paper, if I am in order in referring to it, concerning the peculiarity in behaviour of the rolling of a ship when on the top of a wave. Mr. White has discussed the problem in his "Naval Architecture," and this seemed a very valuable object-lesson as to the manner in which a ship would become unstable on the top of a wave. Mr. White's dramatic model on the wall of a rolling ship encourages me to make a suggestion which, I hope, he will receive seriously; I mean I hope it will not excite his amusement. Why not construct a full-sized model of this kind of the cross section of a ship? A certain length of the ship, but of full size, suspended so that this model ship might oscillate in exactly the same manner as the real ship would at sea. Such a full-sized model would prove very useful in training our young sailors and marines to the motion of the water, and would serve also for the training of seamen gunners. Rocked in this cradle of the deep before putting to sea, our sailors would meet with greater equanimity an equivalent rolling in the Bay of Biscay.

The **Chairman** (Admiral the Right Hon. Sir J. Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): I am sure the meeting desires me to thank Professor Greenhill for his valuable paper. I do not propose to offer any observations upon it, because I feel assured I should not enlighten the meeting if I did. It will always be on record in the Transactions of the Society, and will be extremely valuable to refer to. The thanks of the meeting will be given to Professor Greenhill for this and for the following paper, which is to be placed in our Transactions, but not to be read. That paper follows this, and is on Leclert's Theorem, for which I am sure you will also thank him most cordially.

LECLERT'S THEOREM.

By Professor A. G. Greenhill, F.R.S.

[Communicated to the Thirty-fifth Session of the Institution of Naval Architects, March 14th, 1894; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

This elegant theorem, connecting the curvatures of the curves of flotation and of buoyancy, published in 1870 by Monsieur Émile Leclert, was first brought before the attention of readers in this country by Mr. C. W. Merrifield, in the Transactions of the Institution of Naval Architects, 1870, Vol. XI., and also in the "Messenger of Mathematics," Vol. I.

The geometrical construction for drawing the tangent of the curves of metacentres and of buoyancy, and of cross curves of stability, communicated to this Institution by the late Professor Philip Jenkins, in 1884 and 1889, can be shown as direct corollaries of Leclert's Theorem; so I venture to submit a new demonstration of these theorems, which I hope will put some of the details in a clearer light, and show that most of the theorems useful in Ship Geometry are embodied in Leclert's Theorem.

(1) Let B_1, B_2 denote the C.B.'s (centres of buoyancy) of a ship in two consecutive inclined positions at constant displacement V ft.^{3}, so that $B_1 B_2$ is a small arc of the curve of buoyancy; and let $F_1 F_2$ be the corresponding parallel arc of the curve of flotation (Fig. 1, Plate XLII.).

Produce $F_1 B_1$, $F_2 B_2$ to meet in O; and let the normals at $B_1 B_2$ to the curve of buoyancy intersect in M_1; and the normals at $F_1 F_2$ to the curve of flotation intersect in C_1; so that $B_1 M_1$ and $F_1 C_1$ become ultimately r and r_1, the radii of curvature of the curves of buoyancy and of flotation.

Then since by Dupin's Theorem the normals at B_1, F_1 are parallel, and also at B_2, F_2, therefore—

$$\frac{B_1 M_1}{F_1 C_1} = \frac{B_1 B_2}{F_1 F_2} = \frac{O B_1}{O F_1}; \qquad (1)$$

and therefore M_1 lies on the straight line O C_1.

(2) Now suppose the displacement of the ship is changed from V to $V - \frac{1}{2}\Delta V$ and $V + \frac{1}{2}\Delta V$; and that, in consequence, B_1 changes to b_1 and β_1, B_2 changes to b_2 and β_2, M_1 to m_1 and μ_1, F_1 to f_1 and ϕ_1, and F_2 to f_2 and ϕ_2.

The small increment of displacement ΔV which changes the displacement from $V - \frac{1}{2}\Delta V$ to $V + \frac{1}{2}\Delta V$ may be supposed concentrated at F_1, the centre of gravity of the corresponding water-line area; so that

$$(V - \tfrac{1}{2}\Delta V)\, b_1 F_1 = (V + \tfrac{1}{2}\Delta V)\, \beta_1 F_1,$$

or—

$$\frac{b_1 \beta_1}{B_1 F_1} = \frac{\Delta V}{V}, \qquad (2)$$

since B_1 may be taken as the middle point of $b_1 \beta_1$.

The similarity and parallelism of the small arcs $b_1 b_2$, $\beta_1 \beta_2$, $F_1 F_2$, show, as before, that m_1 and μ_1 also lie in $O C_1$, m_1 and μ_1 being the points of intersection of the normals at b, b_2 and β_1, β_2 to the corresponding small arcs $b_1 b_2$, $\beta_1 \beta_2$ of the curves of buoyancy.

(3) Drawing $m_1 m$, $M_1 D$ parallel to $O F_1$, we may denote $m \mu_1$ by Δr, as it is the increment in r due to the increment ΔV in V; and therefore

$$\frac{\Delta r}{r_1 - r} = \frac{m \mu_1}{D C_1} = \frac{b_1 \beta_1}{B_1 F_1} = \frac{\Delta V}{V},$$

or—

$$r_1 - r = V \frac{\Delta r}{\Delta V}, \qquad (3)$$

Leclert's first expression for r_1, and the one preferred by him, as it expresses r_1 in terms of r and V, which are quantities usually plotted in French calculations for different draughts of water. (Sir Edward J. Reed, "The Stability of Ships," p. 245.)

Also since

$$r = \frac{I}{V},$$

where I denotes $A k^2$, the moment of inertia of the water-line area in biquadratic feet (ft.^{4}), therefore, in the notation of the Differential Calculus—

$$r_1 = \frac{I}{V} + V \frac{d}{dV}\left(\frac{I}{V}\right) = \frac{dI}{dV}, \qquad (4)$$

Leclert's second expression for r_1.

Similar equations obviously connect R and R_1, the radii of curvature of the longitudinal curves of buoyancy and of flotation.

(4) By sharing the change of displacement ΔV between an increase and a decrease on the mean displacement V, the approximate calculation in (3) is rendered more rigorous in practical constructions, and also in its subsequent applications to drawing tangents, according to the method of Professor Jenkins; and the ambiguity as to whether the value of r_1 should be taken to correspond to the first or last displacement is removed.

Simple verifications of formulas (3) and (4) are afforded by a floating body, such as a circular pontoon, a cigar ship, or a spherical buoy.

If the cross section of the vessel is parabolic, then the curves of buoyancy and flotation are equal parabolas: $B_1 F_1$ and $M_1 C_1$ are parallel, and $r_1 = r$.

If the cross section is elliptic or hyperbolic, the curves of buoyancy and flotation are similar ellipses or hyperbolas, and the point O is the common centre.

(5) We notice that an increase of displacement of ΔV on V causes the C.B., B_1, to move towards F_1 through a distance,

$$b_1 \beta_1 = \frac{\Delta V}{V} . B_1 F_1 ; \tag{5}$$

and causes the prometacentre M_1 to move towards C_1 through a distance,

$$m_1 \mu_1 = \frac{\Delta V}{V} . M_1 C_1 . \tag{6}$$

Thus, a small increase of the load, or displacement, or draught of water, will cause the metacentre to rise or fall in the ship, according as the metacentre M lies below or above C, the centre of curvature of the curve of flotation; the metacentre M being stationary, as pointed out by Mr. W. H. White, when M and C are coincident (Trans. I.N.A., 1878, Vol. XIX.).

(6) Suppose the displacement is changed from $V - \frac{1}{2} \Delta V$ to $V + \frac{1}{2} \Delta V$ by the addition of a load, equal to the weight of a volume ΔV of water, whose C.G. is at g; and that the C.G. of the ship changes in consequence from g_1 to γ_1, passing through G. Dropping the perpendiculars $g_1 z_1$, $G Z_1 N$, $\gamma_1 \zeta_1$ on the lines $b_1 m_1$, $B_1 M_1$, $\beta_1 \mu_1$, $F_1 C_1$, which are vertical in the corresponding inclined position of the ship, then $g_1 z_1$, $G Z_1$, $\gamma_1 \zeta_1$ are the righting arms for the displacements $V - \frac{1}{2} \Delta V$, V, $V + \frac{1}{2} \Delta V$; and, laying off F H on the water-line of the upright position to represent to scale the righting moment $V . G Z_1$, the curve of H will be the "cross curve of stability" for this inclination, employed by Professor Elgar and Messrs. Denny.

If h and η denote the position of H for the displacements $V - \frac{1}{2} \Delta V$ and $V + \frac{1}{2} \Delta V$, and if A denotes the water-line area, and Δx the change of draught $f \phi$ in the upright position corresponding to the change of displacement ΔV, so that

$$\Delta V = A \Delta x,$$

then (Fig. 1)

$$\begin{aligned} k \eta &= (V + \tfrac{1}{2} \Delta V) \gamma_1 \zeta_1 - (V - \tfrac{1}{2} \Delta V) g_1 z_1 \\ &= \Delta V . G Z_1 + V . (\gamma_1 \zeta_1 - g_1 z_1) \\ &= \Delta V (G Z_1 + Z_1 N - G n) = \Delta V . n N \end{aligned}$$

$$\frac{k \eta}{h k} = A . n N, \tag{7}$$

by means of which, as shown by Professor Jenkins (Trans. I.N.A., Vol. XXV.), the tangent at H of the cross curve of stability can be drawn, the tangent being parallel to F G when $F_1 C_1$ passes through g, as pointed out by Mr. W. H. White (Trans. I.N.A., Vol. XIX., p. 208).

(7) If the ship heels through a small angle of $\Delta\theta$ radians ($57{\cdot}3 \times \Delta\theta$ degrees) at the displacement V, so that the C.B. is changed from B_1 to B_2, and if $G Z_2$ is the perpendicular from G on the new vertical $B_2 M_1$, and H′ the corresponding point on the consecutive cross curve of stability, then, ultimately,

$$\frac{H H'}{F H} = \frac{G Z_2 - G Z_1}{G Z_1} = \frac{M_1 Z_1}{G Z_1} \,.\, \Delta\theta = \tan M_1 G Z_1 \,.\, \Delta\theta, \qquad (8)$$

a theorem which might prove useful in interpolating cross curves of stability between calculated curves for given inclinations.

(8) If the curves of metacentres $M M_1$, of C.B.'s $B B_1$, and of C.G.'s $G G_1$ for the upright position of the ship are drawn in Mr. Barnes's manner, with respect to an inclined line of draught $F F_1$ (Fig. 2, Plate XLII.), then, from the preceding equations (5) and (6), if the water-line changes from $L_1 L_1'$ to $L_2 L_2'$ in consequence of a slight *diminution* Δ V of the displacement,

$$\tan B_2 B_1 b = \frac{b B_2}{B_1 b} = \frac{A}{V} \,.\, F_1 B_1, \qquad (9)$$

$$\tan M_2 M_1 m = \frac{m M_2}{M_1 m} = \frac{A}{V} \,.\, M_1 C_1, \qquad (10)$$

the theorems for drawing the tangents to the curves $B B_1$ and $M M_1$ given by Professor Jenkins in the Transactions of the Institution of Naval Architects, Vol. XXV.

Equation (10) shows that the curve of metacentres $M M_1$ is horizontal where it is crossed by the curve $C C_1$ of centres of curvature of the curve of flotation, as pointed out by Mr. W. H. White (Trans. I.N.A., Vol. XIX.).

(9) Within the limits in which the ship is wall sided, A and I are constant, and therefore $r_1 = 0$; and the curve C C coalesces with the inclined line $F F_1$.

Also, if we put—

$$\frac{V}{A} = a,$$

so that a is the draught of the vessel of box form of equal displacement V; and if the inclined line $F F_1$ cuts the bottom of this box-shaped vessel in O, then the straight line N O, where $F N = \frac{1}{2} a$, will be the curve of C.B.'s of the box-shaped vessel, and the parallel straight line F h will be the curve for h, the C.G. of the volume of emersion.

If, in the actual vessel, B goes to B_1 and N to N_1 for a change of draught F F_1 of x feet, then—

$$(V - A x)\, B_1 h = V \,.\, B h,$$
$$(V - A x)\, N_1 h = V \,.\, N h;$$

and, therefore—

$$(V - A x)\, B_1 N_1 = V \,.\, B N,$$

or—

$$\frac{B_1 N_1}{B N} = \frac{V}{V - A x} = \frac{O N}{O N_1}, \qquad (11)$$

so that the curve B B_1 is a hyperbola, with O N and the vertical O K through O as asymptotes, if the ship is taken as wall-sided.

Also—

$$(V - A x)\, B_1 M_1 = V \,.\, B M = I,$$

by the well-known formula for B M, so that

$$(V - A x)\, M_1 N_1 = V \,.\, M N, \qquad (12)$$

and therefore the curve of metacentres M M_1 is also a hyperbola, with the same asymptotes.

(10) For homogeneous cargo the curve G G_1 of C.G.'s will also be a hyperbola, with O K for one asymptote, and a sloping line for the other asymptote, the position depending on the specific gravity s of this homogeneous cargo, and on the depth of the hold.

For if the horizontal surface of the cargo at displacement V cuts the vertical G F in f, and the point O′ is taken in F G produced, such that

$$f O' = F O \div s,$$

then f O′ is the depth of a vessel of box form, supposed homogeneous and of S.G. s, which will float at a draught F O.

The curve of C.G.'s of these homogeneous box-shaped vessels for different draughts will be a straight line D D_1, passing through D, the middle point of f O′, and inclined at an angle $\tan^{-1} 2 s$ to the vertical; and, as before,

$$(V - A x)\, G_1 D_1 = V \,.\, G D, \qquad (13)$$

or—

$$O'' D_1 \,.\, G_1 D_1 = O'' D \,.\, G D,$$

so that the curve G G_1 is a hyperbola, with O″ K and D D_1 for asymptotes.

The tangent to the curve $G\,G_1$ will be horizontal, and the C.G. will reach its lowest position when it lies in the horizontal upper surface of the cargo; for in this case the addition or subtraction of a small amount of cargo will not cause the C.G. to descend, and the C.G. is stationary.

These geometrical properties of the wall-sided ship may prove practically useful in cases where, as Professor Jenkins pointed out, an estimate of the qualities of a new design are required in a hurry.

(11) To construct these hyperbolas, say, the hyperbola $M\,M_1$, passing through M, and having the asymptotes O N and O K, by determining the point M_1 corresponding to the draught F_1, draw M Q parallel to O N to meet the vertical $B_1\,F_1$ in Q, produce O Q to meet B F in R, and draw $R\,M_1$ parallel to O N; this will meet $B_1\,F_1$ in M_1.

Or a few points on the hyperbola can be obtained rapidly by drawing a straight line H M K through M in any direction, meeting the asymptotes O N and O K in H and K, and marking off $K\,M_1 = M\,H$, when M_1 will be a point on the hyperbola.

(12) As a well-known illustration of equation (6), we may mention that, as a ship sails from fresh into salt water, in which the increase of density is Δw on w, then the corresponding *decrease* of displacement ΔV will cause M to move away from C to M_1, so that

$$\frac{M\,M_1}{M\,C} = \frac{\Delta V}{V} = \frac{\Delta w}{w}, \qquad (14)$$

and the metacentre thus rises or falls in the ship in going from fresh into salt water, according as M is above or below C.

Again, the removal of a small quantity of cargo, P tons, whose C.G. is at g, from a vessel of W tons displacement (for instance, the consumption of P tons of coal), will cause G to move away from g to G_1, so that

$$\frac{G\,G_1}{G_1\,g} = \frac{P}{W} = \frac{\Delta V}{V} = \frac{M\,M_1}{M\,C}, \qquad (15)$$

and therefore the change of metacentric height

$$\begin{aligned} G_1\,M_1 - G\,M &= G\,G_1 - M\,M_1 \\ &= \frac{P}{W}(G_1\,g - M\,C) \\ &= \frac{P}{W}(G\,M - g\,C); \qquad (16) \end{aligned}$$

and within the limits in which the ship is wall-sided, C lies in the water-line.

Equation (16) has been employed by Mr. Nicholson in his paper on "The Arrangement of Coal Bunkers so as to reduce the Ballast to a Minimum" (Trans. I.N.A., 1885).

If the stiffness of the vessel is measured by W . G M, the loss of stiffness due to burning P tons of coal is

$$\begin{aligned} & W \cdot GM - (W - P)\, G_1 M_1 \\ &= P \cdot G_1 M_1 - P\,(G_1 M_1 - gC) \\ &= P \cdot gC \end{aligned} \qquad (17)$$

approximately; and in a wall-sided vessel C is on the level of the water, so that the stiffness is unaltered if g is the water-line.

(13) In a recent number of the *Comptes Rendus*, June 12, 1893, "*Sur une rémarque de M. E. Guyou relative aux calculs de stabilité des navires,*" *Note de M. Ch. Doyère*, the author points out that equations (1) or (5) are true also when the distances are measured parallel to any fixed direction, so that if ξ and X denote the distances of F and B from any fixed plane

$$\xi - X = V \frac{dX}{dV}. \qquad (18)$$

Then, if $\Delta \xi$ and ΔX denote simultaneous changes in ξ and X,

$$\Delta \xi - \Delta X = V \frac{d}{dV} \Delta X, \qquad (19)$$

whence Leclert's Theorem in equation (3) follows immediately.

MM. Guyou and Simart point out in the *Comptes Rendus*, March 6, 1893, and *Développements de Géométrie du Navire*, that the successive differentiations of Leclert's formula (3), with constant displacement V,

$$\begin{aligned} r_1' &= r' + V \frac{dr'}{dV} \\ r_1'' &= r'' + V \frac{dr''}{dV} \end{aligned} \qquad (20)$$

. . . .

show that Leclert's Theorem is equally applicable to the successive evolutes of the curves of buoyancy and flotation.

RECENT EXPERIMENTS IN ARMOUR.

By C. E. Ellis, Esq., Associate, Managing Director of Messrs. John Brown & Co., Limited.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 15th, 1894; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

The importance of any discoveries which will increase the defensive power of any given thickness of armour as disposed in modern battle-ships, is so great that no apology is needed for introducing this subject to the Institution. By the kindness of the Council I have been permitted to lay before the members a few remarks on the history of the latest developments of the attempts made by manufacturers to furnish a plate equal to cope with the improved armour-piercing forged steel projectiles, which at one time threatened to carry all before them. The adoption of a new type of plate for three important battle-ships by the British Admiralty has brought the entire subject into considerable prominence, particularly in consideration of the extensive shipbuilding programme which is apparently admitted on all sides to be necessarily undertaken in this country.

I think the last paper of importance which was presented to the Institution was that of Monsieur Barba, the Chief Engineer of the Creusot Works, and was read in March, 1891. In that paper, and in the comments upon it made at the meeting, the merits and demerits of steel as against compound armour were fully discussed, and I think I am not going too far in saying that the general opinion was that for all practical purposes compound armour still held the field. It was felt that the acknowledged superiority of this type over steel in (1) offering greater resistance to projectiles of medium quality, as admitted by Monsieur Barba himself, and (2) withstanding the attack of shot fired obliquely, was such that, in spite of the excellent results obtained both by Messrs. Schneider and by Messrs. Vickers in all steel plates, the compound plate was, under all the circumstances, preferable. The then recent tests on board the *Nettle*, which were under review at this period, are, however, valuable at the present time, as forming a standpoint from which we can estimate the extent of later improvements.

I take as examples the compound plate of Messrs. Cammell tested on March 24, 1888; and the steel plate of Messrs. Vickers tested on September 6, 1888. Each trial was made under the ordinary *Nettle* conditions. The plates measured 8 ft. by 6 ft. by 10½ in., and were attacked by the 6-in. breech-loading gun, firing three Holtzer projectiles of 100 lbs. in weight, and two Palliser shot of 98 lbs., with a striking velocity in each case of 1,976 foot seconds, giving according to the Gavre Formula a perforation in wrought iron of 11 in., and according to De Marre's Formula of 13 in. The resistance of the compound plate to each of the Holtzer projectiles was about the same. Each of the shot stuck in the plate, being much split up, the base projecting in each case from 5½ in. to 6½ in. from the face, and bulges were formed at the back of the plate about 2 in. in height. The length of the Holtzer shot is 17½ in., and judging from the back of the plate and from the fact that the shot was somewhat set up, it is not unreasonable to suppose that the penetration in each case would be from 9 in. to 10 in. The plate developed several superficial cracks, but these were not at all serious. In the Vickers steel plate the penetrations were ascertainable in each case, being 13·5 in., 13 in., and 13 in. respectively, with bulges at the back of the plate from 2½ in. to 3½ in.; the projectiles rebounded entire, two of them being slightly distorted and set up. Three short through cracks were formed, but the plate remained entire. It is not necessary for my present purpose to consider the effect of the Palliser shots at these trials, beyond saying that each of the plates stood up well against them. I have taken these plates as favourable illustrations of the armour of the period—1888-91—when Monsieur Barba's paper was read, and I shall now endeavour to show what increase of resisting power has been obtained in some of the later inventions or improvements in manufacture.

Dealing first with steel plates, I must refer to some trials of Messrs. Charles Cammell & Co., who, although fully occupied at the time with the manufacture of compound armour, achieved considerable success in their experiments with steel. Following up a successful trial of an all-steel plate at Portsmouth in May, 1888, they presented further plates for test in December, 1891, and in May, 1892, which were characterised by excellent quality of steel. Under the usual conditions of a *Nettle* trial, each of the plates successfully stopped all the projectiles without any cracking whatever. The penetrations, as might be expected, were considerable, the greatest being about 14 in., but there could be no doubt that a uniformly excellent plate had in each case been presented. The same firm was also successful in the manufacture of nickel steel plates, which were so largely used for the secondary armour of the *Royal Sovereign* class of battleship. The tests upon which these plates were selected were under the following conditions:—The plate, 4 ft. by 4 ft. by 4 in., was not backed, and was attacked by three Palliser 5-in. projectiles of 49 lbs. in weight, with a velocity of 1,200 ft. per second. In the most successful trials none of the shot perforated the plate, and no cracks were found. For this class of armour there can be no doubt that the alloy of nickel proved most beneficial, in providing the peculiar toughness requisite when the plate is unbacked. My own firm were also successful at the same trials, which were competitive, in producing good nickel steel plates, and were allowed, with Messrs. Cammell, to provide the secondary armour for the battleships above-named.

An excellent plate, manufactured by Messrs. Vickers, was tested at Ochta in November, 1890; but, as the results of that trial are so well known, I pass on to give some particulars of the results achieved by the Continental manufacturers in recent trials of steel armour.

I regret I have no records of any of the plates of Messrs. Schneider other than those which have appeared in the public press. I wish, however, to refer to the Texel trial of August, 1893, when this firm was represented. The conditions of the trial were the same as in the case of the Harveyed plates at the same trial (Nos. 1, 2, and 3 in the Appendix), and in the result Messrs. Schneider's plate was perforated by two of the shots, but broke up two of the remaining three, one of these being fired with the highest velocity. The remaining shot, which was fired at the lowest velocity, rebounded intact. The plate, which appeared to have been face-hardened, exhibited no cracks whatever. Another interesting trial of the nickel steel armour of the same firm was held in the summer of last year, when a test plate for the armour being made for the *Tri Sviatitelia* was very successful. The conditions of acceptance were that the plate should receive four blows from Holtzer projectiles of 317 lbs. from a 9·4 gun, with a velocity of 1,945 feet per second, without any portion of the plate being broken off, while in no case was the base of the projectile allowed to penetrate the target to a depth of as much as 7·8 in. Through cracks were permitted. The plate measured 8 ft. by 8 ft. by 15·9 in., and from the account in *The Engineer* (September 15, 1893) successfully passed these severe conditions, the greatest penetration being 14 in. No serious cracks were produced.

The St. Chamond Company, in addition to some successful trials of Harveyed plates which are dealt with in the Appendix, has been singularly successful in the production of a steel armour plate of great toughness and uniform character; and I have the particulars of those trials where this is most apparent. In April and May, 1892, a plate measuring 8 ft. 3 in. square, and 10½ in. in thickness, successfully withstood nine steel 6-in. projectiles weighing 100 lbs. each, fired at a velocity of 2,149 ft. per second without being perforated and without any cracks whatever being formed, except in the bulges formed by the projectiles. Judging from the two cases where it was possible to measure them, the penetration did not exceed 12¾ in. At the trial at Ochta in December, 1892, the same company exhibited a most interesting example of this class of armour. The plate measured 8 ft. by 8 ft. by 10 in., and six shots weighing 87 lbs. were fired at it from a 6-in. gun, at a velocity ranging from 2,177 ft. to 2,198 ft. per second. The penetration varied from 11¼ in. to 12 in., proving the uniform character of the steel, and no cracks whatever appeared in the plate. The calculated perforation in wrought iron of the shot is according to the Gavre Formula 11·7 in., and according to De Marre's Formula 13·8 in. A further trial of a similar plate was made at Texel in August last, but as an account has so recently been given of the results in *The Engineer* (January 19, 1894), it is not considered necessary to do more than to say that the Ochta results were fully confirmed.

Another French firm, the Chatillon Commentry Company, has devoted considerable attention to the manufacture of deck armour, with excellent results. I have the particulars of a trial where, in a plate of 5 ft. 3½ in. by 4 ft. 11 in. by 2¾ in., nine 100-lb. shots were fired from a 6-in. gun at a square in the centre of the plate, the side of the square measuring only 15½ in. The velocity was, of course, low, being 535 ft. per second; but the peculiarity of the trial was that only one fine crack was formed between two of the points of impact. The same firm have also been experimenting with Harveyed armour, with the satisfactory result mentioned below.

Of the German manufacturers, Messrs. Krupp exhibited at Chicago several excellent plates, of which I select two for illustration here. The first is a nickel steel plate measuring 12 ft. by 8 ft. by 15¾ in. Four Krupp's steel and one chilled iron projectile, weighing 718 lbs. each, were fired from a 12-in. gun, with a velocity of about 1,690 ft. per second. The chilled shot broke up and stuck in the plate, while the four steel projectiles were thrown back broken. The greatest penetration was 19·6 in., and the plate remained free from cracks. On March 13, 1893, a 10½-in. nickel steel plate (hardened) was tested with excellent results. Five Krupp's steel projectiles were completely broken up without cracking the plate in any way. The particulars of the rounds are as follow :—

	Round 1.	Round 2.	Round 3.	Round 4.	Round 5.
Gun	5·9 in.	5·9 in.	5·9 in.	8·26 in.	8·26 in.
Weight of shot	112 lbs.	112 lbs.	112 lbs	209 lbs.	307 lbs.
Velocity	1,885 f.s.	2,000 f.s.	2,160 f.s.	1,727 f.s.	1,824 f.s.
Penetration	2·7 in.	Not measurable.	12·2 in.	4·5 in.	Not measurable.

The trial is interesting, inasmuch as the behaviour of the plates resembles closely that of the Harveyed plate, but it is evident that the shot was considerably overmatched.

The old-established firm of the Dillinger Hüttenwerke Company has also given favourable examples of nickel steel armour, exhibiting the same absence of cracking which has characterised so many of the trials of this class of armour. I append the particulars of the tests of two plates which are worthy of notice.

TRIAL, FEBRUARY 9, 1893 : 8⅞ IN. NICKEL STEEL.

Round.	Projectile.	Weight of Projectile in lbs.	Velocity in f.s.	Penetration in inches.
1	Steel, 6 in.	112	1,554	10·5
2	,,	112	1,543	10·8
3	Steel, 8¼ in.	209	1,454	11·5
4	,,	210	1,447	12·2
5	Chilled Iron, 8¼ in.	209	1,442	9·6

TRIAL, MAY 31, 1893 : 15½ IN. NICKEL STEEL.

Round.	Projectile.	Weight of Projectile in lbs.	Velocity in f.s.	Penetration in inches.
1	Steel, 12 in.	714	1,700	22·2
2	,,	715	1,677	21·9
3	,,	714	1,664	21·5
4	,,	714	1,665	22
5	—	714	1,701	12·5

Steel plates are also being successfully manufactured in Russia, Italy, and in Austria; the firm of Witkowitz in the latter country having been recently successful in the Pola trials. An account of these trials has so recently appeared that I need not give any particulars.

The above remarks show that, since the reading of Monsieur Barba's paper before the Institution, a considerable impetus has been given to the manufacture of steel armour, and I have endeavoured to give the results of the best examples of each manufacturer's plates, in order to show what progress has been made. It will be noticed that, with one or two exceptions, none of the plates are hard enough to break up armour-piercing projectiles, which is the special characteristic of the modern Harveyed armour yet to be noticed. As long ago as 1883 Admiral Acton, the Italian Minister of Marine, in explaining to the Chamber of Deputies the reasons for the preference of the Government for compound armour to steel, said that if the face of the steel could be successfully hardened it might possibly be most successful in the future, and Captain Orde Browne, in the pages of *The Engineer*, has for some time advocated the application to steel of the principle of hard faces and soft backs, as seen in compound armour. As will be seen, this desideratum has now been obtained; but before examining the results of the trials of the new Harveyed plates, I must first treat of the experiments of compound armour-plate manufacturers, subsequent to the trial of the standard plate of Messrs. Cammell, above described. Although the question has apparently ceased to be of practical interest, a few instances of the improvements effected in increasing the hardness of the faces of compound armour may here be given.

Passing over the Dutch trials of November, 1889, where a compound plate, made by my company, broke up two forged steel Krupp projectiles, in the words of Captain Orde Browne, "like chilled iron," I come to later experiments. Mr. Alexander Wilson has shown me a photograph of a 10½-in. compound plate, manufactured by his firm, which was tested in August, 1891, and completely broke up three 6-in. A. P. projectiles, and two 6-in. Pallisers, fired with a velocity of from 1,956 ft. to 1,974 ft. per second. I am not able to give the penetrations, but beyond two unimportant cracks the plate was apparently uninjured.

I must now mention some experiments made by my own company in the same direction. The attention of my friend Captain Tresidder had been drawn to the importance of endeavouring to break up the point of a steel projectile before it had time to effect any degree of penetration into the plate sufficient to cause perforation or serious damage by cracking. With this object in view, he tried various methods of rapidly chilling the face of armour plates; and, after obtaining fairly satisfactory results with cold air and steam impinging along the face, he directed his attention to the best way of hardening armour by means of a sudden uniform process of chilling by water. The process devised by Captain Tresidder was, and is, applicable and beneficial to all kinds of plates; but naturally it has its most striking effect where carbon is present in sufficient quantity to ensure absolute hardness. My company being at the time large manufacturers of compound armour, Captain Tresidder's earliest experiments were conducted with that class of plate; and, although it subsequently became apparent that the hardening process was more suitable to homogeneous than to built-up or compound plates commonly so called, the results of one or two of the trials are sufficiently interesting to deserve mention. The nature of the invention may be stated in a few words. It consists in the application of water under such pressure and of such volume as will effectually prevent any envelope of steam forming on the face of the plate, thus ensuring a rapid chilling and resultant hardness uniformly over the surface of the plate.

The experiments were, so far as the chilling process was concerned, uniformly successful; but for my present purpose I only trouble the Institution with the consideration of one trial, which took place at Shoeburyness on August 4, 1892. The dimensions of the plate were 8 ft. by 6 ft. by 10 in., and it was attacked by five 6-in. Holtzer projectiles, weighing 100 lbs. each, with a velocity of 1,976 ft. per second.

Captain Orde Browne describes the result of the trial as follows :—" The whole of the projectiles broke up with very little penetration. The plate, after the trial, appeared to be nearly as stiff and strong as at first."

Similar results were obtained in numerous other trials, the marked feature in each case being the complete breaking up of the best forged steel armour-piercing projectile in the same manner as the old compound plates had invariably broken up chilled Palliser shot. Of the value of the invention as a step in the development of armour, there can be no doubt, but experience soon proved that its efficacy would be more strongly demonstrated by applying it to homogeneous steel plates, highly carburised on the face, armour which has now generally become known as Harveyed armour.

The late Mr. Harvey unfortunately died just at the time when the results of his plate had become known and acknowledged in Europe. Having successfully applied to smaller articles the system of cementation, or conversion, followed by chilling, he directed his attention to the effect of similar treatment in the case of homogeneous steel armour plates. A series of experiments was made under the auspices of the United States Government, and the results were from the first of a very encouraging description.

Inasmuch as this armour has been definitely adopted by the British Admiralty for the three important battleships now building, I have thought it would be interesting to the members of the Institution to give in the Appendix to this paper a detailed account of nearly all the trials that have been made of it in this country and abroad. The list includes the earliest American trials of the Bethlehem Iron Company and Carnegie, Phipps & Co., and the first Harveyed plate manufactured in Europe, that of Messrs. Vickers, tested in November, 1892.

It is no part of my purpose to draw comparisons between the plates of rival manufacturers. I desire rather to call attention to the results obtained by this class of plate in the various trials taken as a whole, in order to demonstrate the extent of the improvement in armour realised by the new process. The British tests appear to be most useful for this purpose, and, with the authority of the Director of Naval Construction, and the consent of the other English manufacturers, I am able to give full particulars of all the British trials.

Speaking generally, the American trials are characterised by conditions rather more favourable to the plate than to the shot; while in France, with one or two exceptions, the reverse has been the case. In England, however, and in some of the trials made abroad, the authorities appear to have gauged most accurately the resisting power of the Harvey plate to the blow to be delivered, with the result that in many cases the shot and the plate appear to be equally matched. A good instance is to be found in the trials of Messrs. Cammell's and Messrs. Vickers' 6-in. steel plates on the

Nettle. An examination of these trials will show that, with the highest velocity (1,960 ft. per second), a 6-in. Holtzer projectile was unable to perforate the plates, damaged as they had been by two previous rounds. According to the Gavre Formula, this shot would have perforated 11 in. of wrought iron (or 13 in., according to De Marre's Formula), so that we get a superiority to wrought iron of at least 183 per cent. Other instances may be found in the nickel steel 10½-in. plate of Messrs. Cammell, and in the nickel steel plate of the same thickness made by my own company, tested at Shoeburyness on November 9 and October 10, 1893, respectively. The Cammell plate was curved to moulds supplied by the Admiralty, and was only penetrated to the depth of 10 in. In the Brown plate the projectile stuck in the plate, broken, and we may assume that each of the plates was a fair match for the blow delivered. The gun used was the 9·2, and, with a Holtzer shot of 380 lbs. and a velocity of 2,035 ft. per second (the highest obtainable), a striking energy was obtained of 10,900 foot tons. These conditions would give, according to the Gavre or De Marre's Formula, a perforation in wrought iron of 22 or 22½ in., showing for the plates in question a superiority over wrought iron of 209·5 per cent. at least. Again, the Chatillon Commentry 6·7-in. plate (No. 13. in Appendix) gives an excellent example of a trial where the conditions of attack and defence approximate to one another. Taking the severest blow, we find that the plate was not perforated by a shot which would, according to the Gavre Formula, pierce a wrought-iron plate of 11·9 in., and, according to De Marre's, a plate of 13·8 in. in thickness; in other words, showing a superiority over wrought iron of 177 per cent. according to the one, and of 205 per cent. according to the other Formula.

It was at first assumed that the Harvey process was considerably better adapted to nickel steel plates than to all-steel, and this is still, no doubt, the general opinion in the United States. In the Annapolis trials of 1890, the Schneider nickel steelplate was undoubtedly superior to the all-steel plate made by the same firm; and in a trial of 3-in. plates in May, 1891, the nickel steel Harveyed plate was stated to be better than the all-steel plate. In the Indian Head trials of the same year, the low carbon all-steel Harveyed plate of the Bethlehem Company was placed considerably below the high carbon nickel steel Harveyed plate of the same company; but in this case the consideration of the question was complicated by the difference in the carbons, as it is probable that a nickel steel plate would not require to be so high in carbon as an all-steel plate, to give the same resistance. Since this trial, however, it seems to have been assumed in the United States that all Harveyed plates should be made of nickel steel. In Great Britain, however, the high cost of nickel has caused manufacturers to turn their attention to producing Harveyed steel plates containing no nickel; and an examination of the details of the various trials shows that all have succeeded in proving the reverse of the theory accepted in the United States. There may, perhaps, be a slightly greater tendency to crack in the all-steel than in the nickel steel plates, as tested in this country, but this is more than compensated for in the superior resistance to penetration. The 6-in. Portsmouth trials all demonstrate this fact, and attention may also be called to the trial No. 27. in the Appendix, when it will be seen that the 10½-in. Brown all-steel plate more effectually broke up the 9-in. shot than was the case in the similar trial of the nickel steel plate under the same conditions. The expense of the addition of nickel renders this question of such importance that I regret there are no foreign trials available for providing further demonstration, if such be needed.

Apart from the question of extra cost, there are also practical considerations which affect the point in question. Some experiments made by Captain Tressider show that a steel plate containing an ordinary percentage of nickel and a high percentage of carbon is practically unmachinable. If, therefore, a nickel steel plate be taken containing, say, 3 per cent. of nickel, and it be super-carburised up to, say, 1 per cent., its face will be so hard (even before the chilling process is effected), that for all practical purposes it will be impossible to drill and tap the various small holes that are nearly always necessary to be made on the face of the armour plates for ships' sides. In the case of steel armour, this difficulty (which, I believe, has already arisen in the United States in the case of nickel steel plates) does not exist, and thus one important objection to the adoption of the Harvey process for ships' plates as required by naval architects has been overcome by its application to all-steel armour, in place of nickel steel.

I must now allude to the doubts that have been expressed as to the difficulties which will be experienced by manufacturers in adapting the process to curved and twisted plates. Both the Dutch and the Austrian Governments appear to have attached great importance to this consideration. No doubt there are, and will be, difficulties caused by the warping effect of the water treatment, and time alone will show whether they are as serious as the detractors of the system allege. I think, however—and I am sure I can speak for the other armour plate manufacturers in this country—that any difficulties thus created will be readily overcome. In the first place, if a plate is uniformly heated, and uniformly chilled, any alteration of its form will also be uniform. A very little experience, therefore, will teach the operator the lines on which to work, particularly if the system of chilling in use is of a suitable character. We know also that the side armour for the *Maine*, made by the Bethlehem Company, has been accepted by the United States Government; and, although I have no accurate information on the point, we may safely assume that the plates were not straight. Both Messrs. Cammell and my own company have also successfully made sample Harveyed plates to moulds having both curve and twist, and probably other manufacturers have done the same.

It may be interesting to give an account of some mechanical tests showing the quality of the soft parts of Harveyed plates which have been successful in trials. In the early stages of our experiments a 4 ft. by 4 ft. by 9 in. plate was tested at Shoeburyness, breaking up the 6-in. Holtzer in the usual way without cracking. Test pieces were taken from the back of the plate with the following results:—

	First Specimen.	Second Specimen.
Breaking strain per square inch	31 tons	30 tons
Elongation per cent. in 2 in.	31	31
Reduction of area per cent....	57	61
Cold bends without fracture	180°	180°

The plate, it may be mentioned, was not of our special armour-plate quality. It gives, however, a sufficient indication that, apart from the face, the body of the steel does not, at least, suffer from the application of the process.

One characteristic of this kind of plate must be specially mentioned, as it cannot be gathered from the particulars of the trials referred to in the Appendix. I refer to the extraordinary resistance given to shot by small fragments of plate only. Perhaps the most conspicuous instance of this is given by the Bethlehem 14-in. plate (No. 29 in Appendix), where a 10-in. Holtzer projectile was fired, at a velocity of 2,059 ft. per second, at a piece of plate weighing only 4⅕th tons, and was broken up, with a penetration of 11 in. The total striking energy of the blow was 14,715 foot tons, or 3,344 foot tons per ton of plate. Another example may be found in a recent trial of a 6-in. steel plate made by my company. The fourth shot of this trial was fired nearly at the centre of the plate, after cracks had been made, such that the point of impact was about the middle of an equilateral triangle, with each side measuring about 2 ft. The 6-in. shot, with a velocity of 1,815 ft. per second, was completely broken up; one small crack only was made, and the fragment of plate represented by the triangle, dished to the extent of an inch, showing the tough nature of the material. If, therefore, the Harvey plate be broken up, but its fragments still adhere to the backing, it still presents a considerable resisting power. It seems, however, from the foregoing remarks, that it might be desirable to have a greater number of bolts per square foot of plate than was the case in the old form of armour.

With the above facts before us, we are enabled to form some idea of the improvements that have recently been effected in armour-plate manufacture, and of the relative value of the various kinds of armour. Without disregarding the excellent qualities of the steel and nickel plates which I have alluded to earlier in this paper, I think I have shown that Harveyed armour would be a more efficient defence to the vital parts of any ship of war, whether battleship or cruiser, than any other type of plate. Opinions may differ as to the percentage of superiority it possesses, but I do not think I am over-estimating its value when I place its resisting power at 50 per cent. above the steel and compound plates of 1888 which I have chosen as the basis of comparison. This advantage can be used by the naval architect in one of two ways: he can either clothe with armour a greater part of his ship, or he can obtain greater resistance, keeping the same thickness of armour. The new development is, therefore, of the greatest importance, and it will be a matter of satisfaction to this Institution that the British Admiralty have been the first naval authority in Europe to realise the value of this new form of armour, and to apply it to their most recent designs.

I desire in conclusion to express my thanks to the various armour plate manufacturers for the information they have kindly afforded me, and to Captain Tressider, C.M.G., for much valuable assistance in the preparation of the Appendix.

APPENDIX.

No.	Manufacturer	Description of Plate.	Date of Trial.	Place of Trial.	Size of Plate.			Calibre of Gun.	Projectile.			T = Thickness of Wrought Iron the Shot would Perforate according to Gavre Formula.	Proportion of T to Thickness of Plate (= 100).	T_1 = Thickness of Wrought Iron the Shot would Perforate according to De Marre's Formula.	Proportion of T_1 to Thickness of Plate (= 100).	Result.	
					Length.	Width.	Thickness.		Weight in lbs.	Velocity in feet per sec.	Description.					On Plate.	On Projectile.
					ft. in.	ft. in.	in.	in.				in.		in.			
1	Vickers*	Nickel steel	Aug. 23, 1893	Texel	6 7¾	4 11	5·9	4·72	57·32	1,443	Krupp's steel	5·65	95	7·2	122	Penetration 6·9 in., no cracks.	Rebounded intact.
								„	„	1,574	„	6·35	107	8·15	138	Penetration 8·1 in., no cracks.	Rebounded intact
								„	„	1,640	„	6·72	113	8·63	146	Penetration 2·4 in., no cracks.	Shot broken, head remaining in plate.
								„	„	1,771	„	7·5	127	9·65	163	Penetrated, one fine crack visible.	Broken up, head remaining embedded in plate.
								„	„	1,880	„	8·18	138	10·5	177	Some penetration, but backing uninjured; serious through cracking, but the plate remains integral part of the target.	Broken up, head remaining embedded in plate.
2	C. Cammell†	Nickel steel	Aug. 23, 1893	Texel	6 7¾	4 11	5·9	4·72	57·32	1,443	Krupp's steel	5·65	95	7·2	122	Penetration 6·9 in., no cracks.	Rebounded intact.
								„	„	1,574	„	6·35	107	8·15	138	Penetration 11·6 in., no cracks.	Broken, head remaining in plate.
								„	„	1,640	„	6·72	113	8·63	146	Complete perforation, no cracks.	Small longitudinal cracks. Slightly set up.
								„	„	1,771	„	7·5	127	9·65	163	Complete perforation, no cracks.	Projectile recovered with considerable longitudinal crack. Slightly set up.
								„	„	1,880	„	8·18	138	10·5	177	Complete perforation, no cracks.	Not recovered.
3	John Brown & Co.	Nickel steel	Aug. 23, 1893	Texel	6 7¾	4 11	5·9	4·72	57·32	1,443	Krupp's steel	5·65	95	7·2	122	Penetration, 7 in., no cracks.	Rebounded.
								„	„	1,574	„	6·35	107	8·15	138	Penetration, 2·5 in., no cracks.	Completely broken up, head embedded in plate.
								„	„	1,640	„	6·72	113	8·63	146	Penetration, 16 in., no cracks.	Stuck in plate.
								„	„	1,771	„	7·5	127	9·65	163	Penetration 6·8 in.	Broken, head remaining embedded in plate.
								„	„	1,880	„	8·18	138	10·5	177	Complete perforation of plate and backing.	Not recovered.

* Two more similar shots were fired at a velocity of 1,443 f.s. with similar results to the first round, except that one of the shots was broken, and a further crack was formed.

† This Plate was found to have been accidentally overheated in course of manufacture, and was not considered representative.

No.	Manufacturer.	Description of Plat	Date of Trial.	Place of Trial.	Size of Plate.			Calibre of Gun.	Projectile.			T = Thickness of Wro Iron the Shot would forate according to G Formula.	Proportion of T to Th ness of Plate (= 100	T_1 = Thickness of Wro Iron the Shot would forate according to Marre's Formula	Proportion of T_1 to Th ness of Plate (= 100	Result.	
					Length.	Width.	Thickness.		Weight in lbs.	Velocity in feet per sec.	Description.					On Plate.	On Projectile.
					ft. in.	ft. in.	in.	in.				in.		in.			
4	Vickers	Nickel steel	Jan. 18, 1898	H.M.S. *Nettle*	8 0	6 0	6	6	100	1,507	Holtzer	7·5	125	8·85	147	Penetration, 6·35 in.; height of bulge, ·7 in.; no cracks.	Broken up.
								"	"	1,815	"	9 75	162	11·55	192	Penetration, 11·5 in.; several cracks; height of bulge, 3·25 in.	Broken up; point remained in plate.
								"	"	1,960	"	10·8	180	12·9	215	Penetration, 13·5 in.; several cracks; height of bulge, 1·5 in.	Broken up; point remained in backing.
								"	"	1,815	"	9·75	162	11·55	192	Penetration, 6·25 in.; several cracks; height of bulge, 3 in.	Broken up; point remained in plate.
5	Vickers	Nickel steel	Aug. 15, 1898	H.M.S. *Nettle*	8 0	6 0	6	6	100	1,507	Holtzer	7·5	125	8·85	147	Penetrated; no cracks; height of bulge, 1·125 in.	Stopped, and broken up.
								"	"	1,815	"	9·75	162	11·55	192	Complete perforation; no cracks.	Broken up; point remaining in backing.
								"	"	1,815	"	9·75	162	11 55	192	Penetrated; no cracks; height of bulge, 2·25 in.	Stopped, and broken up; part remaining in plate.
								"	"	1,960	"	10·8	180	12·9	215	Complete perforation; no cracks.	Passed through plate and backing unbroken.
6	John Brown & Co.	Nickel steel		H.M.S. *Nettle*	8 0	6 0	6	6	100	1,507	Holtzer	7·5	125	8 85	147	Slight penetration; no cracks; height of bulge, 1·375 in.	Completely broken up; head remaining in plate.
								"	"	1,815	"	9·75	162	11·55	192	Penetration, 11 in.; one crack and one hair line.	Broken up; head remaining in plate.
								"	"	1,960	"	10·8	180	12·9	215	Complete perforation; one crack.	Broken up; part being found 9 in. in backing.
								"	"	1,815	"	9·75	162	11·55	192	Complete perforation.	Broken; part found behind backing.
7	Vickers	Steel	June 30, 1898	H.M.S. *Nettle*	8 0	6 0	6	6	100	1,507	Holtzer	7·5	125	8·85	147	Penetrated; one crack in plate; height of bulge, 2 in.	Completely broken up; point embedded in plate.
								"	"	1,815	"	9 75	162	11·55	192	Penetrated; some cracks; height of bulge, 3 in.	Ditto.
								"	"	1,960	"	10·8	180	12·9	215	Penetrated; further cracking; height of bulge, 4·5 in.	Ditto.
								"	"	1,815	"	9·75	162	11·55	192	Penetrated, 11 in.; slight increase of cracking; back of plate where struck broken away; height of bulge, 3·5 in.	Projectile remained in plate, base projecting 6 in. from face; some part of projectile broken.
8	Cammell	Steel	Nov. 8, 1898	H.M.S. *Nettle*	8 0	6 0	6	6	100	1,507	Holtzer	7·5	125	8·85	147	Very slight penetration; face at point of impact forced back 1·5 in.; two fine cracks and one hair crack; height of bulge, ·875 in.	Completely broken up.
								"	"	1,815	"	9·75	162	11·55	192	Penetration, estimated, 3 in.; three fine cracks; height of bulge, 2·875 in.; indent in backing, 2 in. deep.	Point remained in plate, remainder completely broken up into small pieces.
								"	"	1,960	"	10·8	180	12·9	215	Penetration, about 3·375 in.; point of cone, 2·125 in. inside face of plate; four more cracks formed, but plate remained entire; height of bulge, 3·375 in.; indent in backing, 3 in. deep.	Ditto. A small piece of plate remained in backing.

No.	Manufacturer.	Description of Plate.	Date of Trial.	Place of Trial.	Size of Plate.			Calibre of Gun.	Projectile.			T = Thickness of Wrought Iron the Shot would Perforate according to Gavre Formula.	Proportion of T to Thickness of Plate (= 100).	T₁ = Thickness of Wrought Iron the Shot would Perforate according to De Marre's Formula.	Proportion of T₁ to Thickness of Plate (= 100).	Result.	
					Length.	Width.	Thickness.		Weight in lbs.	Velocity in feet per sec.	Description.					On Plate.	On Projectile.
					ft. in.	ft. in.	in.	in.				in.		in.			
9	John Brown & Co.	Steel	Feb. 7, 1894	H.M.S. *Nettle*	8 0	6 0	6	6	100	1,507	Holtzer.	7·5	125	8·85	147	Penetration 1·7 in.; some fine hair cracks.	Broken up.
								,,	,,	1,815	,,	9·75	162	11·55	192	Penetration estimated 7 in.; several cracks.	Ditto.
								,,	,,	1,960	,,	10·8	180	12·9	215	Plate perforated; cracks extended.	Ditto; portion of fragments in backing, and some in front of target.
								,,	,,	1,815	,,	9·75	162	11·55	192	Penetration, estimated, 6 in.; one slight additional crack.	Broken up.
10	St.Chamond	Special steel	Dec. 20, 1893	Gavre	7 6½	2 7½	6	5½	66	2,313	St. Etienne steel.	10·85	180	13·3	221	Complete perforation of plate and backing; small hair cracks only.	Ditto; fragments found directly behind target.
								6·3	99	2,159	Holtzer.	12·15	202	13·9	231	Complete perforation of plate and backing; one hair crack only.	*Ditto; and fragments found behind backing.
11	Vickers	Nickel steel	Dec. 20, 1893	Gavre	7 6½	2 7½	6	5½	66	2,313	St. Etienne steel.	10·85	180	13·3	221	Plate perforated, but projectile lodged in backing; some cracks to edges of plate.	Broken; and pieces lodged in backing.
								6·3	99	2,159	Holtzer.	12·15	202	13·9	231	Plate and backing perforated; considerable cracking round point of impact.	Completely broken up; and found close behind backing of target.
12	St.Chamond	Nickel steel	Aug. or Sept., 1893	Gavre	6 6¾	4 11	6·1	6	90	1,476	,,	6·7	109	8	131	Penetration, 1·25 in.; no cracks.	Completely broken up.
								,,	,,	1,804	,,	9	147	10·6	173	Penetration, 1·5 in.; one crack.	Broken up.
								,,	,,	1,968	,,	10·2	167	12	196	Perforation.	Ditto.
13	Chatillon Commentry	Nickel steel	Sept. 26, 1893	Mont-lucon	5 3	4 3	6·7	6·3	99	2,014	Chatillon Commentry steel.	11 0	164	12·6	188	Penetrated; some pieces of broken shot passing into wood backing; one crack.	Stopped, and broken; base projecting 6·7 in. from face of target.
								,,	,,	2,080	,,	11·55	172	13·2	197	Penetration, 3 in.; two cracks from point of impact of first shot.	Stopped, and broken up; ogive remaining in plate.
								,,	,,	2,142	,,	12·05	179	13·8	205	Penetrated, but not perforated; further cracks developed.	Stopped, and broken up; ogive remaining embedded in plate.
14	St.Chamond	Special steel	Dec. 20, 1893	Gavre	7 6½	4 1¼	9⅞	9·5	317	2,132	St.Chamond Chrome steel.	20	202	20·2	204	Complete perforation of plate and backing; no cracks.	Broken up; head much damaged; and found about 600 mètres behind target.
								,,	,,	1,988	,,	18·1	183	18·25	184	Complete perforation of plate and backing; one crack only.	Small pieces of broken projectile found behind target.
15	Vickers	Nickel steel	Dec. 20, 1893	Gavre	7 6½	4 1¼	9⅞	9·5	317	2,182	St.Chamond Chrome steel.	20	202	20·2	204	Complete perforation of plate and backing; four serious cracks, extending to the four edges of the plate.	Broken up into small fragments; some of which were found immediately in rear of target.
16	Vickers	Nickel steel	Dec. 1, 1892	Ochta	8 0	8 0	10	6·0	87	2,171	Putiloff Holtzer.	11·4	114	13·4	134	Penetration, estimated, 5 in.; no cracks; bulge, ·875 in.	Stopped, and completely broken up; head remaining in plate.
								,,	,,	2,165	,,	11·35	113	13·4	134	Similar to previous round.	
								,,	,,	2,177	,,	11·45	114	13·45	134	Ditto	
								,,	,,	2,179	,,	11·5	114	13·55	135	Penetration (ascertained), 5 in.	
								9·0	408	1,655	,,	17·2	172	17·8	178	Penetration, 15 in.; plate broken across previous points of impact.	Head remained in plate; body broken, and thrown back.
								9·0	403	1,871	,,	20·7	207	21·2	212	Penetration, through plate and wood backing; almost 28 in.; one corner of plate broken off; one bolt broken.	Head remained in wood backing; body broken up.

No	Manufacturer.	Description of Plate.	Date of Trial.	Place of Trial.	Size of Plate.			Calibre of Gun.	Projectile.			T = Thickness of Wrought Iron the Shot would Perforate according to Savre Formula.	Proportion of T to Thickness of Plate (= 100).	T₁ = Thickness of Wrought Iron the Shot would Perforate according to De Marre's Formula.	Proportion of T₁ to Thickness of Plate (= 100).	Result.	
					Width.	Length.	Thickness.		Weight in lbs.	Velocity in feet per sec.	Description.					On Plate.	On Projectile.
					ft. in.	ft. in.	in.	in.				in.		in.			
17	Bethlehem Iron Company	Nickel steel high carbon)	Nov. 14, 1891	Indian Head	8 0	6 0	10½	6	100	2 075	Holtzer.	11·8	112	14·0	133	Penetration, 12 in.; short radial hair cracks on face; height of bulge, 2·25 in.	Projectile rebounded and broke into three pieces.
								,,	,,	2,075	,,	11·8	112	14·0	133	Penetration, estimated, 6·8 in.; short radial hair cracks; height of bulge, about ½ in.	Head remained embedded in plate, remainder completely shattered.
								,,	,,	2,075	,,	11·8	112	14·0	133	Penetration 12·25 in.; three radial cracks; height of bulge, 2 in.	Projectile rebounded unbroken, with one longitudinal crack visible.
								,,	,,	2,075	,,	11·8	112	14·0	133	Penetration, estimated, 7 in.; no cracks; height of bulge, ½ in.	Head remained embedded in plate, remainder completely shattered.
								8	210	1,850	Firminy (Firth).	13·8	131	14·6	139	Penetration, 12·8 in.; two through cracks; height of bulge, 2·5 in.	Projectile rebounded, and was found cracked and flaked. It had been shortened 1½ in. by the blow.
18	Carnegie Phipps	Nickel steel (low carbon)	Nov. 14, 1891	Indian Head	8 0	6 0	10½	6	100	2,075	Holtzer.	11·8	112	14·0	133	Penetration, 14·6; height of bulge, 4 in.; slight radial hair cracks about 4 in. long.	Remained in plate apparently intact.
								,,	,,	2,075	,,	11 8	112	14·0	133	Penetration, estimated, 14·8 in.; height of bulge, 4·75 in.; cracks as before.	Ditto.
								,,	,,	2,075	,,	11·8	112	14·0	133	Penetration, 9·75 in.; height of bulge, 1·8 in.; cracks as before.	Rebounded, considerably set up, with pieces flaked off the head.
								,,	,,	2,075	,,	11·8	112	14 0	133	Penetration, 20·5 in.; height of bulge, 4·6 in.; cracks as before.	Remained in plate apparently intact.
								8	250	1,700	Carpenter.	13 9	132	14·8	140	Penetration, 17·25 in.; height of bulge, 6·75 in.; two through cracks and one deep crack; further crack at back of plate.	Rebounded and broke into several pieces, point being bruised and piece chopped off it.
19	Vickers	Steel	Nov. 1893	Pola	8 0	6 0	10½	6	112	1,936	Streiteben steel.	11·6	110	13·2	125	Penetration, about 9·8 in.; short hair cracks; height of bulge 2 in.	Projectile broken, head remaining stuck in plate.
								,,	,,	1,936	Krupp steel.	11·6	110	13·2	125	Penetration, about 12·6 in.; slight cracking; point of projectile projecting 2 in. from back of plate.	Remained in plate entire.
								,,	,,	1,936	Streiteben.	11·6	110	13·2	125	Penetration, about 17 in.; short hair cracks; projectile projects 6 in. from back of plate.	Ditto.
								,,	,,	1,936	Krupp.	11·6	110	13·2	125	Penetration, about 11 in.; short hair cracks; height of bulge, 2 in.	Ditto.
								9·45	473	1,433	Streiteben.	13	123	12·7	120	Penetration, about 1[illegible]·5 in.; three cracks formed, radiating from point of impact to edges of plate.	Broken head remaining in plate.

No.	Manufacturer.	Description of Plate.	Date of Trial.	Place of Trial.	Size of Plate: Length.	Size of Plate: Width.	Size of Plate: Thickness.	Calibre of Gun	Projectile: Weight in lbs.	Projectile: Velocity in feet per sec.	Projectile: Description.	T = Thickness of Wrought Iron the Shot would Perforate according to Gavre Formula.	Proportion of T to Thickness of Plate (= 100).	T_1 = Thickness of Wrought Iron the Shot would Perforate according to De Marre's Formula.	Proportion of T_1 to Thickness of Plate (= 100).	Result: On Plate.	Result: On Projectile.
					ft. in.	ft. in.	in.	in.				in.		in.			
20	Vickers	Nickel steel	Nov. 1, 1892	H.M.S. *Nettle*	8 0	6 0	10½	6	100	1,973	Holtzer	11	104	12 95	123	Penetration (estimated) 4 in., no cracks; height of bulge ·4 in.	Broken up, point embedded in plate.
								,,	100	1,973	,,	11	104	12·95	123	Penetration (estimated) 4 in., no cracks; height of bulge ·5 in.	Ditto.
								,,	98	1,973	Palliser	10 8	102	12·8	121	Penetration (estimated) 3 in., no cracks; height of bulge ·3 in.	Ditto.
								,,	98	1,973	,,	10·8	102	12 8	121	Penetration (estimated) 3 in., no cracks; height of bulge ·15 in.	Ditto.
								,,	100	1,973	Holtzer	11	104	12·95	123	Penetration (estimated) 4 in., no cracks; height of bulge ·4 in.	Ditto.
			June 1, 1893	Shoeburyness				9·2	380	1,698	,,	17	161	17·25	164	Penetration about 6 in., plate divided into two pieces.	Broken up, head remaining in plate.
								,,	,,	1,808	,,	18 5	176	18·8	179	Penetration about 9·2 in., plate much shattered.	Ditto.
21	Vickers	Nickel steel	April 12, 1893	Gavre	8 0	6 0	10½	9·5	317	1,902	,,	17 0	161	17·25	164	Penetration about 6·3 in., some cracking.	Projectile broken.
								,,	,,	2,296	,,	22·2	211	22·5	214	Complete perforation.	Not broken.
								,,	,,	2,132	,,	20·0	190	20·2	192	Ditto.	Ditto.
								,,	,,	2,066	,,	19·15	182	19 25	183		
22	C. Cammell	Nickel steel	May 12, 1893	H.M.S. *Nettle*	8 0	6 0	10½	6	100	1,960	Holtzer	10·8	103	12·9	122	Penetration slight, no cracks; height of bulge ·3125 in.	Completely pulverised. Point remained in plate.
								,,	100	1,960	,,	10 8	103	12·9	122	Ditto.	Ditto.
								,,	98	1,960	Palliser	10·7	101	12·7	120	Penetration slight, no cracks; height of bulge ·25 in.	Ditto.
								,,	98	1,960	,,	10·7	101	12 7	120	Penetration slight, no cracks; height of bulge ·125 in.	Ditto.
								,,	100	1,960	Holtzer	10·8	103	12·9	122	Penetration slight, no cracks; height of bulge ·375 in.	Ditto.
			Aug. 31, 1893	Shoeburyness				9·2	380	1,808	,,	18 5	176	18·8	179	Penetration about 8 in., one through crack across face of plate; height of bulge 2·25 in.	Completely broken up, point remaining in plate.
								9·2	380	1,948	,,	20·3	193	21	200	Penetration through plate, point extending 18 in. into backing. Plate broken into three pieces by large through cracks.	Greatly shattered. Lodged in plate and backing, but fell to pieces on removal of plate. Body of shot splayed out.
23	John Brown & Co.	Nickel steel	Oct. 10, 1893	Shoeburyness	8 0	6 0	10½	9·2	380	2,035	,,	22	209	22·4	213	Penetration through plate, five radial cracks. Plate came forward but remained entire.	Projectile broken up, but remained stuck in plate, base 2¼ in. from face of plate.
								9·2	380	1,807	,,	18·6	177	18·8	179	Plate perforated and broken.	Shot broken.
24	Bethlehem Iron Co.	Nickel steel	July 30, 1892	Bethlehem	8 0	6 0	10½	8	250	1,700	,,	13 9	132	14·8	140	Penetration (estimated) 3 in. or 4 in., no cracks; bulge about ·75 in.*	Head of projectile embedded in plate, remainder completely broken up.
25	Bethlehem Iron Co.	Nickel steel	July 26, 1892	Indian Head	8 0	6 0	10½	8	250	1,700	,,	13·9	132	14·8	140	Penetration (estimated) 3 in. or 4 in., no cracks.	Head of projectile embedded in plate, remainder completely broken up.
											,,	13·9	132	14·8	140	Ditto.	Ditto.
											,,	13·9	132	14·8	140	Penetration 13 in., one through crack separated corner from plate.	Rebounded entire, slightly set up.
											,,	13 9	132	14·8	140	Penetration 13 in., no cracks.	Ditto. Set up 1 in.
											,,	13·9	132	14 8	140	Same as rounds 1 and 2.	Same as rounds 1 and 2.

No.	Manufacturer.	Description of Plate.	Date of Trial.	Place of Trial.	Size of Plate.			Calibre of Gun.	Projectile.			T = Thickness of Wrought Iron the Shot would Perforate according to Gavre Formula.	Proportion of T to Thickness of Plate (=100).	T_1 = Thickness of Wrought Iron the Shot would Perforate according to De Marre's Formula.	Proportion of T_1 to Thickness of Plate (=100).	Result.	
					Length.	Width.	Thickness.		Weight in lbs.	Velocity in feet per sec.	Description.					On Plate.	On Projectile.
					ft. in.	ft. in.	in.	in.				in.		in.			
26	Cammell	Nickel steel (curved to predetermined lines)	Nov. 9, 1893	Shoeburyness	8 0	6 0	10½	9·2	380	2,035	Holtzer	22·0	209	22·4	213	Penetration to depth of about 10 in.; four through cracks radiating from point of impact.	Base portion found 7 ft. in front of target, remainder stuck in plate, but broken, and point destroyed.
27	John Brown & Co.	Steel (curved to determined lines)	Oct. 26, 1893	Shoeburyness	8 0	6 0	10½	9·2	380	2,035	,,	22·0	209	22·4	213	Plate perforated; four radial cracks.	Shot broken up, head in backing, about ⅓ of projectile thrown back in one piece in front of target.
28	Vickers	Nickel steel	April 26, 1893	Meppen	8 0	6 0	12	11·0	508	1,574	Krupp	16·4	136	15·7	130	Some penetration; plate badly cracked.	Broken up, head embedded in plate.
								6·0	112	2,175	,,	13·7	114	15·6	130	Similar to previous round.	This shot was fired at a small piece of the plate.
29	Bethlehem Iron Co.	Nickel steel	Feb. 11, 1893	Indian Head	9 0	7 0	14	10·0	500	1,472	Holtzer	15·8	112	15 6	111	Penetration, estimated, 2 in.; no cracks.	Head embedded in plate, remainder completely broken up.
								,,	,,	1,859	,,	22 1	157	21·8	155	Penetration, estimated, 5 in.; two cracks formed. Plate dished about 1 in. in depth.	Ditto.
								,,	,,	1,959	,,	23·8	170	23·5	167	Penetration, estimated, 6 in.; two new cracks formed and old ones developed, dividing the plate into three pieces.	Ditto.
								,,	,,	2,059	,,	25·6	182	25 2	180	Penetration, estimated, 10 in. Piece struck (about 4 tons) divided into three fragments, backing uninjured.	Ditto.
30	Vickers	Nickel steel (curved to determined lines)	July 21, 1893	Gavre	7 4½	7 4½	14½	13·4	926	2,050	Chrome steel	32·0	220	28·5	196	Complete perforation, considerably cracked.	Broken up, some pieces found behind backing.
								,,	,,	1,772	,,	26·0	179	23·2	160	Complete perforation, plate much cracked. The shot was fired at a part of the plate much weakened by previous round.	Recovered almost entire about 200 yds. behind backing.

NOTE.—The figures given in the above table as representing the perforations in wrought-iron, according to the Gavre and De Marre's Formulæ respectively, have been taken from a slide rule designed by Mr. Douglas Vickers, and kindly presented to me.

DISCUSSION.

Mr. W. **Beardmore** (Associate): Gentlemen, I am sorry I have not got very much to say about this paper. I should like to have been in a position to have criticised it to a certain extent, but the experiments I have been conducting, so far, in Harveyising plates have not been so successful as these results which you have in this paper. I may say that the Harvey Company undertook to Harveyise a plate for me, but through their experts failing to treat the plate in the same satisfactory manner as the plates you have the results of here, the plate did not stand the shots, and they expressed their regret to me and undertook to Harveyise another plate; but since then they have considered the matter and they seem to think that firms in Sheffield are able to Harveyise all the plates required. I think it is a matter of regret that this should be allowed, because there is no doubt whatever that for the excellent results of the plates we have just heard of we are indebted to Mr. Harvey of America, and not to our Sheffield firms, who have held a monopoly of this trade for such a time. I venture to think that, if the manufacture of armour were extended to more firms than at the present moment, we might look for improvement in the manufacture of armour as a result of the greater competition.

Mr. J. F. **Hall** (Member): Sir John Hay and Gentlemen, I should have very much preferred to have followed the example of my friend, Mr. Riley, and said nothing on this occasion, but I think some of you might consider it rather curious if I did not, considering the way I have been mixed up with this nickel armour plate business. The author of the paper states the recent experiments in armour, and goes on to state the number of plates of nickel steel that have been made during the last few years. I am sorry he has omitted one which I had the honour to produce in April, 1890, which I believe was the first nickel steel armour plate officially fired at in this or any other country. That plate gave a resistance, as I believe our friend Mr. White can vouch for, of about 75 per cent. superior to any plate of the thickness that had ever been shot at under similar conditions. This introduction of nickel to armour plates occupied my attention for several years, commencing about 1876, and in May, 1889, Mr. James Riley read a very interesting paper on the experiments that had, entirely unknown to myself, been taking place in France. That paper gave a publicity to this material which for some considerable time had a very disastrous effect on the markets of nickel, because all the owners of mines thought the price of nickel must go up if the steel makers wanted such a large supply. I notice that Mr. Ellis in his paper says that one of the objections to the use of nickel has been the price. Undoubtedly it has, but after the first enthusiasm was over, the nickel mines began to be developed, and the supply of nickel at the present time is very different to what it was a few years ago, and the price has been considerably reduced. You will excuse my personal observations on this matter, but I thought they might be of some little interest. I am very sorry that Mr. Harvey is dead, because I should have liked to have met that gentleman in this present discussion. So long ago as 1877-78, in connection with a gentleman well known in the steel trade, Mr. Thomas Hampton, of Sheffield, I experimented in a small way on the now so-called Harvey process (I was not in a position to do anything very large); but I got an order for some plates for ordinary targets to be shot at with rifles, and experimented by putting some of these plates in an ordinary converting furnace as we understand it in Sheffield—the cementation process by charcoal, and succeeded in hardening those plates in a variety of ways with water, tallow, oil, and various other methods, on one side only. They were not large plates—they were only plates of 3 ft. or 3 ft. 6 in. square, and something under an inch thick. At any rate it gave me the thought of applying this to armour plates; but unfortunately the gentlemen with whom I was connected at that time did not care to go into the business, or spend any money, and like a good many other things it got dropped under. At the same time there is great credit due to Mr. Harvey for the way he has worked out the problem; because in treating large masses of steel, like armour plates, there is a difficulty which only those who have to contend with it are aware of. I do not believe in the application of the Harvey process at the present time to solid carbon steel, when we have before us the undoubted effects of the alloy of nickel, and with the reduced price of nickel I maintain that, the best plates that can possibly be produced to-day are those consisting of steel with a judicious mixture of nickel and by the application of this process. You then get the toughness that you can only get by adding nickel, and although you may reduce that extreme hardness for breaking up projectiles, I do think that the one benefit is greater than the other. However, that is not a matter for me to decide, but I simply suggest it for your consideration. We all know what they have done in America. They have gone ahead recently quite as fast as we have here. They started very quickly. The late Secretary Tracey of the Navy Department in America told me that it was entirely through reading Mr. Riley's paper, and the remarks made upon it, that he insisted upon Mr. Schneider, with whom he had a very good arrangement for solid steel plates, trying nickel steel plates. Mr. Schneider's representative in Bethlehem told me it was against Mr. Schneider's interest altogether to make nickel steel plates for America. They insisted upon it, other firms had gone into it, and I believe at the present time they are making most satisfactory plates of nickel steel, Harveyised by the same methods as we have described. I do not want to detain the meeting, but I think it was Sir Edward Reed who made a remark at our dinner last night, which struck me very forcibly, as to the tendency which the application of steel, as it now is, might give to our worthy constructors—and I hope our friend, Mr. White, in whom we have so much confidence, will excuse me for publicly making the suggestion to him—of applying nickel steel in a novel way, and that is to the ram and the fore part of the ship. Since the disastrous accident which occurred to the *Victoria*, we are all aware of what a dangerous and wonderful weapon the ram is. It is far more destructive than the guns and torpedoes, and therefore why not use it, use it entirely; make it of nickel steel, make the ship solid, take the guns out, take everything out, and go in for ramming straight at them. Put in good steering power, good rudders, make your class of ship altogether different from anything that has yet been tried, not necessarily a big ship, but a small ship. I see my friend, Captain Persico, of the Italian Royal Navy, in front of me; I do not suppose he weighs more than half of what I do, but if he came into me with a ram, I am afraid I should be upset altogether. Have a small ironclad made with proper steel; apply it so that it cannot sink, make the whole ship, wherever possible, solid inside, say with an arrangement of cork if you like, or anything else that will not bulge in contact with water or wash away; do away with all spaces, so that if this terrible ram strikes through the armour——

The **Chairman**: I do not wish to interrupt Mr. Hall in his very interesting speech, but the next paper applies to the ram, when we trust we shall hear his views upon it.

Mr. J. F. Hall: Then I will not say anything more upon it now. I was not aware that there was such a paper on the list.

Mr. Jas. Riley (Associate Member of Council): Sir John Hay, may I be allowed to make a remark or two? The last speaker has been anxious to do justice to my small efforts in connection with the introduction of nickel steel, but he inadvertently stated something which is not quite accurate.

He referred to the experiments that I related in my paper of 1889 as having been made in France. It is true I quoted some that had been made in France, but the gist of everything I gave in that paper was the results I had obtained in the trials of nickel steel at the works of the Steel Company of Scotland and at Glasgow, and on steel made by that company. May I also add that there is a certain source of satisfaction in finding the readiness with which ideas, which are good, are appropriated; that is the only satisfaction which hitherto has been awarded to me for what has come to pass in connection with nickel steel.

Sir **Nathaniel Barnaby**, K.C.B. (Vice-President): Sir John Hay, I have only a few remarks to make. The first is that it is very pleasant to find you in the chair, remembering the connection you had with armour plates, now, I think, more than thirty years ago. It must be a very agreeable thing for you to hear what we have heard this morning, that there has been an improvement since that time of 200 per cent. in the value of armour. We feel very grateful (those of us who are not in the Admiralty) to the Admiralty officers for allowing us to have put before us to-day this most valuable paper full of facts. Of course many of us have been very intimately connected with the improvement in armour, and I, for one, am extremely sorry that we have not present with us this morning the representative of Monsieur Schneider, Monsieur Barba, who was to have been here, I believe; because his was the firm which made the first great step in the improvement of armour in the plates made by them for the Italian Government, and it was then, and only when that great pressure was applied, that Sheffield woke itself up and began to attempt to make better armour than the wrought iron which they had hitherto made so successfully. What they said was: We have spent so much money in perfecting wrought-iron armour that we hesitate in attempting an altogether new manufacture. However, they did, and both those great firms, Cammell & Co. and Sir John Brown & Co., produced the armour which has since been known as compound armour. Then came other people; Messrs. Vickers, for example, gave us plates which were at least as good, some thought better, than the compound armour plates. Now we come to the two new steps, the introduction of nickel and the introduction of that method of treating the surfaces which has been described to us, and we get an improvement since 1888 of no less than 50 per cent. This is very startling—at least it is so to me. I had no idea that so great an improvement had been made since 1888 as is here recorded, and whether the nickel is necessary, or not, is a question that all England is alive to—I mean to say all manufacturing England—and no doubt we shall get that question settled for us. I should be very ungrateful if I did not express, on the part of unofficial people here, our gratitude to the Admiralty and to the manufacturers for allowing us to have put before us this very valuable collection of facts.

Captain C. C. P. **FitzGerald**, R.N. (Associate): I should like to ask one question with regard to a paragraph in the paper of Mr. Ellis. In the comparison between nickel and all-steel armour before the chilling process takes place, he states that nickel is practically, unmachinable, and that this is an objection to its use. I want to ask him whether this nickel steel is impervious to the arc light, because I understand after plates are on the ship's side, by the application of the arc light you can make a hole in anything that has ever been invented. Perhaps he will tell us whether the arc light has been applied to the nickel steel.

Captain C. **Orde Brown** (Visitor): Mr. Chairman, I have only one or two questions. I see it is mentioned here, as if it were characteristic of American and English experiments, that the Americans have not tested their plates as severely as we have. Up to a certain point I think the opposite was the case. I do not think it would quite do for that statement to go to America without further explanation. There was a time when the Americans were testing their plates with 8-in. projectiles while we were using 6-in. only; in fact, one plate, a Bethlehem plate, a 10½ in, received five heavy blows with Holtzer 8-in. projectiles, and so exactly were they balanced, as to their strength, that the last hole had the commencement of a crack, but nothing more. I do not think you could have anything more closely balanced than that. I quite believe that we have now got the exact balance of the projectile and plate in England. I do not see how it could be otherwise, because the process has been that, the Admiralty began with a light blow from a gun which was more than a match for the plate, and went on firing harder and harder till they knocked the plate in pieces. It appears to me that in such a trial you must arrive at a balance. Then with regard to the application of the Harvey process to thick and thin plates. There is a paragraph on page 224 which says that "Harveyed armour would be a more efficient defence to the vital parts of any ship-of-war, whether battleship or cruiser, than any other type of armour." I found in America last year that there was a certain amount of hesitation in applying the Harvey process to the very thick plates. You observe that the thickest plate dealt with here is 14½ in., fired at in this country, and that was perforated through and through. The next plate I regard as a very remarkable one, and, from this point of view, very interesting, a 14-in. Bethlehem plate fired at in America. That plate exhibited very great powers of resistance, and of course promises well for the application of the Harvey process to thick armour. I think the question of the very thick armour may be decided one way or the other, but it remains to be shown. At the present moment I should like to put one or two questions as to its application. I have not got a practical knowledge of metallurgy, and that leads me to ask questions, rather than to offer criticisms. The water process, I take it, is absolutely limited as to the depth of its effects. Whether you apply it to a plate 6 in. or 18 in. thick, I think that the effect of the water on the skin is absolutely limited to the same depth in both cases. Then you come to the actual Harvey carbonising process itself. I take it, it is difficult to get that beyond a certain limit when you come to very thick armour, so that altogether the effect of the Harveying process, including water, is very much less on thick than it is on the thin plates. Then there is this evil, that the plate has to be in the furnace many days to Harveyise it. That very much increases the expense, and in the most vicious way possible. I hope gentlemen will understand that I am not speaking against the Harvey process, which I believe to be admirable, but I am only putting certain objections in their full force. It takes a very long time in the process, and that would greatly reduce the quantity of armour that could be turned out from any given amount of plant, and would limit the pace at which you could make the armour. All these considerations have led in America to considerable hesitation in applying the Harvey process to thick plates. I think that is where the doubt stands at this moment, and I should have been glad if the lecturer had given us his views on that particular point.

Mr. W. H. **White**, C.B., LL.D., F.R.S. (Vice-President): Sir John Hay and Gentlemen, several of the speakers, including my friend, Sir Nathaniel Barnaby, have treated a passage in which Mr. Ellis refers to my assent to the desirability of this paper being read as having been official action on the part of the Admiralty. Three years ago, speaking in this room, I explained what the Admiralty policy had been up to that date, and it remains exactly the same in regard to their experiments on armour. These trials began in 1888, are still proceeding, and have had, I think, not a little to do with the improvement in armour made in this country and abroad. The Admiralty decided, at the outset, that trials should be made under standard conditions on armour plates sent by any firm. The firm should be represented at the trial and should have a full statement of the facts of the trial put into its hands, without any condition whatever being imposed by the Admiralty as to the use to be made of those facts by the firm. If the firm chose to publish them they were at liberty to do so.

There were many cases of the kind where publication took place. On the other hand, if the trials were not altogether satisfactory, the facts were known only to the Admiralty officers and the firm itself. Mr. Charles Ellis, to-day, with the consent of his fellow armour-plate makers, places before the Institution a great mass of facts which the several firms had individually in their possession. The Admiralty has never objected to publication being made by the firms, and although they have been a great deal abused for what was called secrecy, I am confident that, in the interests of the improvement of armour-plate manufacture, the course that has been followed has been a sensible and a good one. There has been no desire to keep back facts, but every desire to encourage progress. We all know that temporary checks or temporary failures are apt to be magnified in published accounts in a way that is not desirable; whereas experience of that nature properly utilised greatly favours improvement. This paper will always be a treasury of information. As improvement proceeds—and I do not think we are at the end of improvement in armour-plate manufacture—this paper will be almost classical, having brought up to date, in such a convenient form, a great mass of information with regard to the trials made in this country and in other European countries, as well as trials made in the United States. I do not want to repeat what I said here three years ago when discussing Monsieur Barba's paper. I will ask members to refer to the Transactions of 1891. There will be found a succinct account of what the Admiralty did from 1888 to 1891. Since that date there has been very substantial progress; and this has been summed up by Mr. Ellis in an admirable way. Without putting it into exact percentages, one can say this:—whereas in 1891 we looked upon a 10½-in. plate as being a good one if it could stand the attack of a 6-in. gun at 10 yds. range with 48 lbs. of powder and Holtzer projectiles, we now have 6-in. plates which, in some instances, under identical conditions have stood up against the same attack. A fair average measure of efficiency for a 6-in. plate made by the Harvey process may be put at a 42 lbs. charge, or, to state it broadly, in three years the thickness of plate required to face the 6-in. gun has practically gone down from 10½ in. to 6 in. Naval architects are under the greatest obligations to metallurgists at home and abroad who have devoted themselves to this remarkable improvement of armour. Of course the inevitable result has been that the attack has been developed too. We are getting much higher velocities from modern ordnance. Increase of velocity in projectiles is a factor of very great importance in the attack. No doubt we shall get improvements of quality and form in the projectiles which will further emphasise the attack. But, for the moment, the defence has made a great stride in advance, and the fullest use has been made by the Admiralty of this advance in connection with ships now building. In relation to this matter I think it only right to state that, while the advance has been due to manufacturers, the Admiralty throughout have given all possible encouragement to the development of improvements. This statement I am confident the manufacturers will endorse. Mr. Riley has somewhat touchingly observed that his suggestions for improvements have been at once availed of with little recognition to himself. Perhaps he partly blames the Admiralty for not letting any time pass without trying to get his suggestions applied in practice. I was present when Mr. Riley's paper was read at the Iron and Steel Institute, and in the discussion which followed I invited him personally to send us a plate without delay which we would fire at. It was not Mr. Riley's fault that he did not comply with that request. There were matters of business which necessarily engaged his attention to the exclusion of armour plate making. Consequently he has not personally appeared in connection with the development of nickel-steel armour, although to him belongs the honour, as far as I know, of making the first plate which could fairly be described as a nickel-steel armour plate. It was about 2 in. thick, and gave such remarkable results as to suggest at once the desirability of going to greater thicknesses. It is perfectly true, as stated by Mr. Hall, that the first 4-in. nickel-steel plate was made by him, but he soon had successful imitators. In passing, I would allude to what Mr. Beardmore has said. He dwelt on the undesirability of any monopoly existing in the manufacture of armour for the public service. The Admiralty in 1888 endeavoured to interest every leading steel-making firm in the country, which had the necessary plant, in sending experimental plates. These the Admiralty were prepared to pay for. They could scarcely do more. The temporary difficulty under which Mr. Beardmore is labouring, I sincerely trust will soon pass away, and I hope that he will be enabled to manufacture hereafter Harveyed armour for the defence of Her Majesty's ships. The question of nickel in "Harveyed" or "treated" plates has been raised and I think settled in the paper. In this country we are accustomed to make our own experiments, and to draw our own conclusions therefrom. It is not a question of a plate made here, or a plate made there, and tested. The question is far too important to be dealt with in any such way. The point to be settled was, whether in Harveyed plates, supported by strong backing and structures, it was necessary or desirable to continue the use of nickel in alloy with steel. Nobody doubts that nickel in alloy with steel gives very valuable properties; such as extra toughness and freedom from cracking, when plates are not "Harveyed." In unbacked plates of certain thicknesses these qualities of extreme ductility and toughness may also be of considerable value. But it does not follow that in hard-faced plates produced by the Harvey process, ordinary steel may not prove as good as the tougher nickel steel. By direct experiment we have endeavoured to solve the problem, and to discover the best quality of armour to be used under present conditions for the hulls, batteries, and gun-emplacements of Her Majesty's ships. We have proved beyond all doubt, not by one trial, but by repeated trials, on plates of different thicknesses made by different firms, that there is no substantial advantage to be obtained by using nickel steel in Harveyed plates. On the whole the Harveyed non-nickel plates have shown at least equality to, and possibly some advantage in defence over, nickel steel plates similarly "Harveyed." Our experiments were carried on for the purpose of discovering the best armour, irrespective of cost. The results described, by dispensing with nickel, has enabled a given defence to be obtained at less cost. On the armour for a first-class battleship the amount of the saving thus realised, without any reduction in defence, is not unworthy of consideration, even when taken in relation to the total cost of the ship. Whether the existing quality of armour will long maintain itself against possible improvement no one can say. What we may say is this, and I say it with the greatest pleasure, having a full knowledge of the facts; for the present the English armour-plate manufacturers are, on the whole, leading. Of course one recognises that this lead may not long be maintained, because, taking average conditions, we may assume that equality will very soon be reached by rivals, and temporary superiority may pass to the other side. I only speak the feeling of English metallurgists when I say that, we do not forget what has been done in France in relation to steel armour, nor that in recent times French steel-makers have produced "untreated" plates of remarkably good quality. In the United States also very notable progress has been made, and we owe the Harvey process to that country. This friendly rivalry between armour-plate makers at home and abroad, which has gone on so long will, I hope, always continue, and we shall not fail to benefit thereby. Captain Orde Brown referred to the question of Harveying very thick plates. He said we have *only* Harveyed up to 14-in. plates.

Captain C. ORDE BROWN: I thought so.

Mr. W. H. WHITE: It is the "only" that I have in my mind. If 14-in. Harveyed plates are fitted, then upon the figures given in the paper it will be obvious that a very reasonable amount of defence has been provided.

Captain C. **Orde Brown**: I do not think that the 14-in. plate given here in England looks particularly successful. The 14-in. plate in America is undoubtedly remarkably successful. It is in America that they question the wisdom of applying the Harveying process to thick plates.

Mr. W. H. **White**: All I mean is this: It is the "only" as applied to 14-in. Harveyed plates which I challenge. If we take—I do not say I accept that ratio—but if we take Harveyed plates as having an advantage of 50 per cent. over untreated plates, then 14-in. Harveyed is equivalent to 21-in. not Harveyed. I am not aware that in any ship which is at present building, non-Harveyed armour of 21 in. in thickness has been contemplated. So that the manufacture has overtaken the demands of the moment. In any future ships, if it is desired to use thicker Harveyed armour, I have every confidence that armour-plate makers will rise to the occasion. On the barbettes of the *Majestic* and the *Magnificent* 14-in. plates will be carried.

Captain C. **Orde Brown**: Does not the gain that you get from a treatment which is limited in its extent decrease as the armour increases in thickness all the way up? Is not the gain in 6-in. greater than the gain in 9-in., and the gain in 9 greater than that in 10? I would raise the question as to the time also.

Mr. W. H. **White**: I am coming to the time. As regards the variation in gain by Harveying, I am inclined to agree with Captain Orde Brown in principle; but I do not think that the rate of gain diminishes so rapidly with increase in thickness as he appears to contemplate. This has yet to be settled experimentally. As regards manufacture I would point out that, although in the cementation process which precedes chilling considerable time must be occupied, progress in manufacture may be accelerated by the creation of appropriate plant, and by the development of that part of the plant which has to do with cementation in relation to the other processes. The average rate of output has been enormously increased already at Sheffield by suitable arrangements. But if we can get a great gain in the quality of armour by allowing more time for manufacture, that allowance must be made. Similarly, higher defensive quality may involve greater cost; but better defence is a thing worth paying for, because superiority on the quality of your armour tells in many ways. The designs of ships are greatly affected thereby. It is not merely a question of weight of armour for a given defence, but the armour is a load that has to be carried in the ship and necessarily affects many other features in the design. By means of better armour we can either enormously increase the defence obtained for a given weight; or with a given defence we can make smaller ships. Captain FitzGerald made a remark which he perhaps will allow me to answer, as I think we know more about it than any private manufacturer can know. That is in relation to making holes for the attachment of structural details to the hard face of Harveyed plates. That was a matter which had to be considered at a very early stage. We made experiments at Portsmouth with an electric arc, in the way Captain FitzGerald indicated, and corresponding experiments have been made elsewhere. What had been done in connection with the process of electric welding led me to think the case could be dealt with in that way. There was no difficulty whatever; but, as Captain FitzGerald will know, it is a very great advantage when you have numerous holes in the face of the plate to be able to do it in some other way during manufacture. If we can deal with the plates before the chilling process, and then drill most of the holes required, that is a great advantage. Multiplier drilling machines can be used, and the whole work done very rapidly. In fact, these constructional difficulties are readily dealt with when they arise. The other matter dealt with by Mr. Ellis, namely the shaping of the plates, was a matter which had to be settled by experience. Mr. Vickers will, perhaps, say a word or two on that point; and I believe that, in his opinion, the point presents no very serious difficulty in the forms that are likely to be demanded. The broad fact seems to me to be, from the naval architect's side that, thanks to what has been done in America, in France, and in this country, we have the advantage at present of a form of defence which, as against perforation by chrome-steel projectiles, is an enormous gain. Against the attack of high explosives in the form of shells with large bursters, this form of defence is also unrivalled. As naval architects we are immensely indebted to the steel makers of the country for what they have done, and personally I would like to thank Mr. Charles Ellis again for the great labour which he has bestowed on the preparation of this paper, which we all thoroughly appreciate.

Mr. T. E. Vickers (Visitor): Sir John Hay and Gentlemen, so far we have had no great difficulty in making plates to sufficiently correct winding and bend. We make an allowance in the bending before hardening, in order to correct the expected warping in the hardening process, and we are afterwards able with our large hydraulic press to make any small adjustments which prove necessary. In reference to the remarks made by Mr. Hall, as to the use of nickel in the steel for "Harveyed" plates, I may say I was at first quite of his opinion that its use would be of great advantage to them, so as to get the benefit of the hardness effected by the "Harvey" process, and of the toughness due to the addition of nickel to steel. In the course of the trials, however, we Harveyed plates made of steel without nickel, quite as good as regards toughness as those which contained it, the latter being no tougher than the former. The reason is that, nickel steel is affected in its crystalline structure at a lower temperature than ordinary steel, and will harden at a much lower heat. Consequently the nickel steel is affected deleteriously by the long and continued heating in the "Harvey" furnace, and thus loses the advantage which nickel should afford. I believe that for all steel plates to which the "Harvey" process is not applied the use of nickel is highly desirable, as present experience shows that greater hardness, combined with toughness, can be obtained by the use of it. As regards the length of time taken in executing an order for "Harveyed" plates, I may say that we in a very few months shall have plant to "Harvey" at least one plate a day. We can do now about ten a fortnight, so that the time occupied by the "Harvey" process is no serious matter at all.

Mr. C. E. Ellis (Associate): The remarks made by Mr. White on the various points raised in the discussion have relieved me from the necessity of making a lengthened reply. With regard to what Mr. Beardmore has said, it is, no doubt, a matter of regret that the Harveyed plate manufactured by his firm was not successful. It being the only plate of the kind manufactured by that firm, and it being admittedly not representative, it would not have been fair to Mr. Beardmore to have included the details of the trial of the plate in the Appendix. With this exception, and with the exception of an Italian trial, the particulars of which have been kindly given me by Captain Persico, the Royal Italian Naval Attaché, I believe that the list given in the Appendix is exhaustive of all the tests of Harveyed plates in Europe, up to the present time, as I thought it desirable that the Institution should be in possession of all the facts, and therefore I did not confine myself to a few selected instances only. I unfortunately only received the details of the Italian trial a few days ago, too late for insertion here, but it may be interesting to mention generally that the plate was a very good one, and gave excellent results. With regard to the point raised in the discussion that the advantage of the Harvey treatment is more apparent in thin than in thick plates, I must point out that a considerable improvement in the resisting power of the body of the plates (*i.e.*, the part not supercarbonised) is effected by the chilling process. For instance, I have found in the case of the two 10½-in. plates, numbered twenty-three and twenty-seven in the Appendix, that the tensile strain of the mild steel forming the body of the plate was materially raised by the chilling operation. It has also been objected that the output of armour made upon this system must necessarily be small. The simple answer to that argument is that it is merely a question of a few carburising furnaces, and there is no reason why the output of Harveyed armour in any particular works should be less than that of any other kind of steel armour. With regard to difficulties in manufacture, the Sheffield firms have now had sufficient experience to prove that, though there may be difficulties, they are not insuperable. In conclusion I wish to thank the Institution for the kind manner in which they have received the paper, and further, on behalf of my own Company and my fellow-manufacturers, to thank Mr. White and Sir Nathaniel Barnaby for the language they have used in reference to our efforts to improve the manufacture of armour plates.

The CHAIRMAN (Admiral the Right Hon. Sir J. Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): Gentlemen, before moving the vote of thanks, which I am sure will be cordially given to Mr. Ellis for this most interesting paper, I wish to put right a correction which I most improperly made when Sir Nathaniel Barnaby was speaking. It is forty years since I began my investigation into the question of armour plates. It happened in this way:—I was thinking, when I interrupted the speaker, of the Armour Plate Committee which sat at a later period. The French Emperor, before the Russian War, was very anxious to have wooden vessels which could be protected by iron plates, and he had made in this country an iron plate 4½ in. thick, made under the tilt hammer, if I remember right, at Parkgate, which was brought to Portsmouth while I happened to be the Captain of the *Victory*, and I was directed to observe the trials made on that plate fastened on a hulk in Portsmouth Harbour. The result of it was, the wooden ship was thoroughly protected against the spherical cast-iron shot of the then 68-pounder, the 5-ton gun, and the old 32-pounder. The result was that the French Emperor was in the field before us, and built three batteries at the same time that we were building four, but his were ready sooner, and one of them was commanded by our old friend Vice-Admiral Paris. I happened to be at Kinburn, with my ship, the *Hannibal*, and having a little time to spare when these French batteries were going into action, I had the advantage of going on board one to see the effect of the Russian cast-iron shot upon the side of the *Lave*. I then returned to my own ship, fully satisfied with the protection given to that vessel, although men had been killed through the port holes. That was my first experience, and, I suppose, it was in consequence of that, or of some reports in connection with that, that I was selected by the Duke of Somerset in the year 1860 as the Chairman of the Iron Plate Committee which sat until 1864—that is thirty years ago. I now rise up, like Rip Van Winkle, to hear the wonderful improvement which has taken place since those days. Mr. Ellis probably was not born when the Iron Plate Committee, of which I was Chairman, assisted, if I might say so, by some of the most eminent men in the world at the time, Sir William Fairbairn, Professor Pole, Dr. Percy, Sir William Drummond Jervis, and the late General W. Henderson, who formed that Committee. We proceeded to visit a great many of the ironworks—Lowmoor and other places—and we had I do not know how many luncheons from Sir John Brown & Co. Sir John Brown & Co. gave us the greatest assistance, because when we had proved satisfactorily, I believe, to the authorities I have mentioned, with whom I was associated, that under the tilt hammer wrought iron did not afford the protection which was to be derived from rolling, from the fibrous nature of the rolled iron, Sir John Brown undertook to roll us a plate, I forget how long. We had a great meeting at Sheffield, and we saw the first plate rolled. I must not omit to say that, in the steel experiments, we received from Messrs. Vickers, and from Messrs. Cammell also, the greatest assistance. I am afraid I am speaking probably to the grandsons of those who assisted us; but, be that as it may, I thought it right to correct the little interruption which I made to Sir Nathaniel Barnaby's statement, and to point out how it was that I happened, most unworthily, to be associated with this great industry. I may also mention that at that time, or rather at the close of the Iron Plate Committee's labours in 1864, we came unanimously to the opinion that 5½ inches would protect any ship in the world, and we went into some calculations to see whether it was possible to build a ship large enough and long enough to be plated all round with that thickness of rolled iron. I had the honour of waiting on the Duke of Somerset, who was a most excellent First Lord, and always extremely ready to advance everything for the advantage of the Navy, and I mentioned this difficulty to him. He said he would refer the question to the late Chancellor of the Exchequer—the distinguished gentleman who has just retired from the office of Prime Minister. He said he was very tight upon the purse strings, but the Duke of Somerset succeeded in getting out of him sufficient to build three ships 433 ft. long, the *Agincourt*, the *Minotaur*, and the *Northumberland*, which were the result of the Armour Plate Committee's recommendation. Having risen from the dead to tell you these facts which occurred thirty or forty years ago, I would now ask the meeting to give a hearty vote of thanks to Mr. Ellis for the valuable paper he has given us.

THE DETACHABLE RAM, OR THE SUBMARINE GUN AS A SUBSTITUTE FOR THE RAM.

By Captain W. H. Jaques, late U.S. Navy (Associate), Ordnance Engineer.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 15th, 1891; Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

The value of the ram in naval combat is an ever interesting theme, whether one reads of it in Carthaginian history, in the delightful pages of Lew Wallace's historical romances, in the debates of our technical institutions, in the prolific press, in treatises on naval warfare, or in the Transactions of this Institution. Its advocates meet opposition with new zeal and new theories, and we still happily reach our conclusions by friendly discussion and criticism combined with a little experimentation and an occasional collision, although one short naval engagement might produce results that would scatter our theories and provide an easy solution of the problems that have given us so many hours of interesting debate.

While my present object is to present the results obtained in the recent experiments with the Ericsson-Jaques gun and Lässoe projectiles, and the conclusions that have been made public in regard to them, together with suggestions for future construction which have been the immediate results of the successful experiments, I cannot refrain from recalling a few opinions regarding the value of the ram, leaving, however, for some future paper a fuller discussion of the advantages and dangers of ramming, either with a fixed prow or a detachable substitute.

I have followed this subject with great interest for many years, and no doubt many of my hearers will recall my various references to the subject since 1884.

The ram, intentionally and otherwise, has given enough practical tests of its value to favourably influence many tacticians and authorities on naval warfare.

Capt. Grenfell, R.N. :—"The ram has in recent times given proof of its power in actual warfare, and accident has also unhappily shown us on many occasions the sudden destruction which overtakes a ship when this weapon is brought into play."

Mr. W. H. White :—"A strong and suitably shaped bow and great handiness are the essentials of success in ramming, and are easily provided."

Commander Boyle, R.N., presented his views on the "Importance of Rams in War" at your thirty-third Session.

Admiral Sir George Sartorius became a persistent advocate, his views being described by Captain Eardley-Wilmot as "exaggerated."

At the last annual meeting of the Armstrong & Mitchell Company, Lord Armstrong said that the collision off Tripoli had furnished an unassailable argument against gigantic ironclads, which have absolutely no defence against the ram of an adversary. He strongly advocated the building of several vessels specially designed for ramming, such as the United States ram *Katahdin*. He observed that these vessels should not be too large, and should be kept free from the costly complications of battle-ships; that personal dash on the part of the commander would be the principal quality needed in handling such a rammer; and that the occasional loss of such an inexpensive vessel would be of small importance as compared with the loss of a great battle-ship like the *Victoria*.

Dr. Francis Elgar has written:—"The attack of the ram can often be evaded by speed or by skilful handling, and that of the torpedo by watchfulness, tactical resource, and smart conduct on the part of the officers in command. The real defence against rams and torpedoes lies at present much more in the judgment and skill with which a ship can be safeguarded or manœuvred by her officers than in her intrinsic power of resistance."

With the exercise of such judgment and skill it will be much more difficult to hit your enemy, where you wish, with your ship than with the "detachable ram," notwithstanding the facility with which collisions are effected in times of peace.

Lord Brassey says:—"A fixed ram, though superior to the torpedo and the gun as regards destructive effect, is a long way behind both in range."

Although he thinks rams should have a place in the Shipbuilding Programme, he recommends them with some hesitation, quoting the well-known and oft-repeated objections of Captain Grenfell. If Lord Brassey considers a vessel armed with the torpedo or the dynamite gun, when fought as a ram, more formidable than a vessel in which the stem was used to give the fatal blow, how much more powerful would be the projectile from the submarine gun.

Admiral Elliot has lost none of his enthusiasm, and quotes the endorsement of Admirals Colomb, Fremantle, and Long, and Captain Noel. He believes that bow-to-bow ramming will be the ruling feature of fights; that "fleet actions will in future be mainly decided by the torpedo and the ram; that the gun attack will only predominate in single actions; and that, after the torpedo, the most deadly weapon of offence will be the ram." He says:—"All naval officers have recognised the important part which the ram should take in fleet battles, but the structural strength developed in the bows of all our ships is so insufficient for the purpose intended that the danger of self-destruction has had a demoralising effect."

Mr. W. Laird-Clowes expresses the opinion that "the main lessons of the past on the subject indicate—first, that to endeavour to effectively ram a ship that has sea-room, and that is under control, is hopeless, even if she be of greatly inferior speed; secondly, that a vessel that cannot be sacrificed ought never to be deliberately employed as a ram; thirdly, that for ramming purposes a little ship is quite as good as a big one.

In regard to these conclusions, no ship can go into action without the risk of being sacrificed, and small ships can hardly be expected to successfully ram unless they are specially built for this purpose, or carry a cargo like the North American coal schooner. All tacticians, whether in favour of the ram or not, fully estimate the value of escaping the danger that accompanies actual contact.

Although it may be scarcely necessary to give examples to prove the fatal power of ramming, I may refer to the case of the U.S.S. *Tallapoosa* (wood) and H.M.S. *Victoria* (steel). The former was run into by an American three-masted schooner laden with coal, the latter by H.M.S. *Camperdown* during fair weather manœuvres: both sank almost immediately.

The illustrations published in the Admiralty minute on the loss of H.M.S. *Victoria* must fully convince everyone that a ship of any type that receives, at so low a speed as eight knots, a blow such as is there represented, is doomed; we have had too many sad examples not to accept it as an axiom.

The collisions which destroyed the Russian frigate *Oley* in 1869, the Spanish corvette *Fernando el Catolico* in 1873, the dispatch vessel *Forfait* in 1875, the British armour-clad *Vanguard* in 1875, the German iron-clad *Grosser Kurfürst* in 1878, the Transatlantic steamer *Maréchal Canrobert* in 1892, and which so nearly wrecked the Russian iron-clad *Admiral Lazareff* in 1871, the French iron-clad *Reine Blanche* in 1877; the *Minotaur* and *Bellerophon*, the *Hercules* and *Northumberland*; the successes of Farragut in 1864, and the decisive attack of Admiral Tegethoff in 1866; all give enough evidence of the power of the ram, and the probability of being able to successfully carry out the evolution of ramming, for naval architects and artillerists to give their attention to the design and armament of such a type of war-ship.

On the other hand, Captain Eardley-Wilmot, in his "Development of Navies," published in 1892, considers the principle a mistake, and thinks "the gunless ram is a phase of construction based on erroneous assumptions which have a temporary hold on the imagination, but which disappear under practical consideration of the probabilities in war."

It must be admitted that ramming is not an easy operation. Nor are other tactics, when commanders of equal ability meet, having under their control well-equipped craft of modern design.

While cruisers may be cut in two, as merchant ships occasionally are, by high-speed ships striking broadside nearly end on, it will be difficult to secure this advantageous position, since we must give our adversary the credit of equal ability in manœuvring.

Fortunately our opinions *are* based upon imagination and theory, and I trust they long may be; but I am one of many who strongly believe in the efficacy of the ram, and I am seeking a type and equipment that will reduce its dangers, and, if war must come, prove for itself that its principles are not mistaken ones. With skill equal to that employed in other evolutions as great, and perhaps quicker, success may certainly be expected.

In the *Huascar-Esmeralda* combat one shot from a submarine gun would have saved the *Huascar* much unnecessary labour and ammunition; and in the other engagements cited where the ramming action is depreciated, a blow from the detachable ram would have effected destruction, while a number of torpedo boats, with their erratic Whiteheads, would have been necessary to secure the same result. The torpedo cruisers *Almirante Lynch* and *Almirante Condell* fired four torpedoes at the anchored and sleeping *Blanco Encalada*, of which but one took effect, although the attack was made under the most favourable conditions.

The injury sustained by the *Kaiser* at the battle of Lissa, in 1866, would probably have been avoided had she possessed a submarine gun.

Admiral Hobart, Admiral Aube in France, and Admiral Ammen in the United States of America, have long been zealous advocates of vessels constructed especially for ramming, unhampered with other weapons that could entice their commanders from their specific purpose.

Although war-ships of nearly all types have had, in their construction, well-considered devices for strengthening not only their stems but their sterns, for the purpose of ramming, it is rather remarkable that so few rams have been laid down when one considers the importance the ram has been given by tacticians and writers on naval warfare.

After the preliminary trials of the *Polyphemus*, it was stated by the London *Times* in 1883 that her success as a ram was shown to be certain; and, although exclusively *designed* for a ram, "great apprehensions existed with respect to her torpedo arrangements." That journal further added, "The *Polyphemus* is intended to carry no guns, and hence with impracticable torpedo apparatus she would be dependent in action upon her ram alone."

With the exception of the *Polyphemus* (a complicated and costly structure), the Danish *Tordenskjold* (and these two were really more torpedo vessels than rams although they were called torpedo-rams) and the *Ammen* ram, now called the *Katahdin*, there appear to be no special types building for ramming, although we have information from the Press that a double-ended vessel has been designed in England to steam either way and ram with either end. The *Ammen* ram is practically the only vessel that has been built which depends upon the ram *alone* for her offensive power. She has been described by Professor Biles as "an automobile floating projectile of 2,050 tons weight." She is, in fact, a unique war-ship, built for nothing else but ramming, her light rapid-fire battery being available only for defence against torpedo-boat attack. This ram was planned by Admiral Ammen many years ago. In May, 1882, Mr. Gibbons, President of the Pusey & Jones Company, ship and engine builders, of Wilmington, Delaware, read a paper before the United States Naval Institute, on "The Marine Ram as designed by Rear-Admiral Daniel Ammen, U.S. Navy." He described the ram in question as "a projectile, and not a vessel intended in any respect to carry guns, or serve as a base from which projectiles shall be dispatched."

Its form can best be understood by reference to the accompanying drawings (Figs. 1, 2, and 2A, Plate XLIII.). The dimensions are as follows:—

Extreme length	205 feet
Extreme breadth	36 ,,
Breadth of hull proper	30 ,,
Total depth	18 ,,
Draught of water, without coal or supplies	11 ,,
Deep loaded draught	13 ,,
Displacement	1,400 tons.

The vessel consists of a complete iron shell, whose cross section approaches the form of an ellipse, and the longitudinal midship section is not essentially different from that figure. It lies low in the water, and its upper and exposed portion is completely encased in deflecting armour securely laid upon a heavy wooden backing. The armour is regularly diminished over the crown of the deck, but for two feet vertically above the water line it maintains its maximum thickness of three inches.

The submerged portion of the armour increases in thickness from one inch at a depth of 5 ft. 6 in., to three inches at the apex of the sponson, where it and the convex armour of the deck meet in a sharp edge.

A cylindrical pilot-house of steel, 12 ft. 6 in. diameter at outside and 20 in. thick, stands on the crown of the deck, sheltering the steersman, and protecting the smoke-stack which passes up through it.

The ship at the fore end tapers uniformly to a point, and terminates in a heavy cast steel head. In this is mounted a removable point, or die of hammered steel, hardened and tempered. It is slightly cupped at the end, so as to present a chisel-like circumference, the intention of this being that, should impact be had with an inclined surface, the die would not slip, but bite at the instant of contact, thus enabling the ram to successfully strike an enemy's ship at an angle of not less than 40 deg.

A double bottom runs the whole length of the ship. At a distance of 25 ft. from either end is a water-tight partition formed of iron plating, completely separating the end spaces from the interior of the vessel. It is proposed to give to the ram a speed of 13 knots per hour.

By reference to the accompanying drawings, it will be observed that the deck is arched, both longitudinally and transversely; and, considering in connection with this that the ram lies low in the water, the difficulty of striking it with shot at other than lines closely approaching a tangent to the curve will at once appear. The sharp edge of heavy iron presented at her sides renders her a dangerous vessel to ram, even should her great ability to turn quickly permit her to be struck by an enemy's vessel at or near a right angle.

The proposals for the *Ammen* ram were opened December 20, 1890. The Bath iron works of Maine were the only bidders, at a price of 930,000 dollars, and received the contract for her construction January 21, 1891. Her keel was laid August 4 of the same year. February 4, 1893, she was launched and christened *Katahdin*, and a marked departure in type was inaugurated by the revival of an ancient form of naval architecture, and a favourite method of fighting, which resulted in "occasionally a crash, followed by sudden peals of fright, telling of other ships ridden down and their crews drowned in the vortexes; . . . . then in a twinkling the whole after part of the hull broke asunder, and, as if it had all the time been lying in wait, the sea, hissing and foaming, leaped in, and all became darkness and surging water to Ben-Hur."

Probably the first official suggestion for its construction was made by the Naval Advisory Board in 1882, when that Board recommended the construction of five vessels of this type, but it was not until October 18, 1890, that proposals were asked for a harbour defence ram of the following dimensions (Figs. 3, 4, 5, Plates XLIV. and XLV.):—

	Feet.	Inches.
Length over all	243	0
Length on load water-line	242	9
Breadth extreme	43	5
Breadth on water-line	41	10
Draught amidships	15	10
Displacement	2,050 tons	
Indicated H.P.	4,800 ,,	
Speed	17 knots	

A number of changes have been made since she was laid down. Her length and displacement have been increased to 251 ft. and 2,183 tons respectively, and an armament of four 6-pounder rapid-firing guns has been added for defence against torpedo boats. Her blade-like side is a notable characteristic and departure from the more usual parabolic form.

The contract requires a speed of not less than 17 knots per hour, and provides for the vessel's rejection if the speed is less than 17 knots. It is estimated that the horse-power provided should give a speed of about 18 knots; but, owing to the peculiar form of the vessel, there is considerable uncertainty as to the speed that will actually be maintained.

Two horizontal direct-acting triple-expansion engines will drive twin screws. The cylinders are 25 in., 36 in., and 56 in. in diameter, with a common stroke of 36 in. The indicated horse-power is estimated to be 4,800 when making 150 revolutions.

Her armour protection varies from 2·12 in. to 6 in., and weighs about 700 tons. Her conning tower is 18 in. thick.

Although her ram was designed to be a removable wrought steel head, accurately fitted and securely held in position in a steel cast stem, it was built in the usual way. This construction was intended to avoid the usual fatal accompaniment of ramming, with a view of backing off one's adversary, and leaving the spur in the enemy's hull. If such a spur should plug up the hole as effectually as the modern projectile in armour, much of the injury to be done would be diminished. It is a slight move in the direction of the *detachable* ram I have advocated, but for which I would substitute the submarine projectile.

While somewhat similar to the *Polyphemus*, she carries no torpedoes, is a little longer and broader, but has less draught of water and displacement; while their speeds are about the same. She is constructed for partial submersion, controlled by steam-pumps and valves; and is designed with the view of securing the greatest possible structural strength, in order to give the heaviest blow with the least self-injury. With the submarine gun-ram this weight could be put mostly into power and fuel.

I have presented thus in detail the description of the *Ammen* ram, because it is the only vessel especially built for a ram with which a direct comparison can be made with the proposed use of the Ericsson-Lässoe principle of a detached ram, and it may be interesting for the members of the Institution to have the plans and details before them to facilitate discussion.

Although there are many other dangers inherent to the ordinary ram, one of the greatest is that of simultaneous self-destruction when ramming. This is frequently remarked by the advocacy of low striking speeds, one authority stating that "at time of delivering a blow a higher speed than 8 knots was believed not only to be unnecessary, but even dangerous." It will be seen, therefore, that the 600 ft. which the detachable ram (submarine gun) provides for manœuvring is an advantage not to be under-estimated.

In analysing the powers of weapons, Captain Grenfell says:—"If the torpedo and gun are at best on a par as regards destructive effect, the ram is certainly superior to either of them. But as the torpedo is much more limited in range than the gun, so the ram is a long way behind both, its effect being confined to actual contact between the ships. What may be termed the chances of inaccuracy in its use are also enormous. Students of Admiral Colomb's writings will know what a hair-breadth separates, in a ramming attack, the case of ramming your adversary from that of being yourself rammed. At the worst, a failure with gun or torpedo is but a lost shot; but in ramming, if you fail, you may bring immediate destruction on yourself. It is, no doubt, this terrible uncertainty which has thrown into the background the proposals to use the ram as the chief mode of attack which were so numerous some years ago."

It is the aim of the Ericsson detachable ram, or the projectile which is to be fired from the submarine gun, to meet these objections, and to reduce to a minimum the dangers attending ramming with a fixed ram.

To remove the impression that exists in the minds of many who believe that a comparison must be drawn between the velocities and ranges of submarine guns with those obtained by the automobile torpedoes, allow me to explain that while the velocities are very much higher, it is not intended to secure such ranges by this system, but rather to substitute for the *attached* ram, to the power of which so much importance is given, a *detachable* one, by which the dangers of the ram and the risk to the rammer can be avoided or reduced, and a ram obtained which will practically be several hundred feet in length.

The construction and mechanical arrangement of the gun and projectiles are so simple that only a limited description will be necessary to supplement the annexed drawings (Fig. 6, Plate XLVI.).

The firing of explosive projectiles from guns arranged under water has been attended with much danger, owing to the liability of the projectile to be exploded before leaving the gun by the firing-pin striking the valves that were used to exclude the water. By the substitution of a suitable packing, these valves are now done away with, and by means of compressed air the firing position of the projectile is controlled. The gun is breech-loading, with powder discharge. Any system of breech mechanism may be employed.

Experiments with the later mechanisms have been very successful, and all the difficulties have been overcome that caused the failure of an earlier type of this weapon at Milford Haven in the year 1885.

The report of the Naval Torpedo Board which conducted the experiments stated, under date of July 12, 1892, that:—

" Nineteen shots have been made with the ordinary projectiles, and one with the automatic depth-regulating projectile, without rocket attachment.

" The first four shots were made in the Erie Basin, Brooklyn, N.Y., where it was impracticable to use nets to determine the exact trajectory of the projectile under water. The four shots, however, demonstrated that it was possible to obtain a range of 600 ft. with a projectile fired from a gun under water, with a moderate powder charge, and that the horizontal direction was excellent.

" In order to determine the trajectory in the vertical plane, the authority of the Navy Department was obtained to use the Simpson Dry Dock at the New York Navy Yard. Nets were procured and stretched across the dry dock at intervals of 100 ft., up to and including 600 ft. The heads of the nets were so fitted that their middle points could be aligned along the centre line of the dock, and were marked each foot from the middle point. The bottoms of the nets were weighted to make them hang properly.

" A heavy mantelet net was placed across the dock 610 ft. from the muzzle of the gun, when fired, to prevent the projectiles from striking the altars at the head of the dock. The nets for marking the trajectories were 40 ft. long and 20 ft. deep, while the mantelet net was 50 ft. long and 25 ft. deep.

" The *Destroyer* in which the gun is mounted, and which, under the contract with the Ericsson Coast Defence Company, was to be furnished for the experiments, was moored by bow and quarter lines outside of the entrance to the dry dock, and with the muzzle of the gun in the bow of the vessel, at a distance of 650 ft. from the upper altar at the head of the dry dock.

" The gun and its mechanism showed no weakness or defect during the trials, and was satisfactory in its performance throughout. It is well and strongly secured in the vessel. During the trials its axis was 6½ ft. below the surface.

" The muzzle valve, which covers the muzzle of the gun and prevents the ingress of water, was disabled at the second shot by the breaking of the bolt that secures the plate of the valve to the hinge arm by which it is actuated. This bolt had become badly rusted and weakened during a continuous service under water of more than twelve years, and the accident was not due to any defect in design or workmanship. The valve successfully performs the functions for which it was intended, viz., a water-tight shutter for the muzzle of the gun.

" The powder used during the tests was the service sphero-hexagonal, index 27, and the charges varied from 15 lbs. to 30 lbs., the former being used with the automatic depth-regulating projectile. No less than 20 lbs. were used with any of the ordinary type of projectile, and it was found that a charge of 30 lbs. produced a shock of discharge too violent for the tails of the projectiles to withstand.

"The maximum pressure recorded in the chamber of the gun was 1¼ tons.

"The means for determining the time of flight of projectile were not sufficiently accurate to indicate any marked difference of velocity, whether the powder charge was 20 lbs. or 30 lbs., and no practical difference in efficient range was shown by the differences in the weights of powder charge.

"The projectiles furnished by the Ericsson Coast Defence Company under its contract and agreements were of three different types, viz.:—

"Six ordinary; one automatic depth-regulating, without rocket; one automatic depth-regulating, with rocket.

"The length of each was 27 ft. 4 in. The diameter of each was 15¾ in. The weight of the ordinary type loaded was about 1,500 lbs. The weight of the automatic type loaded was about 1,700 lbs. Each type is made dismountable in three sections, viz., head, middle, and tail.

"The head section is of copper rings with composition nose and base. The other sections are of sheet steel, lap-welded to form. The explosive charge is carried in the head section, and space and buoyancy to carry about 300 lbs. of explosives are provided. No tests were made of the mechanism for detonating the explosive charge.

"There was a considerable difference in the form and alignment of the projectiles, due to roughness of manufacture, and in the opinion of the Board much of the variation of the results of the trials of the projectiles of the ordinary type would have been eliminated, had those projectiles been built upon correct forms, thus insuring fair lines with good axial alignment.

"The construction of the tail is too weak to withstand the crushing strains caused by a charge exceeding 25 lbs. of the kind of powder used for the tests. This defect can be overcome by increasing the thickness of the shell in the tail section and introducing more strengthening rings.

"The Board believes that the manner in which the tail of the projectile separates from the piston, after leaving the gun, has a considerable effect upon the trajectory. That a considerable force acts at that point of the projectile is evident from the fact that the tenon guide on the tail of the projectile, and which is secured with two screws of considerable strength, was found broken off.

"But one shot with the automatic depth-regulating type of projectile was necessary to demonstrate that the shock of discharge with a charge of only 15 lbs. of powder was too violent for the strength of the hydrostatic balance provided to maintain the projectile at an approximately uniform depth. The rubber sleeve and its enclosing grating were badly wrecked by the inertia of the water contained therein. The horizontal rudders, which were counterbalanced, had both their forward and after surfaces badly bent, and this injury was undoubtedly due to the force of water acting upon them during the flight of the projectile. Very considerable modifications in the strength and dimensions of the depth-regulating device must be made to accomplish any practical results therewith. Such modifications are quite feasible, and can be made at a moderate cost. The wooden tail fins were completely shattered and splintered when the projectile left the gun, demonstrating the necessity for using metal instead of wood. No trial was made with the automatic depth-regulating projectile with rocket attachment, as it was not deemed prudent to make the test in the dry dock, and a previous test of the hydrostatic arrangement similar in all respects had fully demonstrated its defects.

"During the trials an effort was made to determine if changes in buoyancy of the projectile appreciably affected the trajectory; but the results failed to demonstrate. Changes in positive buoyancy, from 4 lbs. to 24 lbs., were made with the same projectile without affording any practical information upon this point of investigation.

"It was found that a change in the trim of the projectile apparently had some influence with the trajectory in the vertical plane; by increasing the trim by the head from 4 in. to 22 in., the range of the projectile before broaching the surface was extended about 100 ft. Further experiments are necessary to determine the amount of trim by the head required to produce the best results.

"Slight variations in the trim of the *Destroyer*, and consequently in the angle of the axis of the gun with the horizontal, had no appreciable effect upon the trajectory in the vertical plane.

"The practical results of the trials to date may be stated as follow :—

"Had the target been a vessel of a length of 100 ft. and a draught of 20 ft.,

	Feet.
Fifteen of the twenty would have struck her at a distance of	600
Do. do. do.	500
Do. do. do.	400
Seventeen of the twenty would have struck her at a distance of... ...	300
Twenty of the twenty would have struck her at a distance of	200
Do. do. do.	100

"Eight broached the surface between 200 ft. and 300 ft. nets; four broached the surface between 300 ft. and 400 ft. nets; three passed the 600-ft. net without broaching. No trials have been made with the *Destroyer* under way. The speed of the projectile, as nearly as could be determined, was as follows :—

Mean for a distance of—	Knots.
600 ft. ...	29·6
400 ft. ...	52·6
300 ft. ...	71·0
200 ft. ...	94·7
100 ft. ...	118·0

" CONCLUSIONS.

" *Ordinary Projectile.*

" First, the trials have demonstrated the practicability of obtaining a fairly accurate range of at least 600 ft. with a projectile from a gun carried under water.

" Second, the accuracy in the horizontal plane is good.

" Third, the accuracy in the vertical plane is good for a distance of 200 ft. Beyond that point the projectile has a decided tendency to come to the surface, and broaches between 250 ft. and 400 ft. from the muzzle.

" Fourth, by giving the projectile a trim by the head of about 20 in. the broaching point is carried to a distance of about 400 ft. from the muzzle.

" Fifth, variations in positive buoyancy between 4 lbs. and 24 lbs. do not appear to practically affect the trajectory in the vertical plane.

" Sixth, the tail of the projectile is not strong enough to withstand the shock of discharge when a powder charge of more than 25 lbs. is used.

" Seventh, greater accuracy, and possibly a greater range, would result if the projectiles were more accurately constructed.

" Further trials with the vessel under way are required to demonstrate the practical efficiency of the system for use as a weapon of warfare.

" *Automatic Depth-regulating Projectiles.*

" First, the hydrostatic balance, as now constructed, is too weak to withstand the shock of discharge. The inertia of the water enclosed ruptures the enclosing sleeve, and totally disables the depth-regulating mechanism.

" Second, all conclusions stated for the ordinary projectile, except that of accuracy in the vertical plane, apply equally to the automatic depth-regulating projectile, and no conclusion can be formed from the trials regarding the exception."

In the autumn of 1893 the *Destroyer* was taken to Newport for the purpose of using her submarine gun and projectiles to test the comparative strength of various steel torpedo nets. It is hardly necessary to say that the submarine projectile, with its high initial velocity and gradually decreasing speed, is admirably adapted for such tests, as it would simply be necessary to find the distance of each net from the muzzle of the gun where penetration would cease.

It was intended, after finishing these tests, to start a series of trials of the new and improved projectiles of the ordinary type, ordered by the Chief of the Bureau of Naval Ordnance, which had just been finished, and were on board the vessel.

The *Destroyer* had, besides these new and improved projectiles, three old ones much battered, but still good enough for use against the nets.

In connection with the determination of the trim of the projectiles to secure the best trajectory, I wish to call attention to the following letter, written by Mr. Lässoe to Captain G. A. Converse, commanding the U.S. Naval Torpedo Station, Newport, R.I.:—

New York, March 30, 1893.

Commander G. A. Converse U.S.N., Commandant, Naval Torpedo Station, Newport, R.I.

Sir,—

I forward you herewith sketch of tank (Fig. 7, Plate XLVI.), such as I would propose for balancing new projectiles for the Ericsson submarine gun.

From trials in the Erie Basin, as well as in the New York Navy Yard, it appears to me almost conclusive "that a certain amount of buoyancy, not less than 25 pounds, should be retained in the projectile." In all the shots fired with a buoyancy of 25 pounds and upwards, the similarity of trajectories was very close, and a shot could be duplicated without any fear of mishaps. When, however, the buoyancy was reduced much below this, or brought to zero, the path of the projectile became uncertain, and a shot under the same conditions was difficult to reproduce.

I believe this fact may be accounted for by the lack of longitudinal stability inherent in a long projectile without buoyancy, and whose centre of displacement and centre of gravity almost coincide.

From experience gained with the projectiles lately used, I would recommend that the tank be made of such dimensions that the projectile could be balanced with a dip of about 20°, or with the point at least 8 ft. below the surface of the water. I am convinced that a projectile with such a dip and 25 lbs. buoyancy would have an almost straight trajectory up to the 600 ft. limit—that is, its forward point would move in a practically straight line the whole distance, and at the end of its course still have the explosive charge as fully submerged as when the projectile left the gun.

If such a projectile should be furnished with both time and percussion fuse, the assured submergence of the explosive charge at the extreme range of the projectile would seem to be of great importance, as it would make the projectile effective in a zone where its speed would be nearly exhausted, which means between 500 ft. and 700 ft. range.

As the late trials in the Navy Yard tend to prove that both buoyancy and dip have but little effect on the first part of the trajectory where the speed is very high, it would seem that we really have at our disposal a very simple, practical automatic steering apparatus, in the combination of proper dip with buoyant tail end.

Another and fully as important feature in this mode of steering is, "that no matter how heavy a sea might be running at time of firing, the last 100 ft. of the projectile's 600 ft. to 700 ft. range would probably form a most effective zone for exploding its charge, as the inclination of the projectile's axis at a very low speed should form nearly the same angle with the wave slope as it would with the horizontal surface of smooth water.

Very respectfully,

V. F. Lässoe.

With Captain Converse's approval a tank was built and the projectiles were balanced nearly in the manner proposed in this letter. For the first shot, the projectile, which was one of the old ones used the year before, was given a buoyancy of 25 lb. at the tail end, and a dip of about 6 ft. forward. A light steel net of American make, 15 ft. wide and 20 ft. deep, was placed 100 ft. from the muzzle of the gun.

The propelling charge used was only 12 lbs., or about one-third of the service charge. This projectile after passing through the net at a depth of 6 ft. (the centre of gun being 7 ft. below the surface), still showed some tendency to come to the surface at the latter end of its course. The trim and buoyancy of the projectile were, therefore, altered somewhat for the next shot; the buoyancy in the tail end being increased to 35 lbs., and the dip forward to 11 ft.

This alteration in trim and buoyancy had the desired effect, stopping all tendency of the projectile to come to the surface. A heavier steel net was used for this shot; the distance from gun being 200 ft. The projectile, unprovided with cutters, pierced the net 8 ft. below the surface, and kept its proper submerged depth to the end of its range, where, its speed being exhausted, it appeared with its tail end floating and projecting above the surface, while its explosive charge was immersed fully 11 ft., as if suspended from a float.

The third and fourth shot, fired with the same projectile and same propelling charge (15 lbs.), gave exactly the same results, showing conclusively that a proper combination of buoyancy and dip is itself an automatic depth regulator, which, in simplicity, cannot be surpassed.

It has often been suggested that a rotatory motion imparted to the projectile would be the easiest means of getting a straight trajectory. There are, however, some strong objections to this proposition. The rotation could, of course, be obtained in two ways: either by setting the projectile's fins at an angle, and obtaining a rotation by the projectile's speed through the water, or by making the gun rifled, and giving the projectile its rotation in the gun.

The objection to the first proposition, "To rotate the projectile by inclined fins," is that the rotation would diminish with the speed, and that at the very part of the trajectory, where the rotation would be most needed, the speed would be too slow to produce any.

The objection to the second proposition, "To give the projectile its rotation in the gun," is that it would require a projectile with a very heavy shell to stand the twisting strain in the gun. Such a projectile would be far too heavy for its displacement, and would consequently sink by gravity at the latter end of its trajectory, where the speed becomes low.

The plain projectile, with straight fins, and having such a trim that its explosive charge at the end of its run is suspended at the most effective depth (say from 10 ft.

to 12 ft.), would, therefore, seem to be the most practical solution of the problem, especially as a time fuse could be here applied to great advantage. If it should be found advisable to let the projectile sink after the lapse of a certain time, it could be easily accomplished by means of a small hole in the forward end at the rear of the charge.

It is to be regretted that these interesting experiments at Newport were suddenly stopped by the sale of the *Destroyer* to the Brazilian Government, particularly as practical results can hardly be expected from an experimental vessel like the *Destroyer*, in many respects entirely unfit for actual service, and manned by a crew without any experience in the practical details upon which successful results so often depend.

Valuable trials have thus been interrupted to consign an antique experimental craft to a country's naval museum, in which both parties to a controversy have interests that neither wishes to destroy. One would as soon have expected H.M.S. *Nettle* to take a battleship's place in action because successful proofs of guns and armour have been conducted with her.

As already stated, my object in presenting this paper is to secure your discussion of a system that is the outcome of a long series of valuable experiments in submarine artillery, and to supply, if possible, a substitute weapon by which we shall secure the fatal injury to an adversary that is the consequence of contact ramming, and lessen the danger that ramming almost always brings to the rammer. The details of the system are thoroughly worked out; the results obtained are far in advance of any others obtained with submarine artillery; and the gun, projectiles, and appurtenances are simple mechanical contrivances.

As the vulnerability of the bottoms of all modern war-vessels can hardly be disputed, the tendency in future naval wars will be to employ under-water attack, by either the torpedo or the ram. If the opinion of the Director of Naval Construction, confirmed by the Lords Commissioners of the Admiralty, by Sir Nathaniel Barnaby, by Dr. Elgar, and others, be true (and there seems to be no reason to think otherwise), that the *Camperdown's* tremendous gouge in the *Victoria* would not have caused her to sink had her water-tight doors been closed, this is another element in favour of the detachable ram, for the result of the explosion of the 500-lb. charge of high explosives in the submarine projectile would ensure the destruction of the bulkheads and the opening of seams far beyond the region of attack; the ship not having even the resistance of the protective decks to diminish the blow as in contact ramming.

It is stated further that the two ships were locked together for about a minute before the *Camperdown* backed astern and cleared. This contact, and the increased damage done to an already much-injured ship by swinging while the two are clinched, leaves the ramming ship little chance of escaping the fate of her adversary, and emphasises the usefulness of non-contact attack.

If the damage to the *Camperdown* was the result of a collision at a speed of only 6 knots with a vessel moving probably half a knot less, what chance would any ship have of escape if ramming at full or even two-thirds' speed, unless with a broadside blow—*a position of advantage which no commander would allow unless his ship were disabled.* If the shock of this collision "destroyed the absolute water-tightness of some of the partitions adjacent to the place where the blow was struck," how much more would the explosion of the projectile charge?

The commercial standard of fighting has so largely replaced the sentimental, that the objective point will be to destroy the greatest amount of life and property in the shortest space of time. A safeguard against war is the possession of a larger quantity of, and more efficient means of, cutting off your enemy's food supply, and destroying his most valuable property.

Future naval tactics will surely require ships to be told off for ramming, and all will take a hand in this method of fighting, not only as the quickest way to win a battle, but as the last resort of a fatally injured ship. To do this they must come within a few hundred feet, or within certain range of the projectiles (detachable ram) of the submarine gun.

As it will be difficult to strike a fair and square blow with the ram on a fast-moving enemy, the submarine projectile, with its heavy explosive charge, would seem to be the safest alternative. In fleet action ramming will be less dangerous to friend than gun and torpedo fire.

Mr. Laird-Clowes' estimate of an effective range of 800 yards for a Whitehead torpedo is much too great; and, even if it were not, in naval battles of any magnitude where the vessels of opposing fleets are liable to become intermixed, the use of the automobile torpedo must always be attended with danger, as this extended range, when once started on its mission and out of control of the party sending it away, would make it as dangerous to friend as to foe.

Less erratic and possessing more destructive energy than the Whitehead torpedo, and more nearly approaching the power of the contact ram, because of its heavier explosive charge, the submarine projectile will be more efficient than the torpedo, especially as the comparatively low initial speed of the Whitehead practically forbids bow discharge at high manœuvring speed; while the percentage of effective broadside discharge at full speeds is almost nil.

While I have given many reasons why the ram of some sort will be used in future naval warfare, probably the strongest argument in its favour can be deduced from Mr. Laird-Clowes' recent paper on rams. Tell a capable man that something is impossible, and he will develop all his energies to accomplish it.

The next naval war will find every naval commander trying to prove that he can inflict more damage upon his adversary by ramming than by any other means under his control, and that he can accomplish the destruction of the enemy's ship without fatal damage to his own.

The statistics of most value to me, collated by Mr. Laird-Clowes, are those which show the overwhelming percentage of damage done to the ramming ship.

There has never been any doubt in my mind that this was the most serious question to be considered; hence my interest in the *detachable ram* in the form of a submarine projectile of large dimensions, high initial velocity, and consequent power. As far as any comparison of the chances of advantageous attack is concerned, they seem to be largely in favour of the detachable ram.

One of the most useful differences between this and the fixed ram is that in the case of submarine artillery the ram is detached before attack, while the latter is almost certain to be detached by or after the blow. Spurs or projections are not only liable to hold on to an adversary, but are a detriment to quick manœuvring.

The great increase in the resistance of steel armour which we have obtained at Bethlehem with case-hardened nickel-steel plates, decreasing as it does the value of gun attack, makes still more prominent the usefulness of the ram, and consequently the value of a submarine weapon that can reduce the dangers of ramming without reducing itself to the category of the torpedo.

Among the further advantages of this system the following may be mentioned:—

That of attacking at such a distance that a quantity of explosive necessary to insure complete destruction can be employed without injury to your own vessel.

The absence of all danger of disconnecting pipes and valves, extinguishing lights, and generally disarranging the machinery of the ship even if, by any chance, the ram can manage to disengage herself from her adversary after coming in contact with her.

This gun occupies little room, and can be readily fitted to vessels of almost any character.

It is the simplest of all weapons, the projectile, if made of proper proportions and material, containing no delicate parts to be destroyed, disarranged, or rendered useless by discharge.

Whatever advantages any fixed ram may have can be readily combined in the craft that is to carry the submarine gun proposed.

While its range may be less, the projectile's velocity is enormously higher than that of any torpedo. This high velocity is an advantage of the utmost importance.

An examination of the speed record in the official report of the Naval Torpedo Board will show the remarkable speed and consequent energy projectiles of this system possess.

For light cruisers and torpedo gunboats the submarine gun will be of great advantage as a substitute for a ram, since these vessels are too light for ramming.

The type of special vessels that will undoubtedly be built to carry these submarine guns (although they can be placed and worked in any kind of ship) will have the advantage of presenting such a small target that, with their deflected armoured decks and sides, they will run very little risk of being disabled.

With high speed, multiple screws, and rudders for controlling the advantage of position in manœuvring, a small target of deflective case-hardened armour protection, freedom from the usual dangers of ramming, the possession of a detachable ram 600 ft. long; *i.e.*, a submarine 18-in. projectile with an effective range of 600 ft., we have a type of harbour and coast defence craft that can be quickly and economically built, and which would be a most dangerous adversary.

The late Mr. Emil J. Flach, the Swedish engineer, who witnessed the experiments in the United States, in writing about the system said:—"It may be concluded that an efficient trajectory may be obtained if the projectile has a certain buoyancy not too small, and an inclination forward in proportion to this buoyancy. In fact, the projectile has in these two qualities an inherent automatic depth regulator, which in simplicity can probably not be surpassed."

That the results obtained are of much value is evident from the fact that the Chief of Naval Ordnance recommended further experiment with stronger projectiles, which were contracted for, manufactured, and tested under the direction of Mr. Lässoe, the eminent engineer, so long and intimately associated with Captain Ericsson's accomplishments.

This report stated:—"This system of under-water discharge, when perfected, as it undoubtedly will be, will greatly increase the offensive power of the ram, and the Bureau will recommend that all such vessels be supplied with submarine guns. To this end, illustrating the application of submarine artillery as a primary element of the armament of a ram, the Bureau has had prepared a design of a vessel which represents effective features of offence, and which would probably render good service in the defence of our seaboard cities. The pair of submarine guns—placed either in vertical or horizontal sense—designed to be discharged in rapid succession, is intended to use projectiles containing 500 lbs. of high explosive."

The accompanying diagram (Fig. 8, Plate XLVII.) shows Mr. Lässoe's method for their arrangement. He has adopted the plan of placing them side by side, with their muzzles securely fastened in a strong athwartship bulkhead, strengthened by a heavy wrought-iron forging bolted to it and to the frames. The compartments on each side of the middle line bulkhead, in front of the guns, contain the muzzle valves, with their levers and connections; these compartments are always full of water, and the hinged plates only serve the purpose of making up the contour of the bow of the vessel when under way. The manner of shutting and opening these swinging plates is only shown by centre lines in the top view.

The middle line bulkhead forms part of the stem in a similar manner to that of a vertical keel-plate in a side bar keel. This bulkhead is of great strength, and is carried back to cross bulkhead B extending from the upper deck to the keel. By this device the front of the projectile for the first 25 ft. of its travel can hardly be deflected without breaking or bending, as the fins, if carried up to the parallel part, will form a perfect guide in the bore of the gun up to this point of travel. Considering now that the main body of the projectile is in solid water ahead of the stem, and that the tail end is held firmly till the piston leaves the muzzle, it would seem that up to this point there could be no chance of deflection. As the projectile has now probably attained a speed of 400 ft. per second, whatever disturbance may be caused by the expulsion of water from the compartments in front of the gun by the explosion following the piston's departure from the muzzle, will be too late to affect the projectile's subsequent course.

The advantage of having the two guns in the horizontal, instead of a vertical, plane is that the muzzle valves and gear are out of the reach of anchor chains and their operations; and the bow by this arrangement can be so constructed as to be used as a fixed ram, if by any chance this should become necessary.

If the successful experiments conducted by the United States Navy Department are supplemented by a test of the latest improvements that have been recently made in the system (which include automatic firing mechanism that ignites the propelling charge the moment the projectile reaches its firing position), I believe that the views so long held by Commander Converse, the value of which has already been demonstrated by the investigations he has so ably conducted, will be conclusively proved by the further tests he is desirous of making; and that the Ericsson-Lässoe projectiles or detachable ram will provide a substantial reply to Laird-Clowes' question, "To what extent has the value of the ram as an offensive weapon been modified by the progress of the last fifteen years."

In fact, the submarine gun has now been so fully developed that it may be considered entirely out of the experimental stage. Its presence in any vessel can only be an advantage, as the room it occupies is not greatly needed for other purposes, and its effectiveness at short ranges cannot be questioned.

The successful application of this system will provide a small target of high speed and rare manœuvring facility, combining with these valuable qualities all the power of a battleship's fixed ram, while greatly lessening, if not entirely avoiding, the inevitable dangers to the contact ramming ship.

DISCUSSION.

Sir **Nathaniel Barnaby**, K.C.B. (Vice-President): Sir John Hay and Gentlemen, we are all greatly indebted to Captain Jaques for giving us this extremely interesting paper. It is never wise to under-rate the merits of new plans, from whatever source they come, and it is particularly unwise to do so when plans come from the United States, and when they are associated with the name of Mr. Ericsson, and for my own part I should be sorry to say anything by way of casting doubt upon the sanguine statements which have been made by Captain Jaques. It was quite within the limits of possibility that we might have known here to-day something of the effects of this *Destroyer* upon ships in actual war. She is in the harbour of Rio de Janeiro, and a gentleman whom I am pleased to call my friend, Admiral Saldanha da Gama, has seen fit to give up his sword rather than be subject to the attack of these vessels. You will forgive me if I say that I am quite sure that arises from considerations apart altogether from those which govern the sailor. His vessels are absolutely unarmoured, to begin with, but the important thing for him is that he has a large number of wounded officers on board, and a very large number of non-combatants; and he did not dare to subject vessels so circumstanced to the attack of torpedoes. Now, sir, with regard to the use of such a weapon as this, I might refer to the *Polyphemus,* which Captain Jaques has spoken of here, and explain that the *Polyphemus* is a ram, having a submarine torpedo capable of being fired directly ahead under water. That vessel was really built as an answer to the very large ships which were being produced in Italy; not because it was thought that there was any risk of collision between England and Italy, but because it was thought well to build a vessel which would have the power of attacking ships having high speed and great offensive and defensive qualities. The *Polyphemus* has never been repeated, partly because she was much too costly, and much too complicated, but it is quite possible that we may have, as is indicated here, to try once more our hand at the problem of attacking large ships by means of quite small ones. About that I do not propose to say anything, because I do not want to enter into any controversy on that point. I want rather to say a word about the ram itself. It has been stated in another place that the ram of the *Camperdown* was broken or destroyed in giving the blow which sank the *Victoria.* I know I may appeal to Mr. White, when I say that the ram proper of that ship was not injured. I know, too, that I may appeal to him when I say that had the water-tight doors in that ship been closed, the amount of water which would have come into the *Camperdown* would have been very small. Admiral Boys, who had a son on board, has been obliged to leave, or he would have spoken about that, and would have said what he knows himself as to what would have happened as to the admission of water in the case of that action of one ship against the other, had the ramming ship been properly prepared, as she might have been, for the attack. I think it right to say that, because Captain Jaques, it seems to me, somewhat undervalues the ram pure and simple. I think it is a mistake to do that. I believe that we shall find out that the rams are really very strong, and that you may carry away those lighter parts which are built above them, and still have the ship capable of carrying on an action. I will ask Mr. White's concurrence in what I have said, and if I have said anything which does not accord with the facts, I shall be very pleased if he will contradict it. Having said that, I would emphasise what I began by saying, that we are greatly indebted to Captain Jaques for the paper which he has given us.

Professor J. H. **Biles** (Member of Council): Sir John Hay and Gentlemen, I think this Institution is very much indebted to Captain Jaques for taking the trouble he has in writing this paper, if for no other reason than for the reason that he has given us such good plans of the *Ammen* ram. It may be within the remembrance of members of this Institution, that I had the honour of reading a paper here on some of the recent American warships, and the desire was expressed at that time that more information should be given upon the subject of this particular vessel. I had not then received plans which were complete enough to publish, and in consequence the information was not given with that paper; but the very full plans now given really complete that paper, and make the review, at that date, of the progress of American warship building quite complete. We have therefore for that reason, if for no other, to thank Captain Jaques for taking the trouble to send us such good and full plans of one of the most interesting ships of the American Navy. I have not had the good fortune to hear this paper read all through, and therefore am not in a position to say that I have thoroughly understood all that Captain Jaques has to say on the question. The type of vessel, and this particular ram, is something like the *Polyphemus* in many ways. I do not quite understand why it is necessary in a vessel of this type to do away with a light upper structure. It seems to me if a vessel is of any use at all for fighting it is desirable to make her as habitable as possible, and I think that a light open structure, extending the whole length of the vessel, would make her like a modern cruiser, and would not add a very great deal to her weight, or detract very much from her efficiency. Curiously enough, I have had the pleasure of witnessing the production of a design by two American students in the University at Glasgow, a design very much on these lines, but starting from the point of view of making a cruiser instead of a ram, and the ram produced is very much the same as this vessel would be with the light upper structure put on. If I may be allowed to make a sketch I will do so. Suppose this is the cross section of the ram described in this paper (Fig. A, Plate XLIII.). What these gentlemen did was to make a light structure with two decks in it somewhat of that shape. The vessel was large enough to contain in that open structure a crew of about the same number as one of our second-class cruisers has.

Mr. W. H. **White**: Will you put the water-line on, Mr. Biles?

Professor **Biles**: That is about the water-line. [Illustrating.] The idea they started with was to reduce the upper weight of a structure as much as possible, to do away with coal protection, to put the weight of the coal in the bottom of the ship, and so in that way lower the centre of gravity of the ship as much as possible; and the condition I laid down for them as a desirable one to fulfil was, supposing that the whole of this upper structure was shot away, that the vessel should have a range of stability of about 25°.

Captain C. C. P. **FitzGerald**, R.N.: Is there any armour?

Professor **Biles**: The armour was very much of the character of the *Ammen* ram, completely covering that deck and coming underneath the water. It was about 4 or 5 in., and coming to 2½ in. on the top. The vessel was 1,000 tons more displacement than the *Ammen* ram, but she was intended to do different work. It is rather interesting as showing how, approaching the subject from two totally different points of view, these two Americans have arrived at what is almost the same thing. This vessel, that Admiral Ammen has designed, to be made a really habitable vessel should have an upper structure. We carried out some experiments on a pond to find the form of a wave which would be made by a ship going at high speed, and we found it was quite a normal shape of wave, as, no doubt, it would be known to be by those who know the results of the experiments on the *Polyphemus.* A vessel of that form of course looks rather an exaggerated kind of vessel, but it is quite a development, I think, from the *Ammen* type, and, if the *Ammen* ram had a light upper structure given to her, she would probably be an efficient sea-keeping vessel, and one of a useful type. The coal was admitted through scuttles in this armour deck, and there was no coal above. The whole of the coal was shipped through the part of the armour deck outside the ship. The boats were lifted up by derrick arrangements, but this narrowed part did not extend the whole length of the vessel. As the vessel narrowed up enough to make the breadth of the ship the breadth of this house, then it took an ordinary poop and forecastle form.

Captain C. C. P. FitzGerald, R.N. (Associate): Sir John Hay, I am extremely sorry that the writer of this paper is not here to reply, because I am afraid my remarks are going to be very far from complimentary to this style of craft. I propose to make a few remarks on the general question of ramming, as that is at the bottom of the subject. The author makes large quotations from various authorities—Admiral Elliott, Admiral Colomb, Mr. Laird-Clowes, and others, as to the suitability of ramming tactics. I need not repeat them, but the general gist of all these quotations is to show that, in future naval actions ramming tactics will be largely resorted to. The idea is to ignore the gun and the torpedo, and to build small vessels, and settle the dispute with the ram. There is something particularly fascinating in being able to dispose of an enemy with one blow, to do away with all the noise and smoke of guns and the complication of torpedoes, and to go straight at him and sink him at once. But, unfortunately, there are always two who can play at that game. If you think the enemy is going to stay still and allow you to do that, you may find you are mistaken, and that probably he is as good at ramming and avoiding the ram as you are. I speak on this subject of the difficulty of ramming with some little personal knowledge. I have not tried it in battleships at present, I am thankful to say, but I have tried it in small vessels specially fitted for the purpose—small vessels which were brought down, as far as possible, to the manœuvring power of large vessels. Time and speed are only comparative things. You prepare your vessels by locking the safety valve at a very low pressure, and pad them all round. This is nothing new; it was tried in Russia a great many years ago. We tried it the other day in the Mediterranean, and did it, not once or twice, but a great many times. The captains of the battleships commanded the squadrons, and then we had imaginary battles, and points were given for imaginary guns, &c. The only thing certain was the ramming—so we thought, before we tried it, but we found it was not at all certain; in fact, we found that the only way we could make it certain was by going straight end on to each other; and we always concluded that this would in real war mean mutual destruction. But this is not what is intended by "ramming tactics"; it is intended to go broadside on to the enemy, and to sink him, and not to sink yourself. At any rate, the final conclusion we came to was this: that with two men equally able to handle two equal boats, it was absolutely the toss up of a shilling whether you were rammed yourself or rammed the other one. That is the result of considerable experience, therefore I cannot fall in with the idea of those who think a battle is going to be finished by the ram, unless you both choose to go down together, and then those who have the most ships will win. Now, with regard to the general question of construction, the proposition is, I take it, that small inexpensive rams are to be produced to take the place of battleships. I do not know that I am right in saying "to take the place," but I know it is proposed that a certain sum of money should be expended on them which would otherwise be expended on battleships. There is only so much money to work on. If you have one, you cannot have the other. I have always been against it. There are strong advocates for the construction of small, inexpensive rams. Lord Armstrong, as you know, is a very strong advocate, and Lord Brassey is another, and I might mention several others. Sir Nathaniel Barnaby is for smaller and less expensive ships. You can have three or four small cheap rams instead of one battleship, but the question is, Can they take her place? I say, No. You have first to catch your battleship, and then you have to ram her. In order to have an inexpensive vessel, you must have a comparatively small one. Say the battleship costs three-quarters of a million, you could have for that three or four vessels of 4,000 tons each. Take the tonnage at 4,000 tons, which is about the tonnage of a second-class cruiser costing something short of a quarter of a million. The first thing you have to get is speed. If you do not have speed, you cannot ram anybody. Therefore, you must have enormous boilers and engines, in proportion to the size of the ship. In order to get about 19 knots, which would be necessary to ram a first-class battleship of 16 knots—the speed now of many battleships in England and abroad—you would have to build your vessels extremely light, so light that a steam launch would nearly knock a hole in them. How is this vessel going to ram a battleship? She would go down herself. The thing is perfectly absurd. What are you going to give up in order to strengthen this vessel? Your guns, your ammunition, and your torpedoes. The percentage of weight given up to guns and torpedoes in a second-class cruiser of 4,000 tons is extraordinarily small; I do not suppose it is more than 8 or 9 per cent. What increase of thickness could you get in your scantlings, or the skin of your ship, for this sacrifice of guns? Nothing appreciable. You could not strengthen your ship so that she would not go down herself if she rammed. And, then, suppose one of these gunless rams meets an enemy's second-class cruiser with guns and equal speed, what happens between them? They get into gun range, and I do not see why the cruiser is to let the ram get alongside and ram her, going at equal speeds. I should not like to be in the ram. Then, take the case of a fleet action. We are told that this ram in the middle of a fleet action is to "dash in" among the battleships and ram the enemy: she would have to take care that she did not ram her own ships—that would be a difficult matter in the smoke and heat of an action. The fact is, the gunless ram is a delightful fad, and I do not think you will ever get naval officers to believe in her. But, on the other hand, if any of the numerous talented constructors here will produce a gunless ram of speed sufficient to catch and ram a battleship, and to be practically unsinkable herself, we shall gratefully accept her, but until that vessel is actually produced, we shall remain sceptical. Now, as to this particular vessel. In the first place, she is not seagoing—I take it she is not intended to be seagoing—she is a coast defence ship, and for that reason she is not suited for English requirements. We do not require coast defence vessels, and she is certainly not seagoing. Anything of that kind, you may depend upon it, is not a seagoing vessel. We have the section of her here. She might do to go outside a harbour, and if anything came along quietly and just waited outside for her, she might manage to hit her. But she is not a seagoing vessel in any sense, and cannot accompany a fleet. I cannot see that she is anything better than a torpedo-boat, or so good. All our ships must be built with a view to what tactics we are going to pursue. I should say that the money expended on such a vessel would be better expended on torpedo-boats, because you could build half a dozen for it. After all, this game of submarine guns and torpedoes is a game of stalking. You have first to catch your hare. You do not suppose that the enemy are going to "lay to" and allow you to strike them in any way you please. It is the confidence trick over again—they will not do it. The only thing I can liken it to is putting salt on the tail of a bird. If the bird will allow you to put salt on his tail, you can catch him with your hand, and do not require to trouble about the salt. I have given my general views on ramming, and they have not been formed lightly. This vessel is only an extension of ramming, and I think the sooner we get out of our heads the idea about the certainty, or the probability, of ramming when you want to do it, the better. That there will be ramming in action I am very confident, but that it will be quite as much accidental as intentional I am equally certain. Altogether, I am inclined to think the proposed vessel is inferior to a torpedo-boat; inferior even to the proposed gunless ram; and likely to be more dangerous to those in her than to an enemy.

Mr. W. H. **White**, C.B., LL.D., F.R.S. (Vice-President): I have a remark or two to make; but, perhaps, I may recall attention to the fact that Mr. Hall's previous speech on rams was interrupted. He began with nickel steel, and left off when he was dealing with cork. Perhaps he will now tell us where he really stands—how much nickel steel and how much cork he recommends for rams?

The **Chairman**: I beg Mr. Hall's pardon; I remember I did interrupt him.

Mr. J. F. **Hall** (Member): Sir John Hay, I must apologise, in the first place, for saying what I did about rams, &c., during the discussion of the last paper, having in view this paper before us; but I was certainly not aware that such a paper existed. On our notices the paper down is "Submarine Artillery"; the heading of the paper now in our hands is, "The Detachable *Ram;* or, the Submarine Gun as a substitute for the *Ram.*" If I had known *that*, I should have reserved any remarks I might have had to make until this paper was read. I may just mention that I am not the only gentleman in the room who has thought it would be very much more convenient if we could have these papers before us a little sooner. We should then know what we are talking about. I only got this paper immediately after the reading of Mr. Ellis's paper, and have only had time just to glance through it. If I had had the pleasure of doing so before, I should not have had the audacity to stand up here and make the remarks I did during the discussion of the last paper, when I now see that such an eminent authority as Lord Armstrong is a very strong advocate for the identical principle I spoke of; and there are a great many instances given in this paper of people knowing more about the subject than I do who are of the same opinion. The remarks of Captain FitzGerald about the actual execution of ramming have been most interesting, and it is not for me to say anything in reference to them; but it was merely a suggestion on my part that a ship should be designed so that, supposing she were rammed, and supposing it actually took place in any position that a hole was knocked into her, into which the water could pour, it should not overbalance the ship in the disastrous way that it has done. I can only think that the production of such a ship could be accomplished by using the very strongest steel, and filling up the interior with any composition that our esteemed friend, Mr. White, may be able to devise; taking out of the ship a considerable number of the men, a few of the big guns, and, a lot of the unnecessary impedimenta, including all the torpedoes, &c. As far as the main pith of the paper of Captain Jaques is concerned, I have only been able to glance at it; and regarding this proposed submarine gun, it appears to me to be so utterly complicated, that it would require a great deal of study for anyone who, like myself, is not a practical builder of ships, to attempt to discuss it.

Mr. W. H. **White**, C.B., LL.D., F.R.S. (Vice-President): Sir John Hay and Gentlemen, there are some points I should like to speak to on this paper. The question of tactics has been dealt with by Captain FitzGerald, an officer of experience and authority. No more need be said as to the dangers involved in the attempt to ram a ship that is under control, and possesses fairly equal speed.

But I understood Captain Jaques to favour the use of a submarine gun (the pith of his paper lies there) as compared with either a locomotive torpedo or with the use of a ship as a ram. On page 252 of the paper are to be found some very interesting figures. When the use of any submarine attack has to be considered, the most important thing (as Captain FitzGerald clearly explained) is to know, within what range you must come before the attack can be effectively made. With any projectile delivered under water at the highest initial velocity conceivable, but not possessing locomotive power within it, the conditions of resistance are such that there must be a rapid degradation in speed. If page 252 is referred to, it will be seen that for the first 100 ft. this projectile moved at the velocity of 118 knots; I presume *per hour*. In covering 300 ft. it had dropped to a mean speed of 71 knots, and for a range of 600 ft. the mean speed falls to what in modern torpedo work is a moderate speed. Supposing that two vessels were engaged, one armed with a submarine gun, the other with a submarine locomotive torpedo, you might say that the one with the submarine torpedo would be able to deliver its weapon effectively at a range of 600 yds., instead of 600 ft., and at practically the same speed as is claimed for the Ericsson gun. These appear to me very important considerations. Furthermore, it is perfectly clear that if this submarine gun is carried in the bow of a ship which has to come up at speed within 600 ft. of his enemy in order to shoot its projectile, that the officer in charge of that vessel will have some difficulty in utilising the principle of the detachable ram. At full speed it would not take long to move 600 ft.; and he might possibly overtake his projectile, or perhaps come so near to its explosion as to share its destructive effect. We know that with a locomotive torpedo ejected at the bow of a swift ship there is a possibility of the vessel overtaking the missile, and this might occur also with the submarine gun at the bow, especially in view of its more limited range. This limited range within which high speed of the projectile from a submarine gun is maintained seems to me a very important point indeed in regard to the use of such weapons. If the Transactions are consulted, it will be found that a long time ago a plan was submitted to this Institution by Mr. Longridge—a perfectly workable plan—for a submarine gun. Although it is possible that Mr. Ericsson was engaged upon his invention before Mr. Longridge's paper was read, there can be no doubt that Mr. Longridge was working quite independently. Mr. Ericsson, however, as usual, had the courage of his opinions. He built a vessel, the *Destroyer*, at his own expense; and (as is shown in this paper), by gradual experiment, he produced a vessel which (apart from the limitations to which I have referred) was of its kind a very remarkable one. I had the pleasure of a conversation with Captain Jaques recently, and am inclined to think that my friend Sir Nathaniel Barnaby was somewhat sanguine in supposing that, if the *Destroyer* got into Rio de Janeiro bay while the state of war, or revolt, or whatever it is called, continued, we might obtain an object lesson of what this vessel can do. As a matter of fact, Captain Jaques mentions in the paper, and he told me personally some little time ago, that there was nobody on board the *Destroyer*, when she left the United States, sufficiently trained in operating with the submarine gun to do it justice. Those who were interested in her, like Captain Jaques, were very doubtful as to what might happen if they tried to make use of the vessel. In relation to the further quetion of whether, with such a limitation of range, it is desirable to arm the bow of a vessel with a submarine gun instead of specially strengthening her as a ram herself, I should be disposed to think that, on the whole, the balance of advantage will be found in making the bow of a vessel a ram. Captain FitzGerald has remarked that ramming, while it may not be practised as a common form of attack, and must always be a risky form of attack, may yet, on occasion, become a most formidable means of destruction to vessels.

Captain C. C. P. **FitzGerald**, R.N.: No, capture them instead of sinking them.

Mr. W. H. **White**: Undoubtedly the risk of ramming is much increased now that locomotive torpedoes are used; but it is a mode of attack which has been, and may again be, practised with useful effect on disabled or partially disabled vessels.

Sir **Nathaniel Barnaby**: The *Re d' Italia.*

Mr. W. H. **White**: That was a case in point. The *Re d' Italia* was not moving at the time she was rammed. When a vessel is not under control, and the relative motion is not the same as when both ships are swiftly moving, then is the best chance for a ram attack. I am not differing from Captain FitzGerald as to his estimate of the risks of ramming. On the other hand, it costs little to strengthen the bow of a ship, so that it can deliver a deadly blow if the opportunity presents itself, and it is an opportunity, I take it, that very few concerned with warship construction would be content to let pass. Sir Nathaniel Barnaby appealed to me in relation to the *Camperdown.* He has absolutely described the facts. It was the upper portion of the stem and bow of the *Camperdown* which suffered in the collision. The ram proper, the under-water spur, was not disturbed. The only serious damage done to the plating of the *Camperdown* was on one side of the bow as she twisted. The whole of the damage was situated before the collision bulkhead. That is a short summary of the facts which anybody can obtain from the Parliamentary papers. To give effect to Mr. Hall's views, large alterations of structure would be required, in order to make a vessel which would be capable of ramming, and coming out of it without any sensible damage. I do not say it is mechanically impossible. But, taking into account the enormous risks always run by a vessel which makes contact with another vessel in motion, and recognising the fact that those risks are greatly increased by the introduction of torpedoes in the vessel attacked, it does not appear to be a wise policy to spend in ships, built primarily for the line of battle, an enormous amount of material, and a considerable amount of money, in adapting them for ram attacks. I am afraid I have somewhat badly expressed myself, but there is a distinction to my mind. In all matters of this nature one has compromises. It may be justifiable to give a certain strength to the bow if the ram is not purchased too dearly. There can be no sensible objection to that. It may be most objectionable to go so far as many persons would have us go, and to make ramming the controlling feature of a design. I think, as between the locomotive torpedo and the submarine gun, anybody who has looked into it must see that the range of effective action, the tactical possibilities, are so much greater with the locomotive torpedo than with the submarine gun, that, although you do not have to spend so much on a single missile with the submarine gun as you do with the locomotive torpedo, yet that extra element of expense is well bestowed if the torpedo is used instead of the submarine gun.

The **Chairman** (Admiral the Right Hon. Sir J. Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): As Captain Jaques is not here, I ventured to ask my friend the Secretary to be good enough to reply, but he declines the duty. I have nothing to do but to ask you to thank Captain Jaques for producing this paper, which has considerable advantages, and I think we got back into the right groove among some of the more recent speakers, because I do not find in the paper, which I read with some interest, that Captain Jaques advocates the use of the ram in preference to his submarine gun. We are not yet satisfied, as I understand, that the submarine gun is so good as some other weapons we already possess. I cannot think that any opinion which I may express can be of any value in the presence of Captain FitzGerald, who is an officer fresh from the sea, and I know very little about it, but I have a little more belief in the value of the ram than my gallant friend seems to attribute to it. I think of it in this way: when a well-disciplined, well-practised fleet which has been some considerable time together, such as I hope this country may always possess, meets a fleet coming out of harbour not well disciplined, and not understanding its business as they probably would understand it if they had been as long at sea as we had been, in that case I confess I think the ram one of the most formidable weapons we could possess. I may again indulge in a retrospect. I had the honour of knowing one of the most distinguished officers whose flag ever flew, I allude to Admiral Tegethoff. I saw Admiral Tegethoff very shortly after his famous battle of Lissa, and he was kind enough to explain to me the tactics that succeeded on that occasion. Admiral Persano's fleet, as we all know, was not in a position to defend itself. Part of his men were on shore attacking the forts of Lissa, others were being hurried on board. His fleet in number was three times that of Admiral Tegethoff's. Admiral Tegethoff came down from Pola with a strong north-easter and found them in this most unmanageable condition, and he said to me, "I said to my captain, 'There is nothing to do with these fellows but to ram them, and we must set the example.' The captain said, 'I think we are a little too near, sir; do not you think we had better turn round and get a little more scope?' 'No,' I said, 'go at the nearest.'" He said, "I struck the *Palestro* and tore off seven plates in the concussion," and she was afterwards set on fire by the shells of succeeding ships, where she had been bared by this attack of Admiral Tegethoff. "The captain then said to me: 'I think, sir, we should turn round to attack the other.' 'No,' I said, 'attack the *Re D' Italia*.' We steered for the *Re D' Italia*. I was watching her closely. He said, 'I saw her reverse her engines.' I said to the captain"—I am ashamed to say I do not remember the name of the distinguished officer who was the flag captain—"'I think they are reversing—I see it, sir.' We struck her a moment afterwards, and 147 ft. of her side went in. She rolled over toward the striking ship. We had reversed our engines and were drawing away from her when her marines who were on the poop, not knowing what had happened, fired a volley and killed four officers and men on the poop beside me, and wounded several others. After that she went down with 600 men." He said the confusion into which the hostile fleet was thrown by this manœuvre caused the *Affondatore*, which was the next most formidable ship, in which the flag was flying, to withdraw with the other vessels of the fleet, and the victory was gained, which was of the greatest value to the Austrian Empire, and certainly the most creditable of the actions carried out by many of the distinguished officers whom I have had the honour of knowing, and I had the honour of knowing Admiral Farragut and Admiral Boutakoff, and others whose names are familiar to us. I have always thought that Admiral Tegethoff's smartness in seeing his opportunity gave a victory which could hardly have been anticipated, and was entirely due to the promptitude with which a well-skilled officer, handling a well-disciplined fleet, attacked vessels greatly superior to him in numbers, but not in discipline and skill. Under such circumstances I should differ from my gallant friend, and I think if my gallant friend commands, as I trust he may, a fleet on an occasion of that description, he will not hesitate to use the ram and sink all the ships instead of leaving only one. I thank Captain Jaques in your name for the paper he has permitted to be read.

The following reply has been communicated by the author:—

Captain W. H. Jaques, late U.S. Navy (Associate): In thanking you for your appreciation and generous discussion of my paper, I desire to call your attention to those paragraphs which deferred to some future paper a fuller discussion of the advantages and dangers of ramming, and presented the details of the *Ammen* ram to facilitate a discussion of the comparative value of the Ericsson-Lässoe principle of a detached ram. In this connection, I wish to thank Sir John Hay, Professor

Biles, and Mr. W. H. White for piloting my paper from the shoals of a discussion on the value of ramming, back into the clear water of a direct comparison of the advantages and disadvantages of submarine artillery and the usual form of fixed rams. You will note that I had no intention of presenting the plans of the *Katahdin* as those best adapted to ramming, either with or without a submarine gun. I see no objection to the light upper structure Professor Biles suggests. All the United States monitors have it, and the enemy's shot will quickly clear it away in action. Although the value of submarine artillery can be best demonstrated in battleships, I purposely abstained from advocating any particular type, because I wanted to emphasise the point that the submarine gun could be fitted to any kind of craft having adequate draught of water. The detailed report of the Torpedo Board was given in order that all of the facts in connection with the trials might be before you, and that the presentation of the subject should not have the bias of an advocate of the system. In reply to the remarks of Sir Nathaniel Barnaby, I will say, I do not undervalue the ram pure and simple. I am in favour of ramming. I believe that specially fitted rams, vessels with rams, and craft without rams, will all take a hand at ramming. I further believe that more vessels, large and small, can be supplied with the important requisites of the ram, viz., ramming energy, form, and reduction of danger to the rammer, for less money by fitting them with a submarine gun than by any other method. That the *Polyphemus* has not been repeated is an evidence that she did not fulfil the conditions for which she was intended. Her weapon for submarine bow attack is not such a one as I advocate, carrying from 300 lbs. to 500 lbs. of explosive, but an unreliable Whitehead torpedo (with 80 lbs. charge) of comparatively low initial speed, frail mechanism, and extremely dangerous for bow discharge. I am sorry Captain FitzGerald did not discover the "gist" of my paper. Discussions are too frequently conducted on the theory that the writer desires to substitute his proposed weapon for all *others*. There may be such, but I am not one of them. Guns of all classes, battleships and torpedo-boats, armour, torpedoes, structural bow strengths, &c., are all necessary for their respective purposes (and I certainly have taken a most prominent part in their development); but this paper was presented on the theory that all alert, daring commanders will ram when they get a good opportunity. Therefore they should be provided with the best weapon for this purpose. The submarine gun possesses more advantageous qualities than the fixed ram of any sized ship afloat, and its value in converting small craft into rams in an emergency cannot be over-estimated. In criticising that part of my paper to which I asked the *least* attention, Captain FitzGerald has been led away from the principles presented. I have not advocated "that small inexpensive rams shall take the place of battleships." In the comparison he makes between the latter and small craft, he *unintentionally* says more in favour of my system than I do myself. His remark, "that it was absolutely the toss up of a shilling whether you were rammed yourself or rammed the other one," accords with my views, and is a reason for advocating the use of a weapon which, whether it be called a detachable ram or a submarine projectile, can be projected ahead a sufficient distance to insure the attacking vessel the necessary manœuvring room for either backing out, or shearing off, without risk of collision. That a charge of 300 lbs. of gun-cotton exploded 10 ft. to 12 ft. below the surface of the water, and in contact with the side or bottom of an ironclad, would be more effective than the slow, crushing blow of the permanent ram can hardly be doubted. The effect of a heavy explosion will be to start almost every rivet and seam within a radius of 100 ft. or more, not to speak of such other injuries to the vitals of the ship as bursting of steam connections, shifting of boiler saddles, and derangement of propelling machinery. On the other hand, the damage caused by the fixed ram will be found much more localised and less dangerous than that produced by an explosion. The naval tactician of the present day is hardly in a position to say what shall be, or what not. Captain FitzGerald will find his experience in small craft of very little use when he tries the same tactics in a battleship, even though he does think "time and speed are only comparative." If battleships are built impregnable above water, it is not likely that fleets composed of these will fight at long range, but rather at close quarters, where underwater attack may be used effectively. The superiority of the automobile torpedo over the submarine would seem apparent on account of its longer range; but would a commander take the risk to launch any number of these invisible missiles with friends travelling in his wake and probably at a great speed, ready to shear off at a second's notice if the leading ship should have to slacken up? Referring to Mr. White's remarks, Mr. Longridge's "plan for a perfectly workable submarine gun" was discussed in my "Ericsson's Destroyer and Submarine Gun," published in 1885, and full credit given to what Mr. Longridge proposed in his paper of 1868. Captain Ericsson sent his plans to Emperor Napoleon III. in 1854. Mr. Longridge sent his to the Admiralty in 1866, and, as far as I know, no "workable" submarine guns have ever been constructed from his plans. While the range of the locomotive torpedo is greater than that of the projectile of the submarine gun, the Whitehead is very erratic, and its speed is so slightly in excess of that of swift ships that bow discharge entails serious risk. The great initial speed of the Lässoe projectile and its more certain trajectory are elements greatly in its favour. For Mr. Hall's benefit, I wish to state that the construction of the gun, fittings, and projectiles is exceedingly simple. It is the great speed of the submarine projectile for short ranges, such as up to 300 ft. or 400 ft., that makes it pre-eminently fitted to be the arbitrator in battles between ironclad squadrons. It has already been proved in actual trials that such a projectile weighing 1,500 lbs. can travel the first 300 ft. in 2⅔ secs., and it would be comparatively easy with a heavier projectile to reduce the time to 2 secs., equal to a mean speed of 150 ft. per second, or about 90 knots for this distance. If, for illustration, the projectile starts with a muzzle velocity of 500 ft. per second, and the total range where its *vis viva* is exhausted is 700 ft., then its velocity at half the range of 350 ft. from bow will be the square of ½ multiplied by 500, equal to 125 ft. per second; at a distance of 175 ft. from bow, or one-fourth of the range, its velocity will be the square of ¾ multiplied by 500, equal to 281 ft. per second. The utter destructiveness of a projectile striking with a speed of 281 ft. per second and weighing 1,800 lbs. can be imagined, when we consider that it will have sufficient momentum to penetrate the unarmoured hull of any ironclad in existence, leaving a charge of some 300 lbs. of gun-cotton imbedded in the double bottom. With a delayed action or time fuze, the attacking vessel may use such a submarine projectile for penetration at even closer quarters, and still have time to get out of the danger zone of explosion. The general tendency of naval experts has been to look upon the submarine projectile as a mongrel torpedo, leaving out of sight that its mission is not in competition with that of the automobile torpedo. In action between single vessels and at longer ranges, the automobile torpedo may be the beau ideal of submarine attack; but at close quarters in a general *mêlée* the submarine projectile covers a field distinctly its own. Within its useful range, its time of travel is but a fraction over two seconds, and in most cases it would probably be less. The danger of running foul of a friendly ship is therefore minimised, especially if provisions are made for drowning it after a three seconds' run. A *mean speed* for the whole range of the submarine projectile gives quite an erroneous idea of its capability. Being propelled by *vis viva*, the speed at the outer end of its trajectory becomes infinitely small, and it might take many seconds, or even minutes, to decide when it actually stopped. In this manner a mean speed might be brought down to almost nothing. Again thanking you for your interest in my paper, I take this opportunity to express the hope that the British Admiralty may soon see their way to continue experiments in submarine artillery.

LEAVES FROM A LABORATORY NOTE BOOK.

By Professor VIVIAN B. LEWES, F.I.C., F.C.S., Royal Naval College, Associate Member of Council.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, Thursday, March 15th, 1894; Admiral the Right Hon. Sir JOHN DALRYMPLE HAY, Bart., K.C.B., D.C.L., F.R.S., in the Chair.]

(*a*) SOME POINTS AFFECTING THE TRANSMISSION OF HEAT IN STEAM BOILERS.

THE calculated evaporative value of the fuel used in the furnaces of steam boilers, and also the value obtained by calorimetric tests, is invariably far higher than the evaporative power as found in actual working; the difference in many cases amounting to over 40 per cent.; this result being due to a large number of different causes which the constructor of marine boilers has for years been trying to overcome.

Amongst these are: loss of heat by radiation from the exposed surfaces of the boiler, improper regulation of the air supply, and incrustation in the boiler reducing the conducting power of the plates; but I think there is yet another cause which has been overlooked, and to which I wish to draw the attention of marine engineers.

As early as 1876, Heumann, in his researches upon the causes of luminosity in flame, found that no flame was in contact with a cool surface exposed to its action, and that a bar of cold metal plunged into a flame extinguished the flame gases in its immediate vicinity, leaving an area in which no combustion took place, but which grew less and less as the metal became heated, until the rod had acquired nearly the same temperature as the flame itself, when contact between the two was completed.

Before I knew that this work had been done, I had noticed the same phenomenon, and had made experiments which led me to the same conclusion.

In all analyses of flue gases a certain small proportion of unburnt combustible constituents will be found to still exist, and there is no doubt that the chief cause of this is to be found in the fact that the flame, which plays along the upper part of a boiler furnace, and which heats the furnace crowns, combustion chambers, and tubes of the boiler, is cooled by contact with the boiler plates to such an extent that it is extinguished, leaving a thin layer of unburnt gas mixed with the products of combustion between the source of heat and the plate; and inasmuch as the plates on their exterior surface will only rise in temperature a degree or two above the temperature of the water within the boiler, you will never have, under normal conditions, boiler plates heated to a temperature higher than 200° C., whilst the flame has a temperature of over 1,000° C.; the result being that a layer of non-conducting gas is always present, and checks the transmission of heat from the burning fuel to the water within the boiler, whilst the unburnt gas creeping along the plates will, to a great extent, escape combustion, and by this dual action leads to a very considerable diminution in the evaporative value to be obtained from the fuel.

I have made a large number of experiments upon the amount of combustible constituents so escaping.

In making any experiments upon the composition of these checked products of combustion, it is evident that the smaller the admixture of air the better, as the difficulties of analysis increase with dilution. After many attempts to devise a form of apparatus which would allow the products of combustion to be collected, without at the same time giving too great an admixture of air, or interfering with the process of combustion going on, I at length came to the conclusion that the best form of apparatus to use was a tin-lined copper pot, fitted with a false bottom, which gave a space of 1 in. between the two bottoms. A circular aperture 2½ in. in diameter was then cut in the centre of the false bottom, whilst a small exit tube ⅛ in. in diameter was fitted into the side of this lower compartment. On now putting a known volume of water at 0° C. into the vessel, and placing a Bunsen burner with a flame of carefully regulated size below it, so as to allow the flame to pass through the hole in the false bottom and impinge upon the bottom of the vessel itself, it was possible to draw off the products of combustion from the exit tube at the side, without having a larger volume of air than necessary mixed with it. The gases on leaving this tube were first passed through carefully prepared fused calcic chloride, which had been previously treated with carbon dioxide to prevent any free alkali being present, and the increase in weight of these tubes gives the water vapour produced by the combustion. The gas then passed on through tubes containing caustic potash, to absorb carbon dioxide, and then through a tube in which a sample could be taken for determination of the oxygen, whilst the acetylene was next estimated by passing the gas through two absorption flasks containing ammoniacal silver nitrate, an absorption flask containing sulphuric acid to take up any ammonia, and a drying tube. Next to these came a palladium asbestos tube heated to 220° C. in a paraffin bath, and U-tubes containing calcic chloride for estimating the water vapour formed by the combustion of hydrogen, whilst again beyond these came a tube of platinised pumice heated by a flat flame burner nearly to the softening point of the combustion tube, the water and the carbon dioxide formed by the combustion of the methane being estimated in the usual way; beyond these tubes came a trap tube of calcic chloride, and, finally, aspirating vessels, in which the volume of gas sucked through could be measured, giving the total volume of products of combustion drawn through. An experiment tried with this apparatus on a mixture of known composition showed that, an excess of oxygen must be mixed with the products of combustion in order to give satisfactory results with such low forms of combustion as those taking place in the palladium asbestos tube, and a carefully measured quantity of pure oxygen was therefore made to flow in at a steady rate to the second acetylene absorption bottle, so as to mingle with the products of combustion before passing over the palladium asbestos, the gas being kept in a carefully graduated glass gasometer, so that the volume used could be subtracted from the total volume of gases after correcting for the amount used in the various combustions. In this way, the products given off when the vessel was heated to a point half an inch above the inner zone of the flame, and also at the tip of the flame, were determined with the following results :—

GASES ESCAPING DURING CHECKED COMBUSTION.

	Bunsen Flame.		Luminous Flame.	
	Inner.	Outer.	Inner.	Outer.
Nitrogen	75·75	79·19	77·52	69·41
Water vapour	13·47	14·39	11·80	19·24
Carbon dioxide	2·99	5·13	4·93	8·38
Carbon monoxide	3·69	Nil	2·45	2·58
Marsh gas	0·51	0·31	0·95	0·39
Acetylene	0·04	Nil	0·27	Nil
Hydrogen	8·55	0·48	2·08	Nil
	100·00	100·00	100·00	100·00

These results show very clearly that unless the combustion of the flame is completed before it touches the furnace crowns, there will be a loss, due to the escape of unconsumed gases from the extinguished flame. This will also take place in the combustion chamber, whilst the flame passing into the tubes will be put out, and affected to a far more serious extent, the unburnt gases so escaping burning when they come once more in contact with air away from the cooling influence of the boiler, and causing a flame on the top of the funnel, and adding to the high temperatures in the funnel itself.

The loss of heat due to such layers of extinguished gas has been for some time recognised by the more advanced makers of gas-heating apparatus, and Mr. Thomas

Fletcher, of Warrington, has, to a great extent, overcome this trouble in vessels used for cooking purposes and heated with gas, by fixing projecting studs and ridges to the bottoms; these being heated up to a high temperature, allow of the complete combustion of the flame gases, whilst the heat is conducted away sufficiently rapidly to prevent the burning away of the metal studs.

Using copper rods for this purpose, Mr. Fletcher regulates the length of the studs to four times their diameter, and with a vessel so fitted it was found that with a high-pressure gas-burner the duty was increased by nearly 40 per cent.

Any such increase as this in the marine boiler furnace would, of course, be impossible, because so much of the work is being done by radiant heat from the fuel; whilst in using the gas flame it is practically only the heating effect of the flame on the plate and the transmission of that heat by conduction to the water which is acting.

It is very difficult to come to any conclusion as to the amount of heat lost in this way, but where you have the fuel burnt in a simple form of boiler I think the loss of evaporative power due to the layer of non-conducting gas between the flame and the furnace crown may be taken at 10 per cent., and my reason for adopting this number is as follows:—

Coal may be looked upon as containing several constituents:—

(*a*) Fixed carbon;

(*b*) Hydrocarbons, much resembling solid paraffin;

(*c*) Compounds of carbon with hydrogen, oxygen, and nitrogen.

It is impossible, without knowing the heat changes which took place during the formation of these substances, to calculate the calorific value or the evaporative power of a coal, and all such calculations vary very considerably from the results obtained in practice, and also from the figures obtained in carefully conducted calorimetric determinations.

When, however, the evaporative power of a coal is determined in the calorimeter, the result obtained is often higher than the calculated result, which points to the hydrocarbons in the coal being endothermic compounds, which evolve heat during their decomposition, instead of absorbing it, as in the majority of cases; and the error in the calculation is, therefore, probably in placing the actual evaporative power too low. With the results obtained in practice, however, the evaporative power is always far below the calculated efficiency, and this loss is, therefore, manifestly due to loss of heat by such causes as that which I have now brought before you.

If we now take two samples of coal which burn with a large amount of flame, and also the coke obtained from these coals, and contrast the difference between the calculated result and the actual results obtained in practice, we find that the coke has an evaporative power 10 per cent. nearer to the calculated evaporative power than is the case with the coal from which the coke is formed; and inasmuch as the only difference between the coal and the coke is that the one burns with a long flame, which comes freely in contact with the furnace crowns, whilst the other burns with but little flame, it is reasonable to suppose that the 10 per cent. nearer approach to the calculated evaporative power is due to the elimination of the loss by extinction and the formation of the non-conducting layer.

In order to explain more fully what I mean, we will take the case of two bituminous coals and the coke derived from them, which were analysed by Mr. Lewis Wright, and afterwards tested for evaporative power.

	Nottingham Top Hard Cannel.	Yorkshire Silkstone.	Cannel Coke.	Silkstone Coke.
Carbon	67·0	79·0	80·1	89·0
Hydrogen	5·6	5·2	0·6	1·0
Nitrogen	1·2	1·5	1·3	1·0
Sulphur	1·0	1·5	0·4	1·2
Moisture	7·6	4·0	4·1	1·2
Ash	6·6	2·8	11·9	5·2
Oxygen	11·0	6·0	1·6	1·4
	100·0	100·0	100·0	100·0

EVAPORATIVE POWER.

	Actual.	Calculated.	Per cent.
Nottingham Top Hard Cannel Coal	8·78	12·27	71·56
Yorkshire Silkstone Coal	10·01	14·24	70·0
Top Hard Cannel Coke	9·91	12·23	81·03
Silkstone Gas Coke...	11·15	13·83	80·62

A large number of experiments made in 1890-91 so impressed me with the importance of this subject, that I went fully into the matter with Mr. Ernest Gearing, with a view to devising some method by which the efficiency of the marine boiler might be increased by, as far as possible, eliminating this source of loss.

In order to do this, the furnace flues and combustion chamber are constructed of a number of connected tubes or rings, each formed at the ends with inwardly and outwardly projecting flanges, so that each tube is ⊢—⊣ shaped when seen in longitudinal section; these sections are riveted together, and impart great strength and resistance to collapse, enabling the screwed stays commonly used in the combustion chamber to be dispensed with, thus leaving the furnace and combustion chambers more free to expand and contract when under steam, and when the fires are being urged by forced draught, without unduly straining the tube plates and the shell of the boiler.

Built up in this composite manner, the furnace flues and combustion chambers present projecting ridges to the action of the flame, which, rapidly being heated up to a high temperature, allow of the completion of combustion, whilst they also baffle any attempt on the part of the gas to escape along the crown of the furnace. If these ridges were only on the external surface, it is probable that they would soon be burnt away; but, being in direct contact with the flanges projecting into the water space, a large conducting surface is provided, which prevents them reaching the temperature at which they are destroyed.

More complete combustion is obtained, by fitting over them grooved fire bricks, which are keyed into position, each brick being formed with a groove or channel, into which the flanges of two adjacent tubes fit. They prevent the direct impact of the flame on the metal, and themselves get heated to a very high temperature, and help the transmission of heat by radiation.

Underneath the fire-bars the inwardly projecting flanges in the ash-pit may be covered with a sheet-iron tray, which can be removed with the ashes, or, if preferred, they can be cast solid with fire-clay.

An experiment was tried by Mr. Gearing, at the Leeds Forge, in which the evaporative power of a flanged flue, fitted through an open water tank, was contrasted with the evaporative power of a Fox's corrugated flue, and also a plain flue, the result being that the corrugated flue gave an increase of 4·6 per cent. over the plain flue, and the flanged flue 6·2 per cent., no sign of injury to the flanges being noticeable.

(*b*) ON THE SPONTANEOUS HEATING OF COAL.

In 1890 I read a paper before this Institution in which I pointed out that the causes which led to the spontaneous ignition of coal in bulk were, that the carbon of the coal absorbed oxygen, which was chemically more active than the oxygen present in the atmosphere, owing to its compression in the pores of the carbon, and that it then attacked the hydrocarbons of the coal, and so generated heat, which, being prevented from escaping by the large mass of non-conducting material surrounding the spot where the action was taking place, caused a rapid increase in temperature, which in turn increased the chemical action, so that the igniting point of the coal was occasionally reached, and I also showed that the old theory of the ignition being due to the oxidation of the sulphur of the pyrites in the coal was not tenable.

Since then I have had the opportunity of investigating the composition of the gases given off during the spontaneous heating of large masses of coal, and the results obtained fully bear out the facts which I then brought before you.

A large coal store belonging to the South Metropolitan Gas Company had heated, and the smell which was given off from the surface of the coal was manifestly due to the scorching of organic matter, being almost identical with the smell obtained when a piece of wood is lightly charred, the smell also being accentuated by a small quantity of sulphuretted hydrogen evolved at the same time.

A tube was passed into the mass of coal, close to the heated portion, and the gases which were being disengaged were withdrawn through it by means of an aspirator for analysis. The gas when analysed was found to have the following composition:—

	Per cent.
Carbon dioxide	13·15
Carbon monoxide	4·00
Oxygen	1·31
Unsaturated hydrocarbons	Nil
Saturated hydrocarbons	5·10
Sulphuretted hydrogen	distinct trace
Sulphur dioxide	Nil
Nitrogen	76·44
	100·00

A considerable quantity of light oil and water deposited in the tube. This oil began to distil at 92° C., and had a smell similar to that of wood naphtha.

These results show clearly that the heating is due to oxidation of the carbon and hydrogen present, as demonstrated by the presence of carbon dioxide and water, and not in any way to oxidation of the sulphur, as otherwise sulphur dioxide would have been found in the gases which were being evolved, and sulphuretted hydrogen could not have been produced.

(c) THE CORROSION OF STEEL AND IRON PLATES NEAR BOILERS.

In investigating the corrosion taking place in various parts of iron and steel ships, rusting appears to be much more rapid where the temperature is increased by proximity to the boiler than in other parts of the vessel, this being especially the case in steel ships.

The rusting of iron is a definite chemical action, due to the conjoint action of air, moisture, and carbon dioxide upon the metal, and the increased rate of action observed may be due either to increase in chemical action brought about by local increase in temperature, or it may be due to galvanic action set up between portions of the same metal at different temperatures.

The fact that the double bottom plates near the boiler corrode more rapidly than similar plates in other parts of the vessel is an undoubted fact, and the increase in temperature near the boiler is the only factor of difference. It is also to be noted that the plates at the bottom of the cellular spaces which are kept cool by contact with the sea water do not corrode, and cases are not wanting in which parts of a plate, which get locally warmer than other parts, although the difference can only be a few degrees, corrode much more rapidly than the cooler portions.

In order to determine whether this local action was due to increase of chemical or to galvanic action, plates of basic Bessemer steel, charcoal iron, and Siemens-Martin steel, 7 in. by 3·5 in. by ⅛ in., were placed on a stand over the surface of water in large glass jars, one set being kept as cool as possible, a second set at a moderate temperature, and the third set at a warm temperature, and, after 79 days' exposure to saturated air, the results were as follows :—

INCREASE IN WEIGHT OF IRON PLATES, 7 IN. BY 3·5 IN. BY ⅛ IN., IN 79 DAYS' EXPOSURE TO MOIST AIR.

	Cold.	Medium.	Warm.
	Grams.	Grams.	Grams.
Basic Bessemer steel	0·10	0·07	0·06
Siemens-Martin steel	0·03	0·04	0·04
Charcoal iron	0·03	0·05	0·04
Average temperature	9° C. 48·2° F.	15·6° C. 60° F.	27° C. 80° F.
WEIGHT OF RUST FORMED.			
	Grams.	Grams.	Grams.
Basic Bessemer steel	0·33	0·23	0·20
Siemens-Martin steel	0·10	0·13	0·13
Charcoal iron	0·10	0 17	0·13

These experiments showing clearly that the increase in corrosion found is not due to the acceleration of chemical action due to increase of temperature near the boilers.

The double bottom plates and the outer plates of the vessel are in metallic contact by means of stays, and the bilge water will in most cases provide a saline solution through which the current can freely flow, and under these conditions it seems highly probable that the action of hot moist air upon the plates nearest the boiler may set up a galvanic current with the cold plates in contact with the sea, in which the hot plates would play the part of the positive metal, and thus become rapidly corroded.

In order to ascertain if this were so, a piece of steel wire ⅛ in. in diameter was cut into lengths of three feet each, one end of each wire was then dipped into sea water contained in the bend of a large U tube, whilst the other ends of the wires were connected to a key and Thomson's reflecting galvanometer. On now blowing air through water just below the boiling point, and bringing the warm moist air in contact with one piece of steel by means of a tubulure in one limb of the U tube, a strong current was set up, which flowed through the sea water from the metal in warm moist air to the metal in normal air—*i.e.*, the warmer metal became strongly positive, and corroded so quickly that the solution in contact with it became discoloured. I think these experiments clearly show that the rapid corrosion found in the double bottoms near the boilers, or other source of heat, is due to galvanic action, and not to rise of temperature simply increasing chemical activity; but it must also be borne in mind that when the fires are clinkered and the ashes are drawn and quenched with water, especially if sea water be used, gases having a corrosive action on metals are very apt to be liberated, and probably tend to increase the corrosion found near the boilers.

DISCUSSION.

Mr. **Josiah McGregor** (Member): I think, Sir, we are very much indebted to Professor Lewes for bringing such interesting matters before us, as it is in the direction they treat of we must look for any considerable improvement in the performance of the marine boiler. With reference to the remarks which Professor Lewes has made, to the effect that a considerable proportion of the products of combustion contains combustible gases, which pass away, I suppose, with the waste gases into the chimney, I would point out that this is not borne out by the Research Committee's trials of the Institution of Mechanical Engineers, as it appears from these latter that a very small proportion indeed of unburnt gas went up the chimney, even when using the smallest amount of air per lb. of coal. It appears from these elaborate trials the unburnt gas is comparatively small, the greatest recorded being ·75 per cent. of carbonic oxide when the supply of air was only 13 lbs. per lb. of coal. With reference to the table at the foot of page 275, Professor Lewes has given us the actual evaporative power of the combustion of fuel, and the calculated evaporative power. I would just like to ask him how this actual evaporative power was obtained, whether by laboratory experiments or with a sham boiler. I suppose the calculated amount is the theoretical amount deduced from the chemical analysis of the fuel itself.

Mr. F. Gross (Associate): Sir John Hay and Gentlemen, my excuse for addressing you must be an accidental omission by Professor Lewes of the mention of an important feature in connection with marine boilers, namely, the "Serve" tube. All that he has said in the first portion of the paper really only proves that the "Serve" tube—which has now come into general use, we may say, as there are some seventy ships fitted with that tube—gives exactly what Professor Lewes has been trying to show can be done in connection with the furnace. Why the "Serve" tube, which is an established fact, has not been mentioned by Professor Lewes, I hardly know, but yet, there it is; and exactly for the reasons explained, the "Serve" tube gives just that additional heat-absorbing surface which Professor Lewes desires to see in the furnace itself. You cannot by any possible way use the "Serve" tube, with its projecting longitudinal ribs on the inside of the tubes, without having from it the advantage due to the large excess of heating surface which it has over the plain surface. In a small-diametered tube the amount of extra heating surface is as much as 80 or 90 per cent. increase over the ordinary plain tube, and the consequence is that in the smoke-box you immediately have several hundred degrees less heat with the same diameter of "Serve" tube than you would have with the plain tube. Professor Lewes mentions the cooking apparatus by Mr. Thomas Fletcher having these copper block or stud projections, but to us here, naval architects, shipbuilders, and boiler makers, I take it that the marine boiler, as it exists to-day in many vessels, is of much more importance, as showing exactly what he wishes to prove. I do not know that I need say anything more; as I said, it is merely the absence of the mention by Professor Lewes of the "Serve" tube, which exactly proves all he wishes to prove, that has caused me to come forward at all.

Mr. A. E. Seaton (Member of Council): Sir John Hay, I had hoped to have been excused from making any remarks to-day, on the score that I have very little voice to do it with, and the little I have to say is rather to confirm the able paper which Professor Lewes has given us than to criticise it. So far as copper pegs are concerned, they are old friends of mine, because when I began boiler-making, at fourteen or fifteen years of age, I could not get "Serve" tubes, and I had to resort to some other means of providing heat collectors in the tin boiler which I made for my model engine. I came to the conclusion that the fitting of a few pieces of copper wire into what I may call the combustion chamber of my boiler would collect the heat, and by allowing them to project into the water would conduct the heat to the water. It is not altogether, therefore, a new invention, the introduction of copper pegs for that purpose. Professor Lewes has spoken of the "Advance Boiler"; I do not know that it is an advance really. I looked through the prospectus sent me by the company exploiting this concern, and I was struck with the crudeness of the experiments made; in point of fact, when the experimenter states that he did not use the same coal in one place as in another, and admits there was a marked difference in the quality of it, I did not think it was worth while to study closely the results, nor did I think that what he promised was, either new, or likely to be successful, for the reason that Professor Lewes has mentioned. I have no doubt whatever, that if in the flues of a boiler, angle or tee-bars were riveted on as stated, very great oxidation would set in between the two surfaces, with the result that the tee or angle-bars would be forced from the boiler, and probably the rivets wrenched as well. But perhaps the most valuable piece of information which I can give this Institution is something that has recently come under my notice as bearing on the latter part of

Professor Lewes's paper. Some five years ago we constructed a river steamer of very light draught, consequently of very light scantlings, and also very lightly cemented. That ship was placed in our hands a few weeks ago for the purpose of lifting the boilers that they might be examined by the Board of Trade. I am sorry to say that the time had fully arrived when they ought to have been examined, because we found that the shells of the boilers, which were originally 7-16ths thick, were worn through in several places from external action, and the bottoms of the boilers—there were three boilers—were more or less badly corroded. I jumped to the conclusion, somewhat naturally, that there would not be much of the ship's bottom or floors left; but, strange to say, although the floor plates were originally very thin indeed, and, instead of having angle-bars riveted on them for stiffness, they were flanged, very little corrosion at all was observable—practically none, I may say. There was not one penny spent in repairs on the bottom of the ship, or on the floors, or on the boiler bearers; but the bottoms of the boilers themselves had to be renewed. I think I understood Professor Lewes to say that such things did not happen with iron ships. I am sorry to contradict him there; because I have seen, myself, in iron ships a similar state of affairs, but not, perhaps, in quite so short a time. Some few years ago we re-boilered a very large mail steamer that had been in the West India trade. We found that the bottoms of the boilers were not very bad, but the boiler bearers and the upper part of the ship's frames were in places almost completely gone, so much so that we rather wondered to see that the boilers had remained in place. Professor Lewes has done us good service in calling attention to the action of flame on cold surfaces, because it may set some of us thinking in a fresh direction to that in which we are accustomed to think; and, inasmuch as the boiler is now receiving an attention which hitherto was not bestowed on it in this generation, perhaps Professor Lewes may be our pilot, and lead us into safe waters instead of foul ones. I may tell him that the attempts that we have hitherto found in making use of brickwork for the purpose he has named, or any other purpose, as a protector, or as a regulator of the heat in the boiler, have generally resulted in the disappearance of the brickwork. We have also fitted in the flues of our factory boilers deflectors pretty much as Professor Lewes has described, with the result that, at the outset, we believe we did improve the efficiency of the boiler, but that improvement was of short duration, from the fact that the brickwork did not stand. No doubt Professor Lewes will tell us that the burning away of the brickwork was probably due to the superior combustion we were getting from its presence. If we could have taken away one function of the brickwork the other would have remained. I think that is all I have to say on the subject, except to express my best thanks to Professor Lewes for having given us these very valuable notes. He says they are leaves from a laboratory note-book. I presume from time to time he fills that note-book up, and perhaps from time to time we may have the benefit of it.

Mr. C. E. **Stromeyer** (Member): Sir John Hay and Gentlemen, some of the points to which I wished to draw attention have already been noticed by the gentlemen who have preceded me; but I think that the first question, as to the incomplete combustion in furnaces, requires a few additional remarks. The experiments carried out by the Research Committee of the Institution of Mechanical Engineers did show that there was very little incomplete combustion in the boiler. This, I think, is due to the flame having to cross the bridge, which, as it has a very high temperature, would ignite any combustible gases that may have been formed by the contact of the flame with the furnace plate, and they will be completely burnt when they enter into the combustion chamber. At any rate, the large losses of 40 per cent. which were discovered by Professor Lewes in his experiments do not occur in marine boilers. That the results of the above-mentioned trials are worthy of being considered reliable will be evident on making up balance-sheets, as it were, of the heat produced and used, which, it will be found, nearly balance each other. During the discussion of these results I pointed out that besides making allowances for external radiation, which cannot be done very accurately, the fuel which is blown up the funnel with the cinders, of which about 10 to 50 per cent. disappear, should be taken into account. Then, according to my rough estimate, I found in one case that 3 per cent. more heat was got out of the coal in the boiler than had been found in the calorimeter, which, under the circumstances, must be considered a close agreement, and refutes the author's contention that there is a further loss of 40 per cent. due to unburnt gases. As regards the heat-transmitting power of studs and ribs, I quite agree with Mr. Gross in his remarks on the " Serve " tubes, and I think that the whole of the added heating surface on the fire side is practically effective. The resistance which is encountered by the heat as it leaves the flame and enters the iron or steel is very much greater than the resistance it encounters when it leaves the plate and enters the water; and I think everything that can be done to improve the heat absorbing power of the fire side of the heating surface is an advantage. It is an interesting fact that studs which are longer than 2 in. burn away, and I have noticed tube ends burning if they were left longer than ½ in. In the furnace which Professor Lewes suggested, I believe he proposed that angle irons should be fitted, which should take away the heat from the flame, whereas in the earlier part of his paper he mentions that to abstract heat from the flame seriously interfered with the combustion, and I believe that of the two his first-mentioned principle is the more correct, and, as regards efficiency, it is an advantage to remove as little heat as possible by means of the furnace plates, and these, therefore, might be made quite smooth and of comparatively greater thickness than the rest of the heating surface. A brick furnace would be still better, at least, as regards obtaining complete combustion. Of course there are serious practical difficulties in the way of carrying out this principle in marine boilers, because of the trouble that would be caused by the red-hot brickwork, which would take a long time to cool after the fires are drawn. However, the guiding principle seems to be that the worst heating surface ought to be the furnace, so as not to cool the flames too much, and the best heating surface ought to be at the tail-end of the boiler, just before the waste gases escape, so that one gets good combustion to begin with, and a good heat transmission at the end, even when the gases have been considerably cooled. I should also think that the proposed angle irons would burn away very soon. It is true there is not so much burning away as one would imagine in steel boilers, but occasionally one comes across stay nuts which have burnt off, though I believe that even they might without harm be allowed to project very much further into the fire, if a perfect metallic contact could be ensured between them and the plate and the stay. But generally washers and layers of cement are interposed. If the nuts were a good fit on the stays, and were screwed tight to the plate without any intermediate washer, I think they would last much longer than they do now. Another question with reference to the first page of Professor Lewes's paper is that of the basic bricks. It surely is a mistake to suggest the use of basic bricks, for whenever the boilers are put out of use those basic bricks will crumble away, the moisture gets at them and spoils them. In some steel works which I was inspecting, where basic furnaces were at work just when a sudden strike took place amongst the men, it was necessary to cover all these basic bricks in the furnace with unslaked lime, in order to be quite sure that no moisture would get at them. There is also this to be said against their use for furnace bridges, that as they come into contact with the clinker, which contains a good deal of silica, a fusible slag would speedily be formed by the combination of the two materials, and the bricks would simply melt away; therefore, I should think such bricks would be the very last to be used in a furnace. As regards the corrosion and the influence of heat, I have noticed very often in steam spaces that the end near the funnel is corroded very much more than the other end. I cannot quite see how that can be due to galvanic action. There are no salts nor fluids nor carbonic acid that could produce it, and to me it seems to be due simply to the heat. It is a very difficult subject to settle, and perhaps Professor Lewes will further investigate the matter. In some boilers the baffle plates are fitted so that the external cold air can get in between the boiler and the baffle plate. In such cases I do not think that I have ever noticed this sort of corrosion. In some boilers baffle plates are simply bolted against the end plates of the boiler, and there the air spaces very likely acquire nearly the same temperature as the gases. Certainly no fresh air can enter them. I do not believe that the temperature of this enclosed air is exactly the same as that of the up-take gases, but the corrosion seems to be about the same as when there are no baffle plates. In such cases I also noticed that the stays eat away about 3 or 4 in. from the ends. Why such an action should go on I do not understand, but it is certainly the case that the stays waste away very much at the up-take end.

Mr. A. E. **Seaton**: When the nuts have been clear of the up-take that has not been so, I presume?

Mr. C. E. **Stromeyer**: That is the case. One more question was raised by Professor Lewes, viz., the spontaneous ignition of coal. He remarks that there are no sulphurous gases given off of any sort. I believe, if I remember rightly, in his paper of 1890, he suggested that the sulphur or the pyrites in the coal decomposed and caused it to split. Therefore I should think the products ought to show up in the analysis; certainly while the coal is being heated spontaneously it disintegrates, and I was of opinion then that it was due to the sulphur which Professor Lewes mentioned, but probably he can give a better explanation of it than I can. I beg to thank Professor Lewes for his very valuable paper.

Mr. J. **Corry** (Associate Member of Council): Mr. Chairman and Gentlemen, Professor Lewes has, as usual, given us a very instructive and suggestive paper, and there are many things which I think require to be thought over very carefully. One of the first matters that has struck me in looking over the paper was his statement with regard to corrugated flues. "One of the great improvements in furnaces made in late years has been the corrugated flue, which, by increasing the heating surface, increased the evaporative efficiency of the boiler." Of course Professor Lewes knows that the corrugated flue was not designed and the form was not suggested by that alone, but by the necessity of increasing the strength of the flue, and, indeed, I think the general impression among most engineers is that the evaporative efficiency of a plain flue is at least equal to that of a corrugated flue. I think the action of the corrugated flue is not perhaps quite what Professor Lewes has indicated. I do not think that the flame gets all round the corrugations, but practically goes straight across, and that therefore the corrugation is of no advantage as regards its extra heating surface. In fact we know that in other forms of flue, such as the "Purvis" flue, in which the inner surface is practically straight as far as its conducting power is concerned, I believe there is no practical difference. As Professor Lewes's papers seem always to bring out a crop of patents, I think it would be well to indicate what perhaps may arise. He has suggested a form of flue with transverse ribs or webs projecting into the furnace, but I believe the idea he has in his mind would be better met by a furnace formed like a "Serve" tube. I see no practical difficulty in forming such a flue, not by riveting angle irons as proposed by Professor Lewes, but by producing a plate with longitudinal ribs direct from the rolls, which afterwards could be bent and welded into a flue, which no doubt would be very strong and would have the advantage which Professor Lewes desires, without the fear of the want of perfect metallic contact which is essential to good conduction. The point in the paper that I want to refer to specially is with reference to the corrosion of double bottoms. We are all aware—in fact, it has been a source of great difficulty, and has exercised Lloyd's very materially within these last few years —that this corrosion goes on very rapidly indeed. The cause, which I think is simple enough to trace, is the heat of the boiler, and the remedy is to prevent the heat striking the top of the double bottom. This can be done in many ways. One of course would be protecting the upper part of the double bottom or tank top with a substantial coating of cement 3 or 4 in. thick, and also lagging the lower section of the boiler, which should always be clad, in my opinion; and there are also other methods which could be adopted. Undoubtedly it is the heat which causes the rapid deterioration, and whether that is purely a chemical, or partly chemical and partly electric, action I do not pretend to say. However, I do think that the experiments of Professor Lewes in testing the corrosion did not quite indicate the action that takes place in a double bottom. My idea of the action practically is this: A double bottom, as you are aware, is made up of a series of cells, or chambers, enclosed by the tank top, and the boiler being in close contact with this upper portion heats it. There is always a certain amount of water in the bottom of the tank. The heat draws the moisture up, it condenses on the top and sides of the tank and forms into drops of water which fall down again, so that there is a continual shower falling, the moisture is rising and dropping and taking up air with it, and to my mind doing its best to carry out the corrosion. I wish again to thank Professor Lewes for his very able paper.

Mr. John Watt (Associate): Mr. Chairman and Gentlemen, I wish to thank Professor Lewes for his very able paper. The paper just read is one that opens up a very valuable subject and a very valuable discussion. It is not exactly new about the studs in the boiler; the late Mr. Wye Williams in connection with the City of Dublin Steamship Company carried it actually into practice. The furnaces there were almost of a rectangular section, and not round, as at present; the steam pressure was about 8 or 10 lbs. per square inch. The furnaces were slightly rounded on the top, and into this were driven a number of tapered studs from the inside of the boiler. There were several rows of these studs right along the crowns of the furnaces and flues, and these studs were for the purpose, as the paper says, of taking up the heat as it passed through the furnaces. The studs were about 6 in long, about 3 in. inside the water space, and 3 in. in the furnaces, and it was found that these studs just burnt away to about 2½ in. altogether, and at that they remained. They were iron studs, tapered and driven in. There were several thousands placed in the boiler, and he worked them in that fashion. The creeping of the flame along the furnace flue leads to a very important point, that is with reference to getting all the heat out of the fuel. If we take a land boiler, say, 30 ft. long, with its two side flues and bottom flues, we find that the flame has to travel 30 ft. in one direction and come back 30 ft., and travel other 30 ft. That is equal to 90 ft., to extract the heat from the fuel, and it does not even do that, because it goes away to the chimney at about 600° or 700° temperature. In many land boilers we have to place what is termed feed-water heaters or economisers. It seems absurd that you should have a flue 90 ft. long to abstract all the heat, while it could be done by a much easier and much shorter process. It is this process of creeping, that the paper alludes to, that I object to. The flame merely glides along without imparting its heat to the heating surfaces. We should have in all boilers what may be called an impinging action of the flame or gases on the plates or heating surfaces of the boiler. The only way I know for abstracting all the heat from the gases is by means of what is termed the water-tube system. If you have a number of horizontal tubes placed in horizontal rows, but so arranged to be zigzag vertically, the flame from below rising in a vertical direction, striking and impinging upon the tubes, more heat will be extracted by these tubes or by that portion of heating surface, with only a few feet run, than could be with a running flue of ten times the length. This is the most efficient way of extracting the heat from the fuel or from the gases that I am aware of, and thus you can extract more heat from about 4 or 5 ft. run in height by this system than you can do with 90 ft. run of horizontal flue.

Professor V. B. Lewes, F.C.S. (Associate Member of Council): Sir John Hay and Gentlemen, I feel very relieved at my notes not having been roughly criticised. In the first place, Mr. McGregor spoke as to the proportion of unburnt gases being extremely low. That is undoubtedly the case. I do not for one moment wish to say that when you have the cooling action putting out the flame, you are going to get half, or quarter, or even one-tenth of your combustible gases escaping unburnt. But you get very distinct traces of them escaping, and you can increase the quantity of air as much as you please, and you still get them given off; indeed, after a certain percentage of air has been added, you will get more combustible gases escaping, because after dilution it needs a smaller degree of cooling to extinguish them. What I want to make clear is this, it is not so much the small proportion of unburnt gases as the non-conducting layer between the flame and the boiler that you want to do away with. You have a layer of carbon dioxide and steam, together with the other furnace gases damping and stopping the transmission of heat to the water plate, and it is that which you want, as far as possible, to avoid. You find, if you want to complete combustion, you must have some ridge coming in contact with the gases which will be heated up to a fairly high temperature and so allow contact, and the idea of my suggestion was to get completed combustion, and to get therefore an increase in transmission. I apologise to Mr. Gross most humbly. I am afraid my not mentioning the "Serve" tube was because I am unfortunately not an engineer, and therefore I preferred to take Mr. Fletcher's simple contrivance as an example, because he recognised the presence of the layer of extinguished gas, whilst the "Serve" tubes seem to have been adopted because they gave good results, and without any idea of why they did so; but there is no doubt the "Serve" tube containing these ridges must be of great advantage, because in an ordinary tubular boiler you have the cooling surface so large in the tubes that you would have this "putting out" effect to a very large extent there. Mr. Stromeyer gave us some very interesting points, and admitted that in his balance-sheet of loss and gain, he sometimes got 3 per cent. over instead of under. I must confess that I do not expect the amount of gas escaping combustion in the chamber would exceed 3 per cent., and if you can get an error of 3 per cent. on each side, I do not think much of the balance-sheet as a help in a scientific subject of this kind. The great point made by Mr. Stromeyer was transmission. He pointed out that you get a large quantity of these gases burnt up by contact with the boilers or hot fire bricks, but that the transmission question still remains. If you have not got that non-conducting layer between the flame and the surface of the boiler, transmission will be far more rapid. There is no doubt also that if you have good combustion, and if you can possibly utilise your heat at the same time as you are getting perfect combustion, why not begin as soon as possible in the furnace and get away as much heat into the water as you can. As regards the basic bricks, I have nothing to say. The point made by Mr. Stromeyer is a perfectly correct one. All the time you have the heat playing on the basic bricks you will find they will be best. When they cool down, if they get to a temperature at which they will absorb moisture and carbon dioxide, then they will at once crumble. My only remark is, if you do not use basic bricks do not use any at all, because if you use acid bricks they are quite capable, at a temperature which you get in furnace crowns, of forming silicate of iron with the projecting flanges, and you lose not only your bricks but the flanges as well. Mr. Corry's remarks as to the corrugated flue were most admirable, and I admit the justice entirely of his criticisms. As regards his boiler flue, I should like to point out he has got the ribs running the wrong way. In making my furnace flue I had the ribs running the other way, so as to prevent the creeping of the gases along the crown of the boiler as far as possible. If you have the ribs on lengthway, you have the gases able to escape comfortably along to the combustion chamber, perhaps through it. In the double bottoms, I think from my experiments that, although they are not conclusive, they point very strongly to galvanic action playing a very important part. If you have the outer metal skin simply in contact with hot moist air, and the other one kept cool by sea water, you have plenty of points where you can get a current going through one set of stays, and back through another set. In conclusion, I have only to thank you for not having treated me more harshly, and I hope that some of the suggestions which I have put forward may prove to be of use.

The Chairman (Admiral the Right Hon. Sir J. Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): I am sure the meeting will desire me to give its most hearty thanks to Professor Lewes for the lecture he has given us. I trust his note-book is inexhaustible, and that he will frequently give us the benefit of it.

EVENING MEETING, THURSDAY, MARCH 15, 1894.

The Chairman (Sir Nathaniel Barnaby, K.C.B., Vice-President): Sir John Hay asks your indulgence in respect of taking the chair this evening, and has asked me to take it for him. I have much pleasure in doing so. We have before us three very important papers, and I think that it has been generally agreed, as far as I can understand, that the better way will be to take Mr. Thornycroft's paper first, and to regard it, as it purports to be, viz., a paper upon the circulation in the Thornycroft water-tube boiler, and then to take the discussion upon that, taking care that the discussion is limited to the subject of the paper, and does not go over the ground which will be dealt with by the other two papers. The other two papers, to be read by Mr. Milton and Mr. Howden, will be discussed together. I presume no one will think that that is an unfair arrangement, and, that being so, I will ask Mr. Thornycroft to read his paper.

CIRCULATION IN THE "THORNYCROFT" WATER-TUBE BOILER.

By J. I. Thornycroft, Esq., F.R.S., Vice-President.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 15th, 1894;
Sir Nathaniel Barnaby, K.C.B., Vice-President, in the Chair.]

Since I read a paper on "Water-tube Boilers for War-ships" in 1889, such a change in the general feeling regarding them and their actual standing has taken place, that it is unnecessary for me now to point out at any length the decline and failure of shell boilers *for fast vessels*, and the growth and success of the water tube, but rather to describe my most recent practice, and give you the results of my experiments and experiences since my paper before the Institution five years ago.

It was considered then, that possibly boilers such as I had made might be suitable for small torpedo-boats, but that success in such an extreme case did not at all warrant their adoption in larger vessels. However, in the last two years the third-class cruiser *Geiser* and the fast torpedo gunboat *Speedy* have each been fitted with eight water-tube boilers of my construction; and now the Danish authorities are so well pleased with the performance of the *Geiser* that they have decided to fit the armour-clad *Skjold* with similar boilers. Further, in Germany, a new ship of the *Siegfried* class, of 3,000 tons, is also to be fitted with this type.

In the case of the *Geiser* an equal power was given to that obtained in the sister-ship, *Hecla*, with locomotive boilers, but with the reduction of weight of some sixty tons. I wish to call your attention particularly to what my firm undertook to do in the case of the *Speedy*. One thousand more horse-power was guaranteed than with the locomotive boilers in sister-vessels, with a considerably less weight of boilers.

I would beg to call your attention to Fig. 1, Plate XLVIII., which gives a comparison of locomotive boilers and the *Speedy's* water-tube boilers. First, you will see that we have the same length in the ship in each case, and in each case two stokeholds; but in the *Speedy*, four boilers in each stokehold instead of two.

In Table I., Plate XLVIII., you will see the comparison of heating surfaces, grates, &c. It has been remarked that the amount of heating surface provided is much greater per unit of power than is usually employed with locomotive boilers. This, however, is not a necessary condition, as it has been shown that water-tube boilers are capable of being forced to do equal or more work with equal surface; and the large amount of heating surface in the *Speedy* must be looked upon, not as a necessity, but as a means of providing greater economy of fuel. Coal consumption experiments in the *Speedy* have not at present been made, but in the *Geiser* careful experiments over a considerable period show that the coal consumption, even at full power, is considerably less than 2 lbs. per I.H.P.

During the trials of the *Speedy* we had some difficulty with priming, which had not been expected, and this was found to be entirely due to the quality of the water, which was the Sheerness Dockyard supply, and which has been found so far capable of causing trouble that no one of experience will use it willingly. And in the case of the *Speedy* the difficulty was further increased by a large addition of estuary water, caused by a leak in the condenser. I have since made experiments on the properties of these waters, which I shall refer to later on.

When working at the highest power attained the boilers were only forced to a very limited extent, the mean air pressure being 1·7 in.; and even with this air pressure, had the Navy stokers had more practice with the particular form of grates, a higher result could have been obtained. The only point which presented any difficulty in these trials was that of feeding the boilers with sufficient regularity. The *Speedy* has two Weir pumps, which are arranged to deliver into a main feed pipe common to all the boilers, in which the water was in excess of the boiler pressure by some 50 lbs. On each boiler there was a check valve, by which the feed was controlled. This system, which is perfectly efficient for boilers holding large volumes of water, seems to require some modification in the case of water-tube boilers, where the water contained is relatively very small for the rate of evaporation, and I have come to the conclusion that some form of automatic control is desirable. In the Belleville boiler this has already been adopted with success. With the view to lengthen the life of the tubes, they were galvanized both inside and out. The zinc on the outside is, I consider, more useful than the inner coating, which, being exposed to impure water at a high temperature, soon disappears, and is, therefore, only a temporary protection.

In opening up boilers and steam pipes, we have frequently experienced the presence of explosive gases in a most unpleasant manner. It seems to me possible that the very large surface of zinc must be the cause of the generation of these gases. This theory is supported by the fact that we have only had this experience since the tubes have been galvanized, and also by the disappearance of the zinc.

In one case, during the severe frost this winter, a torpedo-boat had been lying with banked fires for five days. A leak was discovered in the exhaust pipe of the steering engine, and the presence of a combustible gas was accidentally made evident by its ignition, when it burned for between three and four minutes, the flame being about three feet long, burning at first with a blue flame, and later with a luminous flame like coal gas.

On studying the papers of Mr. Milton at Cardiff and Mr. Ward at the Engineering Congress of Chicago, I find what other engineers have been doing; and while I have pleasure in acknowledging the honour many have done me in following the principles of my construction, I must call attention to the fact that I am of opinion that many of the departures that have been made will lead to inefficiency, and may be sources of danger.

I have recently made experiments on the relative circulation of boilers when the generating tubes deliver above the water in the separator and below it, and I have found that, in the case where they deliver above, the circulation is rather more than double that when they deliver below.

The method of measurement I adopted was to put a rectangular notch, similar to those usually employed in gauging small streams, across the separator, so that all the water that went down the downtakes had to pass over it, and I then observed the flow over the notch through a glass window in the end of the boiler, and thus, knowing the size of the stream, was able to calculate the circulation. I found that, in the case of the above-water delivery, the circulation was 105 times the feed—that is to say, for every pound of steam brought up by the generating tubes, 105 pounds of water are also passed through them.

The boiler experimented upon with the drowned tubes was similar, as far as possible, to the other, which was of my usual construction, so that the reduction in circulation can only be attributed to the upper ends of the tubes being immersed (Plate XLIX.).

At a meeting of the Civil Engineers in 1889, I described at length the necessary conditions for efficient circulation, and ventured an opinion that it, together with the proper heating of the feed water before its arrival at the heating surface, would retard the formation of scale; and I am now able to state that we have had no trouble in any of our boilers from this cause. It is, therefore, apparent that the large reduction in circulation caused by immersing the tops of the generating tubes will detract from their power of keeping clean, which is so essential to boilers having tubes of a small diameter.

It has been argued that it would be advantageous to have the tubes drowned, because it has been thought that then brass or copper might be used instead of steel; but my experiments show that the proportion of steam to water is greater in the drowned tubes, therefore they have less capacity to take up heat from the furnace gases without damage.

I have made experiments which proved that with water entirely free from oil, and very severe working (20 lbs. of water per sq. ft. H.S.), the tubes could not be overheated; but the addition of a small quantity of the greasy deposit taken from a boiler, working with condensing engines, was sufficient to cause the destruction of the tubes by overheating without any increase in this rate of working.

I further experimented with grease taken from the inside of a boiler to ascertain the temperature of its evaporation, and found that this was so high that when heated on a piece of brass tube it continued to give off vapour after the critical temperature at which brass loses most of its tenacity had been arrived at. From this experiment the effect of a coating of this deposit can be easily surmised.

Under the rapid transmission of heat, gas would continue to be liberated from the surface, which would increase in temperature, owing to the non-conducting power of the film of gas, which necessarily precludes the contact of water with the tube surface; the water being only enabled to preserve the tubes because its boiling point is lower than that of grease.

Consideration of these facts seems to me to prove that for a high rate of working in boilers where grease may be present in the feed water, brass tubes are quite unsuitable; copper may, perhaps, be used, as the temperature at which its tenacity is greatly reduced is much higher.

M. Du Temple found that copper tubes lose their strength in time, but the relatively small diameter of his tubes to their length seems to be an element which might cause this trouble, and a further unfavourable condition is the immersion of their upper ends.

In the experimental boilers before referred to, and in which glass ends to the separators enable internal working of the boilers to be observed, I made experiments on priming, and the phenomenon which takes place seems both important and interesting.

Waters which cause priming on boiling produce foam consisting of a mass of bubbles of various sizes.

Water which is very bad produces bubbles so durable as to remain a considerable time without breaking, and by them the steam space of a boiler may be entirely filled; and so soon as this takes place, instead of simply steam leaving the boiler, the discharge consists of foam, which is broken up in its rapid motion along the steam pipes.

This is a great contrast to what is seen when pure water is evaporated. In this case steam emerging from the surface of the water retains no film of liquid for sufficient time to be seen; this is what might be expected, as pure water is known to be incapable of forming bubbles.

The effect of bad water is very marked in the discharge from the tubes, both in delivering above and below water. In the former case, with pure water, the discharge of steam and water is periodic. The water and steam are discharged quite separately, but with a priming water the discharge is a steady one, consisting of a mixture of steam and water in the form of very wet foam.

In the case where the tubes discharge below water, the flow appears to be unsteady in both cases; when the water is pure, the water and steam are discharged alternately, as in the above water delivery; at the pause in the flow the water runs back into the tube on to the ascending column, so that there is to some extent an oscillating flow in the upper ends of the tubes. This occurs in the same way with a priming water, only to a more marked extent, columns of foam being thrown the full height of the separator. In this way tubes delivering below water are capable of causing a priming effect, when tubes delivering above will not do so.

The impurities in water which may cause priming are not easy to determine. It is well known that waters which do not prime by themselves, when mixed do so in a most astonishing manner; for example, either salt water or pure water may work in a boiler without priming, but by mixing the two very bad priming is started. I have tried water taken from the Thames at the Nore, and well water from Sheerness; both these are good samples of priming waters, but when mixed in about equal proportions produce such a priming mixture that the very slowest rate of evaporation causes violent foaming.

As this mixture corresponds with the water used during part of the *Speedy's* trials, the priming then experienced is now explained.

Returning to the question of circulation. It has generally been admitted that it is necessary to provide tubes, other than the steam generators, for conveying the water from the separator to their lower ends. If this is not done, it is evident that some of the generating tubes must serve this purpose; or if this is not the case, the motion of water in the tubes will not be a circulation, but only motion alternating in direction, which is not favourable for preventing the formation of scale, or providing the necessary supply of water to prevent their over-heating.

At first sight, it would appear that in my improved type of boiler as fitted in H.M.S. *Daring*, Fig. 5, Plate L., the heat to which the down tubes are subjected might be a source of impaired circulation; but, if the question is examined, it will be found that, owing to the fact that care is taken to mix the feed water with the large volume of water in circulation, and that these tubes are only exposed to the cooler gases, the heat required to bring the descending columns to the boiling point would be more than could be obtained in this way, while at the same time all heat added below the boiling point must be looked upon as a gain in efficiency, this arrangement at the same time making the boiler more compact and enabling a larger fire grate area to be obtained in a given boiler-room. The gain in this direction is further increased by putting boilers side by side, and leaving out what in one alone would be the external fire-box walls.

Fig. 6, Plate L., shows an arrangement in which seven boilers are placed together in a battery, four such batteries arranged in four stokeholds giving 60,000 sq. ft. of heating surface. By this arrangement I have been able to get a maximum of surface into a particular given space, and the boilers being arranged along the centre of the vessel give convenient access to the side coal bunkers, and tend to make cool stokeholds.

The fact that the boilers form, as it were, one continuous mass has many advantages, including great simplicity of the casings, together with the reduction of their external area to perhaps a minimum. At the same time, the exit for the gases from the boilers being along the centre of the ship, they require very simple uptakes to the funnels.

As each fire is common to two boilers, one boiler cannot be put out of action without another boiler losing half its fire, but this boiler would still do half duty, as half its surface would be in no way affected. So I do not consider this any objection to the arrangement. The very large volume of space above the fire in these boilers is very advantageous to ensure complete combustion of the furnace gases. In boilers of the *Speedy* type this space had already been increased far beyond that usually adopted in other boilers, but in this type the fire-box is larger still, and I think there is no doubt that an advantage is thereby gained.

In some boilers where this space is limited, special means have to be provided to ensure proper combustion before the gases come in contact with the heating surface.

DISCUSSION.

The **Chairman** (Sir Nathaniel Barnaby, K.C.B., Vice-President): It will be very evident to you that this paper admits of a discussion narrowed down in the way which has been suggested, and we are now open to receive the remarks of those who would like to speak upon it.

Mr. F. C. **Marshall** (Member of Council): Sir Nathaniel Barnaby and Gentlemen, I am really sorry to say I cannot, from experience, say anything on the paper brought before us to-day. I have been invited by the Admiralty to tender for certain forms of water-tube boilers. So far, I have not quite made up my mind as to what form I shall adopt. I know my old friend, Mr. Thornycroft, will not think me unkind when I say I do not intend to adopt the *Speedy* type; but, as you have asked me to open this discussion, I must speak frankly. The *Speedy* form of boiler—which I would remark, and I am sure Mr. Thornycroft will admit, is a very old form of boiler—does not commend itself to me. I do not like tubes exposed to the fire with no water in them, I think they are very liable to give trouble; nor do I like, as a principle, curved tubes for boilers which may, or may not, get a large amount of oily or earthy matter into them, and need at some time cleaning. For myself, I prefer the straight tube in all cases, and for that reason I may say I prefer, and shall probably myself adopt, something of Mr. Yarrow's type of boiler. But that, of course, is a matter of personal opinion; seeing I have absolutely no experience in the matter, it may be worth very, very little. There may be defects in the Yarrow boiler which I have not discovered, but the curved tubes present, to my mind, a serious defect in any boiler which is to go on board ship. I think Mr. Thornycroft's *Daring* form of boiler (I use that expression merely with reference to the name of the ship) is a better type than that of the *Speedy*, because he has, as we call it technically, a row of "downcoming" tubes along the centre of the boiler, so securing a direct communication of water between the upper and lower cylinders of the boiler. I think the *Daring* form will be found to be very much more effective, and less liable to give trouble. Whether water-tube boilers will ever become the boilers of the mercantile marine, and of the future, perhaps we shall have more to say on Mr. Milton's paper and Mr. Howden's paper, which I am very glad to know we are to have the privilege of hearing to-night, the discussion of which may bring the weight of this important Institution to bear on the question of cylindrical *versus* water-tube boilers. With regard to the question of whether water-tube boilers will eliminate the difficulties recently experienced with the cylindrical and locomotive types, I have to-day, only, heard a very indifferent account from a personal friend of mine who has visited what we must call the home of the water-tube boiler, Toulon, and the South of France—of those introduced by the Messageries Maritimes and the French Navy. One would have hoped that my friend would there have found water-tube boilers in their perfection, working without trouble; but I am sorry to say he tells me that, in every ship, on board of which he took the trouble to go, he found where there were water-tube boilers that the tubes were all out of the boilers. That does not look as if we were to be relieved of the boiler difficulties (that is the all-important question) by the introduction of a multitude of curved and other tubes.

Mr. J. I. **Thornycroft**: Were these curved or straight tubes that were out of the boilers, may I ask?

Mr. F. C. **Marshall**: They were curved and straight, I believe, and I think there were some others, but principally curved. I believe we shall always find that we have trouble wherever we introduce anything we cannot clean in a marine boiler; but, while saying this, I wish to cast no reflection on my friend, Mr. Thornycroft, who has most assiduously worked at this subject for many years, and who deserves the greatest credit for the admirable and ingenious methods with which he has worked out his views, which in certain cases—in a very great many cases, I may say—have been found extremely successful.

Mr. W. **Laird** (Member): Sir Nathaniel Barnaby and Gentlemen, I think at least we may congratulate Mr. Thornycroft on having achieved such considerable success with his tubulous boilers. I know it has been a subject of anxious thought with him and his colleagues for many years. I remember his reading a paper here on the subject some years ago. Of course, all of you who are interested in marine engineering know that for the last forty or fifty years many attempts have been made to make a successful water-tube boiler, and there are other forms of boiler than those that Mr. Thornycroft has adopted that have been more or less successful. But there is no doubt whatever that many of the boilers that have been turned out by his firm have done their work exceedingly well. Now to come to the broader question. We are seeking to get high power developed from these tubulous boilers. It arises to a great extent from the fact of the great demand for speed in vessels of different classes, not only small vessels such as those that are called torpedo-boats, or torpedo destroyers, but for larger vessels of war and even for merchant ships. The necessity for getting the highest amount of power out of a given amount of weight is most important for the success of the naval architect, and therefore they gladly seize upon any opportunity of getting something that will give them a greater amount of power, with less weight, than the old-fashioned type of engines and boilers. They feel, at the same time, it is not wise to go too fast in this direction, because, as that very experienced engineer, Mr. Marshall, has pointed out to us, there are dangers when you depart from the old-fashioned idea of having boilers accessible in all parts and easily cleaned. On the other hand, we come to the fact that we are able, by proper care, to supply our boilers now with almost perfectly pure water. That is the first element of success in boilers fitted with water tubes of small diameter, such as those we see on these diagrams here. I may say, without in any way disparaging what Mr. Thornycroft has told us, that my firm are making now five groups of boilers, of four each, each boiler to give out about 1,000 horse-power, or 20,000 horse-power in the aggregate. I merely mention this to show that, so far as our experience goes, and it has been rather a wide one, it has led us in this great competition for light weight, high performance of machinery, and great speed of vessels, to give up in some cases even the improved type of locomotive boiler which has produced such excellent results, not only in the hands of Mr. Thornycroft but of Mr. Yarrow and others, and to fall back at last upon the tubulous boiler. And why? Because we get them to do a given amount of work for less weight. The great saving of weight is in less water space. Allusion has been made to what may be done in sea-going ships. I happened to be in Sydney in the spring of 1893, and people who travel as much as the Australians do, are very much alive as to what are the best and most reliable ships. They consider the question of the passages, and the regularity of those passages, with almost as much eagerness as we watch the racers across the Atlantic in this country; and there is no doubt whatever that the vessels of the Messageries Maritimes Company, fitted with the Belleville tubulous boiler, are considered as certain, and faster, if anything, than the very best of our English-made ships. I could, but I do not wish to go into any details; but that will show you that progress is being made in the application of water-tube boilers to ocean-going ships. I may say that during the last few months we have recommended and proposed for coasting vessels, where high speed and light draught of water are considered essential, water-tube boilers of one type or another. I believe myself that the time will come when water-tube boilers, properly designed and carefully led up to by experiments and thorough trial, will take their place for all classes of ships, but not to the exclusion of the old boiler, because in some cases it does not matter whether you have a few tons or even 100 tons more or less in the boilers. It will take a long time to upset the confidence that exists now in the public mind, and in the minds of marine engineers, in the old cylindrical type of boiler, but the requirements of speed and weight carrying and draught of water are becoming so imperative that I think marine engineers will give this matter careful study. I think we may congratulate Mr. Thornycroft for the very able and pleasant way in which he has put the facts before us to-night; and the only reason why I speak of him as one certainly of the pioneers of the successful use of water-tube boilers is that, he has taken the trouble on more than one occasion to take the members of this Association into his confidence, and, in a frank and manly way, to tell us all he has been doing.

Mr. J. I. **Thornycroft**, F.R.S. (Vice-President): Sir Nathaniel Barnaby and Gentlemen, I feel that very few remarks are called for from me at present. We have only had two speakers on this subject, and I feel that I must set one against the other, if that is fair, because it amounts to this. By the confession of Mr. Marshall, he has not examined the question as Mr. Laird has done. Therefore, I beg you to remember what Mr. Laird has said, and set it against Mr. Marshall's experience, and then I feel my answer is almost complete. Mr. Marshall has said he prefers straight tubes. After very careful examination into the subject, I came to the conclusion that for many reasons curved tubes are better. With regard to internal deposit, as Mr. Laird has told you, it is now possible to have pure water to put in the tubes. As I told you in my paper, the Belleville Company say they have proved that, even though salts or deposits exist in the water, if proper care is taken to heat the water before it comes to the heating surface, these salts will not deposit on the surface in a form difficult to remove, but will be found as mud in some quiet place, and in their boilers they make a special quiet place; but in my boiler the lower vessel is not exposed to fire, and there we find the mud. We have had a lifeboat working now for about four years, and it has done very hard work in very rough weather; and sometimes, I believe, for as long as ten hours at a stretch it has been able to work, as it were, on a trial trip, and to hold its own. Now this boiler has done that under circumstances in which it must have had a certain amount of salt water in it, and yet our own foreman, who examined it, found that the tubes were yet in a good condition only a short time ago, and therefore, I think I can say with confidence that these small curved tubes may be used with success, and as this is one of the early applications of the boiler I have great confidence in the curved tubes. I will reserve any further remarks I have to make till the discussion on the other papers.

The **Chairman** (Sir N. Barnaby, K.C.B., Vice-President): Gentlemen, I am glad Mr. Thornycroft has said that he will be ready to take part in the general discussion, and I am sure you will be pleased to give him your hearty thanks for the trouble he has taken in preparing the paper which he has given us to-night.

ON WATER-TUBE BOILERS.

By J. T. Milton, Esq., Member of Council.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 15th, 1894;
Sir Nathaniel Barnaby, K.C.B., Vice-President, in the Chair.]

At the meeting of the Institution held at Cardiff in July last, I had the honour to read a paper "On the Present Position of Water-Tube Boilers for Marine Purposes." Since that date some more experience has been had with these boilers, and, as the matter is one in which all marine engineers take much interest, and in which many of them are now exercising their ingenuity and inventive talent, I have thought that another paper, giving further information of some types of boiler now being made, and inviting criticisms of points of detail, both of principle and of construction, would meet with the approval of the Institution, and would be of service at the present time.

Since writing the major portion of this paper I have received the proceedings of the International Engineering Congress, division of Marine Engineering, held at Chicago in July and August last. These contain an excellent paper on tubulous or coil boilers by Mr. C. Ward, the originator and maker of a type of water-tube boiler successfully fitted on board the U.S.S. *Monterey*. The boilers described in this paper are (1) Ward's boiler, consisting mainly of nests of tubes one above another, bent into the form of concentric circles, each tube being, however, attached at one end to a descending header, and at the other to an ascending header leading into the steam spaces; (2) the Cowles boiler; and (3) Mosher's boilers, which may both be considered to be modifications of the Thornycroft boiler; (4) the Towne boiler, consisting of water slab casings, with two sets of inclined water tubes crossing each other, and a steam drum; (5) the new Herreshoff; and (6) the Roberts boilers, consisting of rectangular casings surrounding the fire. In the former the sides are shielded by horizontal, while in the latter they are shielded by vertical water tubes; in both, the spaces above the fire are packed with several series of zigzag tubes, side by side and over one another, these tubes being nearly horizontal. The Roberts boiler has a horizontal cylindrical steam chest above the boiler, the new Herreshoff has a vertical steam chest in front of the boiler.

Of the above-mentioned boilers we have no experience on this side of the Atlantic. The paper further treats of the Belleville, the Thornycroft, and the Yarrow boilers, and is well worth careful study by all interested in water-tube boilers.

Since reading the paper at Cardiff, the Babcock and Wilcox boiler therein described has been in continuous work at sea on the S.S. *Nero*, and up to the present time has given satisfaction. The Thornycroft boiler also, as fitted in H.M.S. *Speedy*, has been successfully tried, and has fully answered expectations.

At the present time large numbers of water-tube boilers are being fitted in vessels for the Navy. The Belleville boiler is being fitted in H.M.S. *Sharpshooter*, and in two new armour-clads. Another gunboat is being fitted with the Du Temple boiler, while the large numbers of new torpedo-boat destroyers being built are nearly all being fitted with water-tube boilers of various types, including the Thornycroft, Normand, Yarrow, and Du Temple previously described, and also types by Messrs. J. S. White, A. Blechynden, and others. It must be admitted that, but for water-tube boilers, the very high speed of these vessels could not be obtained; so that if these boilers had not been available, the vessels themselves would probably have had no existence.

Turning to the Merchant Navy, Messrs. Fleming & Ferguson are now constructing a pair of water-tube boilers for a vessel building by them, intended to be classed by Lloyd's Register. These boilers are shown in Plate LI. Each consists of a steam and water chest, 6 ft. in diameter, and two water chambers, 3 ft. in diameter, extending the whole length of the boiler, and connected by numerous bent tubes. These chambers are connected outside the boiler casing by external circulating pipes of large diameter. The fire grate extends practically over the whole space below the water chambers, and the products of combustion rise up amongst the tubes on the way to the chimney.

The tubes—which are of iron, lap welded, 2½ in. in diameter—are expanded in the chests, and are afterwards beaded over. The chambers are built into the framework of the boiler casing before the tubes are fitted, so that the tubes have no strain on them due to the weight of steam chest, &c.

It will be noticed that the tubes are all made with the upper end $2\frac{9}{16}$ in. in diameter, and their length is such that they can all be put in place from the inside of the steam chest. Any one tube can be cut out and replaced without disturbing the neighbouring tubes. Although the tubes are curved, owing to their comparatively large diameter, a light held at one end may easily be seen to shine through the other end if they are clear.

A boiler of this general type has been at work on shore in Messrs. Fleming & Ferguson's works for some time, and has given satisfaction both as regards evaporative efficiency and also in giving no trouble whatever.

Some of the different types of the same general design of boiler as proposed by the makers are shown in Plate LII., Figs. 1, 2, 4 and 6.

In the boilers shown in Figs. 1 and 2 the products of combustion have a longer course amongst the tubes before reaching the chimney. In the boiler Fig. 4 there are three, and in that shown in Fig. 6 there are four water chambers, making two or three fires abreast, as the case may be. These forms of boiler may be either double-ended, as shown, or they may be single-ended. Plate LIII. shows a further design of a very large pair of boilers which it is proposed to fit in a large vessel. In this case the water chambers, &c., are placed in a fore and aft line, while the firing is done athwartships. There is a very large space provided for combustion above the fires below the tubes. These boilers are intended to work at a steam-pressure of 250 lbs. per sq. in., the fires being worked under a forced draught of one-half inch air pressure.

The following Table gives some particulars supplied by Messrs. Fleming & Ferguson of the weights, surfaces, &c., of these various types of boilers:—

TABLE I.

Type of Boiler.	Working Pressure, lbs. per sq. in.	Heating Surface in sq. ft.	Grate Surface in sq. ft.	Total weight of boiler and contained water (cold), with casings, and all mountings and fittings, except chimney.	Total weight per sq. ft. of Heating Surface.
Navy type, shown in Fig. 1, Plate LII. one furnace	200	1,150	30	21 tons	41 lbs.
Two boilers for steamer where height and width are kept a minimum, shown in Fig. 2, Plate LII. ..	200	In two boilers, 1,450	In two boilers, 44	Two boilers, 34 tons	52 lbs.
Single-ended boiler, with two furnaces, similar to half of boiler shown in Fig. 4, Plate LII. ..	200	1,150	48	23 tons	45 lbs.
Double-ended boiler, four furnaces, shown in Fig. 4	200	2,200	88	38 tons	39 lbs.
Single-ended boiler, with three furnaces, similar to half of boiler shown in Fig. 6, Plate LII. ..	200	1,550	60	31 tons	45 lbs.
Double-ended boiler, with six furnaces, shown in Fig. 6	200	3,400	110	55 tons	36 lbs.
Double-ended boiler, with six furnaces	200	4,800	138	75 tons	35 lbs.
Boiler being made, as per Plate LI.	220	1,450	50	30 tons	46 lbs.
Large boiler, with four furnaces fired crossways, as per Plate LIII. ..	250	5,000	165	110 tons	49 lbs.

Messrs. Anderson & Lyall, of Glasgow, have made a boiler on the plan illustrated in Plate LIV., but this type has not yet been tried at sea. The makers of this boiler are of opinion that in order to abstract as much heat as possible from the products of combustion, they must be subdivided into a number of small streams, each of which must be forced to act upon a considerable extent of surface, and, to ensure this, they have retained some of the heating surface in the old form of smoke tubes.

In this boiler the water-tubes are not spaced close together, and a large space or combustion chamber is formed between them and the barrel containing the smoke tubes. These features of the design are intended to provide for the proper combustion of the furnace gases; and in actual use considerable combustion and much evolution of flame takes place above the water tubes.

The design illustrated shows water sides to the fire space, but the makers have proposed plans for forming these sides with iron casings, protected from the intensity of the fire by water tubes nearly in contact with one another, as is done in several other types of boiler.

Messrs. Anderson & Lyall inform me that the total weight of boiler and all accessories, including chimney and water, of an installation they have under consideration, is 40 tons 3 cwt. The boiler will have a grate surface of 69 sq. ft., and a total heating surface of 2,340 sq. ft. This weight is equivalent to about 38 lbs. per square foot of heating surface. The working pressure will be 180 lbs.

The boiler appears to have a very high evaporative efficiency. During a five-hours' trial of January 31, 1894, with the shop boiler made on this plan, the evaporation was equivalent to 12·05 lbs. from and at 212°, the rate of combustion being 18·29 lbs. per square foot of grate. The coals used were Welsh, samples of which were kindly tested by Mr. C. J. Wilson, and found to have a calorific value of 14,467 thermal units, equivalent to an evaporation of 14·97 lbs. of water from and at 212° Fahr. The steam generated was practically dry, the wetness found by the most approved method being less than one per cent. It may be stated that the trial was controlled by my colleague Mr. Stromeyer, and was, therefore, conducted entirely independently of the makers.

A form of boiler used on the Continent is that known as the Dürr boiler. Those intended for marine purposes are very similar in design to the land boilers made by the same firm. One of the marine type is shown in Plate LV.

The chief parts of these boilers are:—

(1) A water chamber extending over the front of the boiler divided into two parts by a diaphragm plate, which is made in portable pieces, each being secured by nuts threaded on the screw stays.

(2) A number of slanting rows of tubes communicating at their upper ends with this water chamber, the lower ends being closed.

(3) One or more steam receivers placed over the water tubes, connected at the front end to the water chamber.

(4) A nest of superheater or drying tubes, placed over or between the steam receivers.

The water tubes are made at their front ends with rings welded on and turned conically, the conical portions fitting into the milled holes in the back plate of the water chamber, without requiring any expanding, rolling, or jointing of any kind. As the tubes are placed at an inclination, while the water chamber is vertical, the tube ends have to be turned in a special manner to fit at the proper angle. The diameter of the tubes at the rear ends is somewhat reduced; these ends are closed by an end plate fitting with a conical joint kept in place by one bolt, with cross-bar, straps, &c. The tube ends are carried on an iron plate forming part of the framework of the boiler, protected with bricks, and the tubes are perfectly free to expand or contract.

Circulation is obtained by means of internal concentric tubes fixed to the diaphragm plate, and communicating with the front part of the water chamber. These inner tubes reach nearly to the end of the water tubes.

The water level of the boiler in ordinary working is about the centre of the steam receivers. The water passes from these receivers down the front part of the water chamber, then through the inner tubes into the outer tubes, where part of it is evaporated. The steam and water then pass out of these tubes into the rear part of the water chamber, whence they are led into the receivers.

The water tubes at the sides are placed as near each other as possible, to prevent loss of heat by radiation. This is effected by bending them alternately to the right and left.

A hole is provided in the front plate opposite each water tube, to enable it to be drawn out or replaced. The holes in the outer plate are closed by hollow caps with conical fitting portions placed from the inside, and, like the tube ends, these caps fit tight without requiring any rolling or jointing of any kind. The taper ends of the tubes, and also of the caps, are untooled at the extreme ends; these portions, therefore, are of slightly larger diameter, the collar forming a stop, which is a safeguard against their being blown out from any cause.

The tubes are cleaned on the outside by a steam jet.

Baffle plates are fitted between the tubes to ensure a proper circulation of the furnace gases amongst the tubes.

The superheater consists of concentric tubes similar to the water tubes, and the steam circulates through them in the same way, first passing through the inner tube, and then through the annular space between the tubes, where it is dried, or, possibly, superheated.

The makers of these boilers, Messrs. Dürr & Co., of Ratingen, are represented for this country by Messrs. Van Rietschoten & Houwens, of Rotterdam, who have been good enough to furnish me with the particulars of these boilers. Although making principally land boilers, of which they have made 944, having a collective heating surface of over 1,000,000 sq. ft. during the last six years, they have made several marine installations—among others, two being for the German Navy. These boilers are also said to be giving perfect satisfaction in large paddle towing steamers working on the Rhine. Messrs. Rietschoten & Houwens inform me also that the German Naval authorities have made experiments with these boilers, forcing them to a consumption of coal at the rate of 70 lb. per square foot of grate per hour without developing any defects whatever.

Besides the boiler described in my previous paper, Mr. Yarrow has used another type, shown in Plate LVI. This consists mainly of a horizontal steam and water chamber connected at both ends with water spaces, which are in turn connected by a number of water tubes. In this respect the boiler somewhat resembles the Lagrafel boiler. The construction of the water chambers, however, is different. Each tube passes through both chambers, being expanded into both front and back plates of both spaces. The top and bottom portions of the tubes are cut away at the parts passing through the chambers, leaving the sides intact. The sides, therefore, serve as stays, while the openings left by cutting away portions permit of the circulation of the water. The ends of the tubes are then stopped up, one end being fitted with a screwed plug, the other end being fitted with a gland and packing.

A boiler proposed by Mr. A. E. Seaton is shown in Plate LVII. It consists of four segments, each connected to a horizontal cylindrical steam chest. Each segment is formed of a horizontal or slightly inclined cylindrical steam and water drum, connected at the front end directly to a deep water chamber. At the back end there is a somewhat similar chamber connected to the drum by means of a circulating pipe which enters the chamber at the bottom. The two water chambers are connected by a large number of slightly inclined water tubes of small diameter. The grate is placed beneath these nests of tubes, considerable space being allowed between the fire and the bottom rows of tubes. The circulation of the gases amongst the tubes is provided for by baffle plates, and by some of the tubes being arranged to touch one another, forming diaphragms.

A feature peculiar to this boiler is that no stays are fitted to the water chambers, the outer ends of which are formed of ribbed or corrugated doors. One joint at each end, therefore, exposes all the tube ends similarly to the doors of a surface condenser. This is a point of much importance when considering the accessibility for cleaning or inspection.

Another boiler adopted in the French Navy, and fitted in the *Friant*, *Charles Martel*, *Elan*, and other vessels, and also used in several steam yachts, is shown in

Plate LVIII. This boiler, designed by Mons. Niclausse, is made by the Cie. Anon. des Générateurs Inexplosibles, of Paris. The sketch and information have been furnished to me by Mons. Niclausse through his English agent.

The boiler consists of a series of headers fitted side by side, each having a number of compound tubes fitted to it, the whole being placed above the fire and surrounded by a suitable casing. The headers each communicate at their upper open ends, with the bottom of a horizontal cylindrical chest which, when in work, contains steam and water, the water-level being at about its centre.

The headers are made of malleable cast iron, and are each constructed with a centre diaphragm dividing it into two portions, the inner serving as an upcast for the mixture of steam and water issuing from the generating tubes, the outer forming a space for the descending water.

For each tube holes are bored through the front and back of the header, and through the diaphragm of nearly equal diameter; those in the two outer walls of the header being slightly conical or taper, the smaller end of the hole in the outer wall being exactly the same diameter as the larger end of the hole in the inner wall.

The steam generating tubes are reduced in size at the rear end, and are closed by iron cap nuts screwed on to them, the nuts being slightly smaller than the diameter of the tubes. The front ends of the tubes are secured to malleable iron castings, termed by the makers "lanternes." These "lanternes" are turned with conical surfaces where they fit the walls of the headers. The parts near the tubes which fit the back wall are thick and rigid; the front ends, however, are made thinner, to give more elasticity. The "lanternes" are all turned to gauge, so as to be absolutely interchangeable. The middle part of the "lanterne" fits easily into the hole in the diaphragm; its shell is cut away at top and bottom, so as to afford freedom for the motion of the water in circulating.

Inside the steam-generating tube is placed a smaller water-circulating tube, which is secured to a smaller "lanterne" fitted inside the other, but extending only from the front of the header to the diaphragm. The front joint of this inner "lanterne" is screwed.

The tubes are arranged in pairs, each pair being kept in place by a cross girder fastened by a stud screwed into the header. The construction of these details is shown by the sketch in Plate LVIII., drawn to a larger scale.

In practice it is found that the tubes are readily removable from the front of the boiler, and may be replaced quickly, the boiler thus affording exceptional facilities for cleaning and inspection.

Some tests have recently been made with this boiler under forced draught with very satisfactory results, the steam being produced freely and being found to be dry. Other experiments have been made by feeding the boiler with impure water, but its ready accessibility for cleaning has enabled it to withstand exceptionally bad treatment in this respect without derangement.

A boiler designed by Mr. A. Blechynden, and being made by the Naval Construction and Armaments Company at Barrow, is shown in Plate LIX.

In general design it presents some features in common with the Yarrow boiler, but it will be observed that the tubes are not straight, all being slightly curved, while the outer rows are made to shield the casing similarly to the outer rows in the Thornycroft and some other boilers.

A noticeable feature in the boiler is the plan by means of which any single tube may be cut out and replaced from inside the steam chest without disturbing the neighbouring tubes.

Plate LX. shows a boiler which has been made and successfully used by Mr. J. Samuel White, of East Cowes. It consists primarily of two lower water chambers and an upper steam chest connected by numerous water tubes, the whole being enclosed in a casing. The grate is below the level of the lower water chambers, a considerable space being allowed between the fire and the lower parts of the tubes to serve as a combustion chamber. The front and back of the casing are shielded by 1¼ in. tubes, which are reduced at the ends so as not to unduly weaken the chambers where they are joined to them, and two longitudinal diaphragms of nearly vertical tubes, touching each other and with similar reduced ends, extend from the front nearly to the back of the boiler, forming return flues. The products of combustion have thus to pass from the grate down the centre of the boiler and return along the side flues to the chimneys. The flues are filled with a number of double spirals of smaller tubes. These are clearly indicated on the drawing. The diaphragm of tubes mentioned as forming the division between the flues is supplemented by baffle plates where required.

Very ample external circulating pipes are provided.

The provision for the circulation of the furnace gases by means of the return flues is such as to ensure their being brought intimately into contact with the heating surfaces, and to effectually prevent their taking a short cut to the chimney before parting with their heat.

Turning now from the descriptions of the individual types of boilers, let us consider what are the special qualities in which water-tube boilers are supposed to surpass the ordinary boiler. It must be remembered that unless the balance of the advantages and disadvantages in any particular case is decidedly in their favour they are not likely to be used, as the preference would otherwise be given to the old, well-tried form. The advantages are mainly :—

(1) The means of obtaining higher working pressures than can be obtained with ordinary boilers, owing to the excessive thickness of plates which would be necessary both for the shells and for the heating surfaces.

(2) Economy of maintenance.

(3) Decrease of weight and space required for producing a given power, or an increase of power obtainable with a given weight or in a given space.

(4) Less liability to serious accident through damage by neglect, and also, in case of such damage, less serious consequences, owing to the small quantity of water they contain.

Regarding the first of these considerations, it may at once be conceded that with *all* the types of water-tube boilers very high pressures may be obtained. It is probable that the limit in this respect will, for many years to come, depend not upon the boilers, but upon the engines which have to use the steam after it is made.

The objects of desiring to have steam of high pressure appear to be twofold. First, in order to obtain higher powers with a given size or weight of engine; secondly, as a means towards obtaining greater economy of coal consumption, the greater pressure rendering a greater range of expansion possible, and therefore making the engine more economical. In order to do this, however, it will be essential that the boiler supplying the higher pressure steam should be quite as economical as regards evaporation per lb. of coal as the present boiler, otherwise we shall be losing at the boiler what we gain at the engines. The boiler must also produce dry steam; that is, there must not be a large percentage of moisture in the steam as delivered.

For efficiency of evaporation two things are needed, viz., completeness of combustion, and proper circulation of the products of combustion amongst a sufficient amount of heating surface to enable the latter to abstract the whole of the available heat from the former, which should reach the chimney comparatively cool.

These conditions involve both space and weight, and are thus to some extent in antagonism with the requirement of large power on small weight and space. Different types of boilers, therefore, according as the requirements of economy or of large power predominate in the conditions they have to fulfil, provide for these factors more or less completely.

As regards perfection of combustion, it is recognised that so long as coals are used as fuel sufficient air must be supplied, either through or above the grates, to properly burn the distilled gases from the coal, as well as the carbonaceous part of the fuel; and that the mixture of gases and air requires both time and space in which to become thoroughly mixed before their temperature is reduced to a certain critical point, below which further combustion is not possible.

In ordinary boilers with roomy combustion chambers these conditions are fairly well met, and in some of the water-tube boilers also these conditions are sought to be obtained; in others, however, in which the products of combustion are hurried direct from the fire into the narrow spaces between the tubes, economy cannot be expected.

Mons. D'Allest, the originator of the D'Allest boiler, attaches great importance to this point, and his views are borne out by the trials quoted in the Appendix of my previous paper, some of which are reproduced in English figures in Table II.

These trials, made by French naval officers with boilers of very similar design in all respects, except that of the circulation of the furnace gases amongst the tubes, and under similar conditions, showed that where the furnace gases rose straight up amongst the tubes imperfect combustion resulted, smoke of great intensity being produced while the evaporation was only equivalent to 7·25 lbs. of water, from and at 212°, per lb. of coal; in the other boiler, in which the gases passed first into a roomy chamber, where more complete combustion took place, and then traversed the same amount of heating surface, there was no smoke, and an average of 10·76 lbs. of water evaporated from and at 212°, a result not only excellent in itself, but remarkable as being almost 50 per cent. in excess of the other. If the natural draught results only are taken, the average is 11·21 lbs. of water from and at 212°. Attention is also called to the results obtained with forced draught in the cases of the 2,000 and 9,000 I.H.P. vessels. These experiments are very valuable, being made by French naval officers, entirely independently of the makers of the boilers, and therefore disinterested.

The importance of providing for proper combustion and circulation of the furnace gases amongst the heating surfaces is shown also by the results of the experiment made by Mr. Stromeyer on Messrs. Anderson & Lyall's boiler, which have already been given.

TABLE II.

VARIOUS PARTICULARS OF EXPERIMENTAL TRIALS MADE WITH D'ALLEST BOILERS.

Description of boiler.	Duration of experiment.	Grate surface.	Heating surface.	Total weight of boilers, including all mountings, casings, chimney, and water.	Total weight of boilers per sq. ft. of heating surface.	Consumption of Cardiff coal per sq. ft. of grate per hour.	Actual evaporation of water per lb. of coal.	Equivalent evaporation from and at 212° F.	Equivalent evaporation per sq. ft. of heating surface per hour.	Equivalent evaporation in lbs. per hour per ton of boiler.
	Hrs.	Sq. ft.	Sq. ft.			Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Experimental boiler ..	6	35·9	1,076			10·29	10·67	12·44	4·28	—
Ditto	6¼	30·8	1,076			15·15	9·58	11·15	4·84	—
Ditto	6	35·9	1,076			15·50	9·23	10·83	5·60	—
Ditto	6	43·0	1,076			15·36	8·97	10·43	6·41	—
Ditto	3	35·9	1,076			25·09	8·02	9·42	7·86	—
Ditto	3	35·9	1,076			31·00	8·75	10·28	10·61	—
Part of installation of vessel of 2,000 I.H.P.	3	Total in vessel. 100·75	4,090	42·1 tons	23 lbs.	45·75	8·24	9·39	10·59	1,029
Ditto	3					35·84	9·07	10·34	—	—
Ditto	8					15·36	9·43	10·75	—	—
Part of installation of vessel of 9,000 I.H.P.	6	Total in vessel. 645	21,528	288·8 tons	30·5 lbs.	20·48	9·80	11·26	—	—
Ditto	12					12·30	10·07	11·53	—	—
Ditto	3					24·60	9·50	10·86	—	—
Ditto	3					30·72	9·23	10·58	9·70	726

Under the head of economy of maintenance, many points have to be considered, some bearing generally upon design, others on details, and the question also of the size and material of the tubes is important.

Regarding the material of the tubes, it appears that, at least with the smaller tubes used with the very light type of boiler, seamless steel is the most suitable, although seamless copper and lap-welded iron tubes have been used. The seamless tubes are preferred, not because of the relative weakness of the weld in lap-welded tubes, for even welded tubes, of the small sizes used, possess an enormous margin of strength in proportion to the working pressure; but in order to obviate the possibility of minute imperfections in the weld, which have the effect of reducing the thickness available for resisting corrosion, it having been found that, occasionally, an almost imperceptible corrosion would open a minute hole through the tube at such a defect, completely spoiling it. Undoubtedly seamless tubes would possess the same superiority over welded tubes, even for the larger sizes of water tubes.

While recollecting the good work which iron lap-welded tubes have done in the past, as ordinary boiler tubes, it should be remembered that the corrosive influences to which they are subjected, are on the outside, where the weld is more likely to be perfect than the inside, and where, if any imperfections exist, they are at once visible. If water-tube boilers come into general use, however, our tube makers must supply us with seamless tubes at a reasonable price. With the demand for them, no doubt they will be forthcoming.

Next, with the small tubes, comparatively thin tubes must be used; but with larger tubes this is not so necessary, and the greater thickness will give larger margins against wear and tear and corrosion, than can be obtained with smaller tubes. In most of the types of boilers, the most vulnerable parts appear to be the tubes, if we except, perhaps, the furnace fittings, which are in general not dissimilar to those of other boilers. In most of the boilers it is a comparatively simple operation to renew any individual tube, although in some boilers it would appear to be necessary to remove several tubes to obtain access to others.

Another point, as to which great differences present themselves amongst the various types, is the facility for examination and cleaning. In this respect, those boilers have the advantage in which the tubes are straight, and of sufficient size to enable them to be looked through. Those also in which an examination can be made without the breaking and remaking of numerous joints, have an advantage over those requiring one or two joints to be broken for every tube that has to be examined. Then, again, there are joints and joints; some are metal to metal joints, others require jointing material. The former would in general appear to require more skill and care in making than the latter, but would probably be more satisfactory and permanent when once properly made.

The above remarks as to joints apply only to what may be called door joints. The joints between the tubes and water chambers, or between different lengths of tubes, again vary in the different boilers. Some engineers prefer ordinary rolled or expanded joints; others demand screwed joints. In some of the boilers, with zig-zag arrangement of tubes, the number of screwed joints at the bends or elbows is very great.

Some of the boilers described may be made equally well of large or of small size. For instance, the Belleville boiler may be made with as few as four elements, or a much greater number may be employed. In small vessels, where it is required to subdivide the power, it will be advantageous to make them of small size; but in large-powered vessels, and in those in which it is desired always to work at about the full power, great subdivision of boilers appears to be a mistake, a less number of larger boilers being more easily attended, and requiring less complication of fittings and pipes.

An important point bearing upon the question of durability is the possibility of keeping the outsides of the tubes free from soot and from the accumulation of fine ashes, the latter, especially when moisture is present, being very destructive to iron structures. Great differences exist amongst the various boilers in this respect. Another point which must not be overlooked is whether the design provides for a depositing chamber in which the impurities of the feed water will accumulate. Although it is fully recognised that these boilers demand absolutely pure water for feed, and evaporators and filters, &c., are supplied, yet it is inevitable that some sea water and other impurities will occasionally be introduced into the boilers. These appear, in the main, to become separated out from the water, into a solid form, more at the time the water is being raised in temperature to the boiling point, than during the time the water is being evaporated. Those boilers would appear to have an advantage which provide, in the course of the circulation of the water, quiet places in which the impurities can settle without encrusting the heating surfaces.

The importance of the proportions of the weight and space occupied to the power of the boilers varies much in different vessels. In ordinary cargo steamers both considerations are comparatively unimportant. The first consideration in these vessels is economy of coal consumption, and the boilers which give the best results in this direction will be preferred to others, even if they occupy more space and are considerably heavier. In passenger steamers, however, the weight and, more especially, the space occupied are important; but in these vessels also, especially those engaged in long voyages, economy of coal consumption is still of vital importance.

In war-vessels, however, the case is very different. What may be termed the weight efficiency and space efficiency assume the first importance, the questions of economy and durability taking relatively second place. In some cases, indeed, the question of economy hardly comes in at all, the question being mainly that of obtaining the greatest power on the smallest possible weight and in the small space available. In other cases, however, combined with the question of large power is the requirement of economy of consumption at low power. It is evident, therefore, that the same type of boiler can hardly prove to be the best for all purposes.

ON THE COMPARATIVE MERITS OF CYLINDRICAL AND WATER-TUBE BOILERS FOR OCEAN STEAMSHIPS.

By James Howden, Esq., Member.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 15th, 1894;
Sir Nathaniel Barnaby, K.C.B., Vice-President, in the Chair.]

A comparison of these distinctive types of boilers appears to be not inappropriate at the present time, which witnesses another revival of the water-tube boiler for sea-going steamers, after the frequent, but hitherto abortive attempts, which have been made for this purpose during the last thirty-five years.

This revival of the water-tube boiler is the more remarkable because of the claims made by its supporters of its superiority to the cylindrical boiler, whose speedy extinction by it some, at least, confidently predict.

This hope or expectation, for it is as yet unrealised, of the new school of boilerists, is also remarkable in being entertained in view of the following facts regarding the cylindrical boiler:—

(1) In being entertained, after thirty years of uniform, unrivalled, and continuing success of the cylindrical or "Scotch" boiler, for every usable or practicable steam pressure yet required in sea-going steamers.

(2) In being adopted at the period when the cylindrical boiler is still rising in efficiency, and when examples of single boilers of the type, in moderate dimensions, supplying steam of 200 lbs. working pressure for 2,500 I.H.P., are being worked at sea without the slightest feeling of risk, damage, or inconvenience.

(3) In being advocated in view of the indubitable fact that the design and introduction of the cylindrical boiler was chiefly owing to the failure of the water-tube, sectional, and all other forms and types of boilers to supply sea-going steamers with high-pressure steam safely, easily, and economically; and in the face of the still more important fact that, from the day of its introduction, all the serious troubles and vexations, previously caused by the other types of boilers named, came to an end, and the cylindrical boiler quickly became the universal type for steamships solely by reason of its unrivalled merits.

Without at present noticing the chief cause for this phenomenal attack on the cylindrical boiler, it will enable those who have not the experience of the past to guide them, to judge more intelligently of the relative merits of these respective types of boilers, by giving a short account of the difficulties and troubles experienced in the attempts to supply steam of high pressure at sea shortly before, and at the time of, the introduction of the cylindrical boiler.

The first sea-going steamer known to the writer using steam of a high pressure had, therefore, compound engines and a surface condenser. This was the steamer *Thetis*, of Glasgow, built by Messrs. Scott & Co., of Greenock, in 1857, and engined and boilered by Mr. J. M. Rowan of Glasgow, who had associated with him Mr. Thomas Craddock as the designer of the machinery.

The boiler was of the water-tube type, and constructed for 120 lbs. working pressure.* The greatness of this pressure for a steamship at that period may be judged of from the fact that the average steam pressures used in sea-going steamers at that date was not over 20 lbs.

No actual drawings of the boiler of this steamer appear to exist, but Mr. Robson, then Board of Trade surveyor, who has a good recollection of the boiler, has furnished me with sketches of it, from which I have made up Figs. 1 and 2, Plate LXI.

The tubes, I believe, were over 3 in. in diameter. It will be seen that this boiler is not unlike some of the latest designs of water-tube boilers. It ran only six round voyages between Glasgow and Liverpool when the tubes began to give way, and thereafter proved so troublesome that the steamer was laid up, the boilers and engines removed, by Messrs. Scott & Co., of Greenock, and the ship refitted with low-pressure boiler and simple engines. This water-tube boiler stood but a few months' actual work.

In 1859 Mr. J. M. Rowan, with Mr. Thomas R. Horton, produced a new design of compound engines, and a sectional boiler formed of a series of "leaves," each of which consisted of a number of water tubes of 10 in. or 12 in. square section, standing in a line vertically, and united in a common box at top and bottom. These square water tubes had each four 2½ in. tubes passing from top to bottom, through which the fire gases passed. An iron casing, lined with fire brick, prevented in a greater or less degree the escape of heat from the fire gases. This boiler is shown in Figs. 3 and 4, Plate LXII., as it was fitted in the steamer *Athanasian*, built by Mr. James R. Napier, for the Glasgow and Bordeaux trade, which began running in the springtime of 1860, but did not run long until her boiler began to give trouble. Between 1860 and 1862 some ten steamers were built on the Clyde, Tyne, and Tees, and fitted with these engines and boilers. Of these a number were paddle steamers for the river Hoogly.

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* In all further references to steam pressures in this paper it will be understood that the pressure stated is per square inch and above the atmosphere.

The boilers of these steamers, which ran in fresh water in India, continued to run, with more or less repair and a fair efficiency, for about ten or eleven years, when they were replaced by water-tube boilers of the *Propontis* class, also designed by Messrs. Rowan and Horton in 1869. All the boilers in the seagoing steamers of the *Athanasian* class lasted a very short time.

In 1859 I began marine engineering by contracting with the "Anchor" Line for the machinery of a small steamer, named *Ailsa Craig*, for their Mediterranean trade. The engines were compound, and the boilers were to work at 100 lbs. pressure, all being on designs patented by the writer and Mr. Alexander Morton. Figs. 5 and 6, Plate LXI., represent the boilers. They passed the Board of Trade requirements for above working pressure; and, after being fitted on board, began to run early in 1860. The boilers, as will be seen, were of a strong design; but, like most of the high-pressure boilers of that period, were inaccessible inside for cleaning, if once incrusted with salt deposits. The boiler ran safely, for a period, on entirely fresh water, but after a year's work it got salted up, and began bulging out in places between the stays. The plating had to be cut in places to remove the incrustation, and then patched; but after a while this was found to be too troublesome and expensive, and the boiler was removed, after having worked exactly two years, and replaced by a water-tube boiler in August, 1862.

Towards the end of 1860, when the *Athanasian*, having the sectional boilers of Messrs. Rowan & Horton, had been running for eight months, the corrosion of tubes and other difficulties in these boilers had become so great that the owners of the vessel employed the writer to design and construct a boiler to work at 100 lbs. pressure, to be accessible inside and outside for repair and cleaning, and to be capable of using salt water without being easily injured. These requirements I undertook to accomplish by the design shown in Figs. 7 and 8, Plate LXIII., which represent the boilers I constructed and fitted in this steamer in June, 1861, after removing the Rowan & Horton boiler. This boiler worked satisfactorily, and the steamer continued to run steadily for several years, using so much salt water that the battery of cylinders forming the boiler required to be scaled more or less every return voyage from Bordeaux. Access to the cylinders was obtained by a manhole in the front end of each. Access to the outside of the cylinders was obtained from the front end by means of the spaces between the cylinders, through which the fire gases also passed on their upward course to the funnel.

Some months after the *Athanasian* was refitted with this boiler, Messrs. Randolph, Elder & Co. tried their first high-pressure boiler in the steamer *Murillo*, sailing under the Spanish flag. The boiler was a water-tube one, designed by Professor Williamson, of Birmingham, and is shown in Figs. 9, 10, 11, Plate LXIV. The tubes were 6 in. external diameter by 12 ft. in length, in three rows on each side of the furnaces. The fire gases were caused to pass to and fro across the tubes in their ascent, and finally around the steam receivers. The water level was below the upper ends of the tubes. The bottom ends of the tubes in each of the four divisions were fixed into cast iron boxes, which served as a common pipe for the feed water. The working steam pressure was 90 lbs. or 100 lbs. The steamer was built along with a sister ship, the *Velasquez*, for the fruit trade between London, Liverpool, and Spain, but only ran one voyage when the boiler tubes gave out, and she was laid up in London, to which port she had returned early in 1862. On her collapse I was requested by Messrs. Randolph, Elder & Co. to furnish them with a plan of boiler similar to that with which the *Athanasian* had been refitted, with a tender for its erection in the *Murillo*, which they were to submit to the owners. The plans and tenders for erection were accordingly supplied, but, after a considerable lapse of time, Mr. Elder informed me that the owners had at last decided to use a much lower pressure and a plain boiler.

This "plain" boiler took the shape of Figs. 12 and 13, Plate LXII., and was the first cylindrical "Scotch" boiler made in Great Britain. The diameter was 9 ft., length 10 ft. 6 in. It was a double-ended boiler with four furnaces, two at each end, 2 ft. 9 in. diameter. The tubes were 336 in number, 4 ft. 6 in. long, and 2¼ in. external diameter. The working pressure was about 50 lbs., the cylindrical shell plates being ½ in. in thickness. The sister ship *Velasquez*, without ever having made a voyage, had her water-tube boilers removed, and replaced by a duplicate of the cylindrical boiler fitted in the *Murillo*. These refits were made towards the end of 1862.

The fitting of these steamers, under the circumstances mentioned, marked an important era in marine engineering.

Messrs. Randolph, Elder & Co. began their career as marine engineers in 1854 with their compound engines and jet condensers working with steam of 25 lbs. pressure supplied by the flat-sided multitubular boilers of the day, analogous in character to the cylindrical boiler. So long as they kept to the return multitubular boiler and steam pressures not exceeding 30 lbs. they were successful. When, however, from about 1859 to 1863, they raised the steam pressure to 40 lbs. and 50 lbs. (the higher pressure attempted in the *Murillo* and *Velasquez* was an exceptional case), they designed and used various forms of water-tube boilers, the tubes, of considerable size and thickness, generally standing vertically, and one design had a spiral water tube which guided the gases spirally in their ascent, and caused them to act against the vertical water tubes forming the outer ring of the boiler, which was of circular form in plan.

Probably as many as ten or twelve steamers were fitted with these boilers between 1859 and 1863, but in no case, I am aware of, did they continue in use over two or three years at the most, and in most of the cases the trouble given by the boilers and their absence of economy in working led to both engines and boilers being removed, and replaced with simple engines and low pressure multitubular boilers.

It was a critical period for the continuance of the compound engine, or increase of steam pressure above 25 lbs. or 30 lbs. per square inch. Fortunately, when the boiler question had threatened to put a stop to further progress in marine engine development and economy, the case of the *Murillo* transpired, and the adoption of the cylindrical boiler. This boiler, and the similar one in the sister ship *Velasquez*, though made hurriedly and somewhat roughly, continued to run, voyage after voyage, untroubled by any conditions of working. The incessant care and anxiety attending the use of water-tube boilers now ceased, and engineers, relieved from the incessant care demanded by the boilers, now gave their attention to the improvement of the engine. The continued success of these boilers also led the Board of Trade to sanction this form for high pressures, and from 1865 or 1866 we find cylindrical boilers as large as 12 ft. 6 in. diameter permitted for passenger steamers, at pressures as high as 70 lbs.

I shall only mention further, in connection with this period, that after the first boiler of the *Ailsa Craig* was removed, I refitted that steamer with a water-tube boiler (shown in Figs. 14 and 15, Plate LXIII.) in August, 1862, it being designed to be accessible for cleaning and repair outside and inside. The reason for using this boiler instead of the one I had erected in the *Athanasian* a year before, and which had continued to work successfully, was that the latter was too high for the smaller Anchor Line steamer. The vertical water boxes, with the tubes between, had plate doors bolted to planed faces on the boxes. The doors were stayed in the middle by bolts passing through each from end to end with nuts outside. They were easily removed by unscrewing, and access was obtained to all the tubes from both ends if required for examination, cleaning, or renewal. No difficulty was experienced in removing and rejointing these doors, or in keeping them perfectly tight under 100 lbs. pressure of steam.

This boiler ran the trial successfully, and also a first voyage to the Mediterranean and back, though it was found on the return of the vessel that a considerable quantity of scale had been deposited inside the tubes, especially those nearest the fire. This scale was, however, removed without difficulty, and the steamer proceeded to the Mediterranean on a second voyage without delay. On the return from this voyage a number of the tubes were found to be seriously corroded. These were not the tubes nearest the fire, but those at the bottom, furthest from the fire. A number of these tubes were removed for safety. This was done easily and quickly, by reason of the accessibility from each end. After this time several tubes required to be removed each voyage. This process became so discouraging, as well as expensive, that before this water-tube boiler had been working eighteen months it was condemned and replaced by a common return multitubular boiler, and the engines altered to work with low-pressure steam.

The boiler, Figs. 7 and 8, fitted in the *Athanasian* in 1861 continued, as mentioned, to work satisfactorily, and early in 1863 the owners purchased the steamer *Sicilia*, for the purpose of refitting her with the same kind of boiler. The *Sicilia* had, with a sister ship, the *Italia*, been fitted for a London company, by Messrs. Robert Stephenson & Co. and Messrs. Scott & Co. respectively, with Messrs. Rowan & Horton's engines and boilers of the same design as originally fitted in the *Athanasian*, with the same disastrous consequences as regards the boilers. I reboilered the *Sicilia* in the summer of 1863 with a larger boiler of the same type as Figs. 7 and 8, the working pressure being also 100 lbs. The first voyage of the *Sicilia*, after refitting, was from the Clyde to the River Plate, from which she returned without damage to the boiler. These boilers, though quite workable, with sufficient care, at 100 lbs. pressure, were not remarkable for economy. They likewise, with their brickwork and protected casings, occupied more space and were heavier than cylindrical boilers of the same power, and as the engines of these steamers were also somewhat expensive to maintain, both engines and boilers were eventually removed after several years' working, and replaced with simple engines and low-pressure boilers. There were a number of other steamers than those I have mentioned fitted at the time with water-tube boilers, and some years after, between 1869 and 1874, when greater experience in working high pressures at sea existed, there was a revival of the water-tube boiler in the steamers *Haco*, *Dakota*, *Montana*, *Propontis*, and others, all of which, however, had but a short and fitful existence.

These accounts of the many attempts to introduce high-pressure steam into sea-going ships by means of water-tube and sectional boilers show that they were in every case unsuccessful; and though in some instances steamers did continue, with great care and considerable repair, to keep running for a few years, the results were not satisfactory, and in a comparatively short time every one of the twenty-five or thirty steamers having these boilers were refitted by plain or cylindrical boilers. Those having cylindrical boilers, as I have mentioned, continued the use of the compound engine, and steam pressures rose gradually, through the unfailing efficiency and safety of the cylindrical boiler, from 50 lbs. to 60 lbs., 80 lbs., 100 lbs., 120 lbs., 160 lbs., 180 lbs., and 200 lbs., as confidence in this boiler and in the material used in its construction increased; and engines were designed to secure the advantage of these pressures.

As is well known, some cylindrical boilers of very large size are working at 200 lbs. pressure; so that if pressures of, say, 250 lbs. can be used profitably by suitable engines, it is evident that such a pressure can be quite as easily and as safely dealt with as 200 lbs. is now, by merely reducing the diameter of the boiler. There is no pressure ever likely to be used in steam engines which the cylindrical boiler is not capable of sustaining as safely as those it has done at every stage of increase during the last thirty years of its existence.

We are, however, asked to believe that this unequalled efficiency and economy, safety, and adaptability of the cylindrical boiler has been all, more or less, a delusion, and that the old water-tube type which gave so much trouble and caused so much loss thirty years ago, and since, to over-sanguine engineers and steamship owners, is, after all, the rightful heir to the throne, and the "Scotch" usurper, whose pretensions are now being found out, is to be immediately banished by the help of French allies, and the hitherto maligned water-tube is to reign in its stead.

That this picture is not greatly overdrawn, and represents the ideas of a number of engineers at the present time, the following quotations from Mr. Seaton's paper on this subject, read a few months ago at the Engineering Congress at Chicago, will show. Referring to the cylindrical boiler, he says:—"Unfortunately, the cylindrical boiler can never be free from its liability to deformation, from the nature of its construction, and the practical necessity for a want of uniformity in distribution of stays, or from the severe strains, often resulting in deformation, due to difference in temperature. It also requires careful handling, especially in the raising of steam, so that, whatever may be the urgency of the case, no careful engineer would risk pushing the fires so as to enable him to get under way as rapidly as could be desired." Then, as regards the water-tube boilers, Mr. Seaton says: "With the use of pure water, tubulous boilers can be thoroughly relied upon, and the day is now at hand, or at all events not far distant, when one or other of the present designs of boilers composed wholly, or almost wholly, of comparatively small tubes, will take the place of the present boilers, with the result that steam may be raised in not much more than one-tenth of the time now occupied; the variation in pressure may be rapid without fear of consequences; forced draught may be employed to an extent not now deemed advisable; and the weight of the evaporative apparatus very considerably reduced. Such boilers may be used not only in small special steamers, but in the largest ocean-going vessels."

This lament over the sad infirmities and defects of the cylindrical boiler, which alone has met the most exacting requirements of marine engineers for all practical pressures and purposes, for upwards of a quarter of a century, and is still without a rival, does seem rather premature. With many examples of cylindrical boilers still running in good order after twenty years' continuous service, strictures as to their inherent liability to deformation and other weaknesses fall harmless. This criticism, I submit, is still more inappropriate when brought forward to make the cylindrical boiler compare unfavourably with a type which can hardly be said to have yet stood any sufficient testing at sea without incurring serious damage and giving much trouble. The cylindrical boiler has a record which cannot be wiped out by mere statements on paper, and it will certainly take many long years for any other type to establish a record one-half as good.

The improved conditions of the present day in regard to feed water, and better provision, in some arrangements, for convenient repair, are, so far as I know, the only circumstances which place the water-tube boiler to-day in a more favourable position to ensure efficiency and longevity than it had thirty years ago. The designs of that day were very like those of the present day, and the material used, lap-welded iron tubes, is still the same. Unquestionably with our greater knowledge and experience better results should now be produced than were possible with water-tube boilers thirty years ago, but these improved conditions and increased experiences also bear upon the cylindrical boiler. While these advantages may give a longer term of life to the hitherto tender water-tube nursling, they at the same time give a still more vigorous life to the healthy athlete who has hitherto overcome all competitors.

Comparing the qualities of these types more definitely from analysis of their structural differences, and the action thereon of the fire gases, will, I believe, show clearly that inherently, the water-tube boiler is, and must continue to be, more troublesome to work, more liable to derangement, less safe, less economical for seagoing steamers, quite as heavy, and occupies more space for an equal power continuously sustained, than the cylindrical boiler.

The distinctive features of the cylindrical boiler are:—(1) Structurally, the cylindrical boiler is the most perfect in form conceivable for resisting strains from interior pressure, and at same time accommodating furnaces, chambers, and tubes, also for giving access to all parts outside and inside. The cylindrical shell being in perfectly equal tension has no weak points and requires no stays, while the flat ends are chiefly stayed by the structural parts themselves, cylindrical shell, furnaces, and tubes. The rod stays in steam space are of the simplest character. The combustion chambers are simply and easily stayed to the shell and to each other, and the flat backs of the chambers in single-ended boilers are most conveniently stayed to the flat ends of the boiler, all these stays being simple screwed rods with nuts. Double-ended boilers with one combustion chamber common to each fore and aft furnace (the best arrangement) dispense with all these end screw stays, and is the ideally perfect cylindrical boiler.

The furnaces are likewise of the most perfect form to resist collapse under pressure. The several well-known forms of furnaces used in marine boilers for the highest pressures, and for diameters over 4 ft., prove that, even the largest size can be safely used. Should it be said that the furnaces sometimes collapse, and that this is a weak point in the cylindrical boiler, I admit that furnaces do sometimes collapse, owing to the plates above the fires overheating from deposit of grease or heavy incrustation, but I have never heard of one such case where any rupture of the furnace plating has occurred so as to create danger. The more careful treatment of the feed-water now common should make these cases more and more rare, but absolute security against collapse can be obtained by the use of ringed furnaces, where the pitch of the rings is reduced somewhat as the pressure increases. Even with very great overheating of the furnace plates, only slight bulging, easily set up again, can be produced in these furnaces, and collapse is impossible with water in the boiler. The tubes of the cylindrical boiler, even when a leakage occurs, cause little trouble and no danger. Plugs can be pushed in from the smoke-box end to stop most of the leakage, if not all, and it is generally not necessary to do more until arriving at a port, when, if a spare tube is not at hand, a tube stopper will enable the boiler to run for months without replacing the defective tube.

(2) It contains within one enveloping shell its water, steam, fires, and fire gases, while the heat generated, until it leaves the boiler, is entirely utilised for its proper purpose of evaporation by being surrounded by water from first to last. This feature ensures a more effective heating surface and greater proportional economy than can be attained by any other type, such as the water-tube boiler, not possessing this feature.

(3) The fire gases act on the smaller interior surface, while the water receives the heat on the larger exterior surface of the communicating plating. This feature ensures a quicker and safer evaporation than when the conditions are reversed, as in the water-tube boiler.

The effect of these two latter distinctive features of the cylindrical boiler and boilers of similar class is that, from the combustion of an equal quantity of coal, and with an equal heating surface, a considerably greater evaporation, or power, will be obtained from the cylindrical than from the water-tube boiler, while a much higher rate of combustion can be safely utilised in the former than in the latter type.

The greater economy of the cylindrical boiler here claimed is proved by the fact that an equal, if not greater, evaporation per lb. of coal is obtained in this boiler from two-thirds to one-half the amount of heating surface than that required in water-tube boilers. This will be clearly shown from examples given further on. In proof of a much higher rate of combustion being more safely utilised in the cylindrical boiler, I point to the fact that, from the very small surface of the furnaces of a cylindrical boiler, if of fair length, about one-half of the total evaporation is obtained with absolute safety, in some boilers even for twenty years, without injury, from the same furnaces. I may point to the analogous case of the locomotive furnaces, though not nearly so favourably disposed as the semi-circular form of the cylindrical boiler, in support of the astonishing extent of evaporation per square foot of surface which can be safely taken from such furnaces. The limit of safe combustion in the cylindrical boiler has not yet been half tested.

Examining now the water-tube boiler and its distinctive features, we find that it is composed of a large number of separate parts having a separate connection with a common feed-water vessel or vessels at their lower ends, and with a common steam receiver or receivers at their upper ends. Further, that the heat is received on the outside or larger plate surface, varying more or less according to the diameter and thickness of the tubes. The passage area for escape of the globules of steam being very limited, the tube surface, exposed to a high heat, cannot be so well protected by the water from its action as it is in the cylindrical boiler, where the quantity of water is large and common to the whole boiler, and where the globules of steam evaporated have vastly freer means of escape. That these features in the water-tube boiler make them less effective per square foot of heating surface, and less durable than the other, is abundantly proved by experience.

If any water-tube boiler is worked at a high rate of combustion, such as is quite safe in a cylindrical boiler, say to give an evaporation of 10 lbs. of water per square foot of heating surface, two results will inevitably follow. (1) If it is found capable of reaching this evaporative power, and I find no case of its being nearly approached by this type of boiler, it must have a short life and be utterly unfitted for any sea-going steamer, and (2) it must consume an enormously greater quantity of fuel than the cylindrical boiler per lb. of water evaporated. It so happens that in the water-tube boiler even a moderate evaporative power, combined with a moderate economy, can only be had under conditions which shorten the life of the boiler, and prolonged existence, with a moderate economy, can only be secured by a greatly reduced evaporation per square foot of surface, and consequently a large increase in size and weight of boiler. As these alternatives proceed from essential features pertaining to water-tube boilers when working, I may be pardoned for occupying time in further explanation of these features and their consequent results.

The following diagrams will render this explanation more clear. Fig. A, Plate LXIV., represents a portion of a water-tube boiler, consisting of six tubes 4 in. external diameter, thickness ·3125 in., and pitch 6 in., leaving a passage for the fire gases between each tube of 2 in. The space occupied by these tubes is 18 in. in length, by 9¼ in. in breadth, this being the circumscribing parallelogram. Fig. B, Plate LXIV., is a portion of another water-tube boiler, having tubes 1¼ in. external diameter, a thickness of ·125 in., and pitch 2¼ in., leaving a space of 1 in. for the passage of the fire gases between each tube. In exactly the same space occupied by the six 4 in. tubes there are forty 1¼ in. tubes, and, in one foot in length in each case, the area exposed to the action of the heat in Fig. A is 6·28 sq. ft., and in Fig. B 13·09 sq. ft., or 2·084 times more in the small tube boiler. Another important point is that the area for the passage of the fire gases between the tubes in Fig. A is 72 sq. in., while in Fig. B it is 96 sq. in. A further point, having a special bearing on the relative economy and efficiency of the two cases, is that the sectional area of the fire gases passing between the tubes is in

Fig. B only one-half that in Fig. A. The combined effect of these differences on the evaporative power and economy of these respective boilers, or portions of boilers, is most important. Let equal quantities of heat pass over these tubes in the direction of the arrows in a given time at equal temperatures, at their first contact with the tubes nearest the fire it will be found that the fire gases will pass through Fig. B much more slowly than through Fig. A; first, because, to begin with, the area of passage is 96 sq. in. in Fig. B, and 72 sq. in. in Fig. A. The initial temperature and volume being alike in each case, the initial velocity of the gases must be in the ratio of 1·33 in A to 1 in B. Further, a given number of units of heat in fire gases passing over equal surfaces having equal lower temperatures, as in plates of boilers evaporating water under equal pressures, the number of units of heat utilised bears a certain proportion to the time in which the fire gases have been in contact with the surfaces—the longer the contact the greater the number of units of heat utilised. It follows, therefore, that of the given number of units entering B, a larger portion is taken up by that boiler *per unit of heating surface* than there can be in A, because the heat passes over the surface of B more slowly. Moreover, as there is a greater surface area in B than in A, the efficiency of B is still further increased by the tubes taking up more heat than in A on a given distance travelled by the fire gases. The combined effect of these several favourable conditions in boiler B is to lower the temperature of the fire gases much more rapidly than in A, which again proportionately reduces their volume, and, consequently, also their velocity, so that these cumulative advantageous conditions increase in a geometrical ratio.*

The ultimate result is, that the same quantity of heat units generated by combustion on the grates of A and B in equal times, and passing through equal spaces in boilers made in these proportions, the gases have their velocity reduced much more quickly in a boiler arranged as in B than as in A, and consequently a much greater proportion of heat can be utilised in a given time in B, rendering it, therefore, more suitable for higher rates of combustion. Another consequence is that the heat which has passed between the tubes to the surrounding casing is of much lower temperature in B than in A, and its casing requires less protection from injury and from loss of heat. This fact is in itself an important feature, as the large casings which surround and enclose water-tube boilers require considerable protection from the action of the fire gases and escape of heat, and are expensive to maintain, and, if effectually protected, add greatly to the weight. Water-tube boilers of the A class, therefore, require a much

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* This effect of reduction of velocity of the fire gases with equal surfaces and areas in increasing the efficiency of the heating surface of a boiler, and the economy and power of the boiler, I have treated cursorily in my paper "On Forced Combustion in Steam Boilers," read at the Engineering Congress held at Chicago in August last; also in a letter to *The Engineer* of October 26, 1892. Though an important factor in boiler economy, I have not seen it referred to by any writer on such subjects.

heavier protection than the boilers of the B class to preserve the casings, and prevent escape of heat. The small-tube boiler, while much more efficient than the large-tube boiler for mere purposes of evaporation, is, however, quite unfitted for ocean steamers. The chances of damage are in proportion to the number of its tubes. Though nearly double the weight of the steam could be generated without difficulty in B in a given time than could be generated in A, this quicker evaporation would be at the expense of its durability. The thickness of the tubes must necessarily be limited in small diameters. The high temperature acting on the tubes next the furnace, which, from the small sectional area of the contained water and its rapid evaporation, must always be filled with steam and water combined, causes them to work under conditions fatal to longevity, while these, and the other tubes, are working under the continual risk of foulness of water, whether from grease, salt, or other impurities, which are present in all marine boilers more or less, whatever precautions are taken, and which, sooner or later, will act upon the material of the tubes. If they are thin, they must go quickly, if thick, with proportional increase of water area, they will endure longer; and, if capable of being well cleaned out at short intervals, their durability will be still further increased.

Having said so much regarding the distinctive constructive features of these two types of boilers, and the action of the fire gases in each, I must at this stage separate the class of water-tube boilers for torpedo and other light high-speed steamers and the class for ocean steamships, with which latter I have chiefly to do. Of the former class, those designed and constructed by Mr. Thornycroft and Mr. Yarrow in this country, and by Mr. Ward and others in America, give wonderful proof of what can be accomplished for short periods, by great ingenuity combined with first-class workmanship and materials; but these boilers are quite unfitted for working at sea. The great number, smallness, and closeness of their tubes, on which their steaming qualities depend, while absolutely necessary to take up, with the necessary rapidity, as I have explained, the high heat from the rapid combustion of a large quantity of fuel, unfit them for continuous work at sea. If one tube gives way, the whole contents of the boiler will find egress therefrom, and cannot be stopped. The boiler must then cease work, and be practically taken to pieces before the tube can be withdrawn and replaced. These boilers are suited for short periods of working only, and could not continue running at high power for days together at sea. There is a tendency at the present moment, both in this country, on the Continent, and in America, all more or less under the prevailing water-tube epidemic, to overrate these performances. The Table on page 328, compiled from actual performances of vessels at sea by Mr. McFarland of the United States Navy Department, the talented and courteous Secretary of the Marine Engineering and Naval Architecture Section of the Congress at Chicago, shows that, even these small water-tube boilers under high forced draught do not put the locomotive type, which is analogous to the cylindrical type in its action, much in the shade in the matter of weight per indicated horse-power, while in all, or mostly all, other points the locomotive boiler is superior.

With water-tube boilers, capability of working at sea depends on the tubes being of a diameter large enough to contain a sufficient quantity of water to prevent rapid destruction from the heat, and, of sufficient thickness to withstand rapid destruction from the water either by reason of its friction or impurity. Another essential condition in water-tube boilers for ocean steamers is that the boilers be subdivided to such an extent that, in the event of an injury to one section, it could be shut off without greatly reducing the total power. Further, provision should be made for replacing injured tubes without practically having to take the boiler to pieces.

These several conditions, which are absolutely necessary in water-tube boilers of whatever design for sea-going steamers, afford a basis of comparison with cylindrical boilers.

It has been my endeavour to avoid referring to any particular form of water-tube boiler of the present day as more or less suitable or unsuitable, as my contention is not with any particular design of this boiler, but with the type in whatever form. I may be allowed, however, in comparing these boilers of the class capable of working at sea with cylindrical boilers, to select the Belleville boiler for this purpose, as, in its latest form for sea-going steamers, it fulfils all the conditions I have specified as necessary for such steamers. The selection of the Belleville boiler for comparison must not, however, be taken as a reflection on the merits of any other form of this class of boiler.

That the conditions I have specified as necessary in water-tube boilers for sea-going steamers have been adopted by the Belleville Company shows that they have found them, from experience, to be necessary. And I would here remark that, in examining critically the design and arrangement of the Belleville boiler, it is impossible to withhold one's admiration of the careful study which has been given to every point of detail, and for the provision made for minimising, as far as possible, the special dangers pertaining to this type of boiler. The tubes in the latest Belleville boilers for ocean steamships are 5¼ in. external diameter, and from ⅜ in. to ¼ in. in thickness. The boilers are subdivided into numerous sections, each of which can be detached from those adjacent, and special provision is made for the replacement of injured parts. I understand that there is a special arrangement of this boiler for war-ships, with tubes 3 in. in diameter; but as it appears that in all countries alike, durability, safety, and permanent efficiency are sacrificed in such ships to erroneous ideas of lightness and high trial power, I shall not further refer to this form of the Belleville boiler. The makers, from their wide experience, have had good reasons for adopting the large size of tubes they now use in boilers for ocean steamships. They are the only water-tube boilers, I am aware of, that have made long ocean voyages.

Examining this boiler in its action and utilisation of the fire gases, it will be evident, for the reasons set forth in connection with Figs. A and B, that these large water tubes cannot be worked at a high rate of combustion without a great waste of fuel, arising from the size and disposition of their tubes, and their reduced efficiency per unit of heating surface. Even at what would be a low rate of evaporation per unit of heating surface in a cylindrical boiler, this water-tube boiler would allow a large portion of heat to escape up the chimney and by radiation from the casings, if not specially protected.

Coming to actual performances, I find that the steamers *Polynésien* and *Armand Béhic* are reported to have attained on trial 8,000 I.H.P., while their average working power at sea is 5,000 I.H.P. The respective grate and heating surfaces in these boilers are 580 and 23,800 sq. ft. We have thus the following results:—

Indicated H.P. per square foot of grate	13·62	Trial.
Heating surface per I.H.P.	2·975 sq. ft.	
Indicated H.P. per square foot of grate	8·62	Sea.
Heating surface per I.H.P.	4·76 sq. ft.	

I have no information as to fuel consumed, but, as the draught is directly upwards from the fire to the chimney, it must necessarily be high, and will require to be greatly checked to prevent waste of fuel.

The boilers, as fitted in these steamers, are twenty in number placed back to back, and side by side, and fired from the wings. There are twenty furnace doors in each stokehold, or forty in all, but each two doors give access to a common furnace grate, so that each boiler has 29 sq. ft. grate surface and 1,190 sq. ft. H.S.

The space occupied by the boilers lengthways in the ship is 70 ft., and 14 ft. athwartships, with a height of 13 ft. 4 in., not including uptakes. The weight, including water and all mountings and funnel, is 380 tons.

These particulars enable us to compare their power, weight, and the space they occupy in the ship, with (1) the size, power, and weight of cylindrical boilers capable of working continuously at the highest power attained by the Belleville boilers on trial—that is, 8,000 I.H.P.; (2) the size and weight of cylindrical boilers capable of working with ease and economy at the sea power of the Belleville boilers—that is, 5,000 I.H.P.—but which can be worked as high as 6,000 I.H.P. when required. The cylindrical boilers I assume as working with my system of forced draught, it being easier, more comfortable, more economical, and involving less wear and tear on the boilers than natural draught.

These cylindrical boilers capable of maintaining 8,000 I.H.P. are three in number, double-ended, 14 ft. 6 in. diameter by 19 ft. 6 in. in length, having six furnaces each 3 ft. 7½ in. inside, or mean diameter, or eighteen furnaces in all. Aggregate grate area, 360·5 sq. ft.; and heating surface, 14,000 sq. ft.; 8,000 I.H.P. from these boilers gives 22·22 I.H.P. per sq. ft. of fire-grate, and 1 I.H.P. from 1·75 sq. ft. of heating surface.

I only mention here the fact that, from furnaces of the same size there has been maintained over several years, in ordinary course of working at sea, equal rates of power per square foot of fire grate and per square foot of heating surface.

The space occupied by these boilers with their non-conducting covering is 45 ft. by 19 ft. 6 in., or 877·5 sq. ft. floor space, against 980 sq. ft. floor space required for the Belleville boiler, or 102·5 sq. ft. less space for the higher powered cylindrical boilers. The space occupied by the cylindrical boilers is actually still less in comparison when the stokeholds are taken into account. Those required for the Belleville boilers are two, 70 ft. in length, and, as space must be given across the stokeholds to allow the parts of the boilers to be removed and repaired, the stokeholds must be quite equal in width to those required for the cylindrical boilers. Taking the width in both cases at 8 ft., and their lengths equal to that occupied by the respective boilers, we have for the Belleville boilers $(14 + 8 + 8) \times 70 = 2{,}100$ sq. ft. of occupied boiler-room area, and for the cylindrical $(19{\cdot}5 + 8 + 8) \times 45 = 1{,}597{\cdot}5$ sq. ft., or only ·76 of the space required for the Belleville boilers. These cylindrical boilers are, however, far beyond the power of the water-tube boilers. Taking their normal power at sea, as stated by Mr. Milton in his paper read at Cardiff last year, at 5,000 I.H.P., then two cylindrical boilers, 15 ft. 6 in. diameter by 20 ft. in length, will be amply sufficient for this power, each boiler having six furnaces 3 ft. 9 in. inside, or mean diameter; grate surface, 250 sq. ft.: heating surface, 10,000 sq. ft. The indicated horse-power per square foot of grate in this case is only 20, and the heating surface as high as 2 sq. ft. per indicated horse-power, leaving a considerable reserve of power available when required. The space occupied by the boilers in this case is 32 ft. by 20 ft., or 640 sq. ft., as against 980 sq. ft., and, if the same width of stokeholds be taken for these boilers, we have $(20 + 8 + 8) \times 32 = 1{,}152$ sq. ft., against 2,100 sq. ft. for the Belleville boilers of same power. Instead of therefore occupying less space in the ship, the Belleville water-tube boilers, in comparison with the cylindrical of same power, occupy space as 1·82 is to 1.

In calculating the weight of the cylindrical boilers, I have taken their maximum pressure at 175 lbs., to ensure a constant working pressure at 170 lbs., Board of Trade rules being followed.

The weight of the three boilers to maintain at sea 8,000 I.H.P. including the fans and engines and all forced draught apparatus, water, funnel, and all mountings, as in the water-tube installation, is 361 tons, or 19 tons less than the lower powered Belleville boilers.

The total weight of the two cylindrical boilers with water, all mountings and forced draught fittings complete, capable of maintaining easily the same power at sea as the Belleville boilers, economically and safely, is only 272 tons, or 108 tons less weight than the

Belleville boilers. When examined, therefore, on the points in which this boiler is supposed to excel, space occupied, and weight, it comes very far behind the cylindrical boiler when worked in the most effective manner.

There is, however, in connection with this comparison of weights, the very important item of the weight of the water in the boilers of these two types. Though I have no means of calculating the weight of the water in the Belleville boilers, it is probable that it is not more than one-third that of the cylindrical boilers, and about $\frac{5}{12}$ths that of the two cylindrical boilers. But for the much smaller quantity of water carried in these tubulous boilers they would compare still worse in regard to weight than they do, for the necessary brickwork and the enclosing iron casings, if got up in a durable manner, and so as to effectively prevent escape of heat from the furnaces and casings in boilers for sea-going steamers, is often heavier than the shell plating of a cylindrical boiler of equal power. It is often overlooked that the specific weight of fire-brick is more than one-fourth that of iron, so that a 9-in. wall of fire-brick is as heavy as $1\frac{3}{8}$-in. steel plate per square foot of surface. It is not, however, sufficient to have only a brick wall to prevent escape of heat. This must again be covered by a considerable depth of non-conducting substance enclosed by an iron casing.

In these tubulous boilers the aggregate weight is thus so far saved by the reduced weight of water carried. This is claimed by its advocates as a great advantage, but to practical engineers concerned in working steamships across the ocean with ease, safety, and speed, this feature will be regarded as a serious defect. The cylindrical boiler owes no small part of its durability, as well as its safe, steady, and effective working, to the large proportion of water to heating surface it contains. The good time which Mr. Seaton thinks is at hand, to which I have already referred, "when boilers composed wholly, or almost wholly, of comparatively small tubes will take the place of the present boilers, with the result that steam may be raised in not much more than one-tenth of the time now occupied, the variation in pressure may be rapid without fear of consequences, forced draught may be employed to an extent not now deemed advisable, and the weight of the evaporative apparatus very considerably reduced" is not, I fear, likely to be realised.

The feature of raising steam in less than one-tenth of the time required for cylindrical boilers, which Mr. Seaton considers so valuable as to be one of the principal recommendations for the adoption of this class of water-tube boiler in the largest ocean steamships, experience shows, would be a sufficient reason for their exclusion from that class of steamships. Raising of steam in one-tenth of the time in such boilers means that for a given power there must not be more, generally considerably less, than one-tenth of the water that is in the cylindrical boiler of equal power. Experience with tubulous boilers, having such a limited quantity of water, running in quiet waters for a few hours only, shows that the most incessant watchfulness must be exercised in the admission of the feed water, which rises and falls so quickly that each boiler requires the constant attention of a very active man to keep the water to about its proper level, even with the greatest regularity of the feed-pumping engines. Any stoppage of these engines or irregularity occurring with the water supply would, with the large fires required in ocean steamers, produce in the space of a few minutes, before the fires could be drawn, disastrous consequences. Now consider the effect of, say, twenty of these quick steam-raising boilers being used in an ocean steamer of, say, 5,000 I.H.P., instead of the two double-ended cylindrical boilers I have specified as sufficient for this power. These twenty water-tube boilers would require for continuous work at sea twenty men constantly engaged in regulating the feed supply, and even then the feed water and steam pressure, and consequently the revolutions of the engines, would fluctuate greatly, a most objectionable result. The two cylindrical boilers, on the contrary, would only require the occasional attention of the engineer of the watch in the charge of the machinery generally. or his assistant. The large quantity of water acts as a storage of power, like the flywheel of an engine, and prevents rapid fluctuations, and gives ample time to call into action the reserve feed pumps, or take other necessary precautions, should any accident happen to the ordinary supply.

The practice of the makers of the Belleville boiler, who have undoubtedly given most careful attention to all the weak points which their experience has shown attend the use of these boilers, is quite against the conditions Mr. Seaton desiderates, as they appear to use not one-tenth, but about one-third, or so, of the water in their boilers for mercantile steamers that would be used in a cylindrical boiler of the same power. Yet they have evidently experienced difficulty in the regulation of the feed water. I am informed that they now use an automatic regulation of the feed water, which requires only one attendant in such steamers as the *Armand Béhic*, with her twenty separate boilers. If this is so, and this attendant is not assisted by others in the stokeholds, this automatic feed regulator is a marvel indeed, and the attendants must be specialists of a very high order. What may be possible, however, as regards regulation of feed in these French steamers, maintaining, as nearly as possible, uniform speed and power from day to day, with trained specialists in charge, would be impossible and dangerous with ordinary men picked up promiscuously, as is almost universally done among the numberless steamships of this country. If one-twentieth of the steamships now running with cylindrical boilers were fitted with Belleville boilers, the casualties from this one difficulty with the feed water would, I am convinced, be legion.

Taking the case of war-ships and cruisers when in actual warfare, with speeds varying rapidly from fullest possible to dead slow, with most variable stoppages and startings, automatic feed regulation would be utterly deceptive, and dangerous in the highest degree, without a man being in exclusive attendance on every two or three boilers at most, and, if a difficulty did once occur, it could not fail to multiply quickly. What this means on a large vessel with forty or fifty separate boilers on board can be easily imagined. A degree of safety attainable with these boilers in a merchant steamer with attention would be impossible of accomplishment in a war-ship at the very time when efficiency was most needed. I have, therefore, been unable to come to any conclusion as regards war-ships than that even these tubulous boilers with large tubes are quite unsafe as well as unsuitable. They may run trials with much success, and likewise may cruise at a steady speed for a lengthened period without mishap; but for meeting the conditions of actual warfare, they are, in my opinion, quite unsuited.

It has been also claimed that the quick steam-raising properties of the water-tube boilers would be a great advantage in a war-ship when cruising in time of war and suddenly called upon to steam at full power. The supposition, I believe, in this case is, that the war-ship would have only some of her boilers under steam when the emergency arose, the greater part having merely the fire-bars coaled ready for lighting. I can well understand how difficult it would be to maintain fires in water-tube boilers even in the lowest possible state of combustion, when only a fourth or fifth of full power supply was being required. The difficulty with water-tube boilers would then doubtless be so great that only those boilers required for the actual steam supply would be used, the others being merely prepared for lighting. This would, however, be a most dangerous condition for a war-ship to be in when, from sudden attack or other contingency, command of full power was of vital moment. What advantage would it be, although full steam could be got up in such water-tube boilers in an hour, or an hour and a half, after lighting fires? Ten or fifteen minutes, or less, would often be enough to decide loss or safety, victory or defeat, vital manœuvres carried out, or frustrated. The use of cylindrical boilers would obviate this danger, the larger quantity of water they contained enabling them to be kept safely, with steam on and fires banked, ready to be raked up when wanted, so that full steam could be attained in a very short time. I grant that in war-ships with closed stokeholds, in which a plenum more or less must be maintained by the fans, and where no provision exists for absolutely excluding the air from the furnaces, it is difficult to keep much fuel in the furnaces without generating more or less steam. This difficulty is, however, completely overcome by the use of the system of forced draught which I introduced to the notice of the members of this Institution at the meetings held here ten years ago. In this system the air of combustion is under complete regulation, and can be adjusted in a few seconds by a slight movement of a valve from the highest possible rate of combustion, to complete suspension of combustion, or any intermediate rate between these two extremes. For example, it is easy to maintain a rate of combustion only one half, or less, that of natural draught with a good supply of fuel on every furnace grate. A war-ship with this system of forced draught could cruise at the slowest speeds with all the furnaces in operation and containing an ordinary supply of fuel, but merely maintaining combustion and requiring a sprinkling of coal at long intervals to keep the fires from going down. The ship could also be kept lying under steam for half a day, or more, with the engines stopped, and the steam pressure maintained at whatever pressure desired, and with the fires in such a condition that by merely giving them a slight rake on starting the engines, and admitting the air pressure, the vessel could proceed at her highest speed within two or three minutes of the order being given. This is a very different kind of preparedness from that relied upon by being able to kindle fires and raise steam in water-tube boilers in an hour and a half.

Many more reasons can be given to show why cylindrical boilers are much preferable for war-ships, and all other sea-going steamers, as being much safer, more efficient, durable, and economical, and requiring greatly less care in working. As regards safety, I may point out that, in water-tube boilers, if one tube is injured, or any of the numberless joints gives way, the boiler is entirely disabled, as all the water and steam in the boiler will find egress from the rupture if the fires are not drawn, which often may be impossible to do. The bursting of a single tube is a much more serious thing in a water-tube boiler than in a cylindrical boiler, and has every chance of being exceedingly dangerous, for under the high pressures now used the outflow may be so rapid as to fill the stokehold with steam, and necessitate the immediate exit of the attendants, if that is possible.

Further, as is well known, every fitting, such as feed check valves, water gauges, with their cocks and pipes, stop valves, safety valves, blow-off cocks, and the numerous steam and water pipes connected therewith, creates an additional risk, and requires also additional care and attention. How much more danger, therefore, actually exists, and how much more care and attention should be necessary in the case of the *Polynésien*, and the other French steamers, in which there are twenty boilers, and twenty sets of each of the different parts I have enumerated, than exists or would be required for the two, or the three, cylindrical boilers equal in power to the twenty boilers, in which latter, two sets of each only are required in the one, and three sets in the other?

The fact of the present " boom " in water-tube boilers for naval purposes does not alter the facts regarding them which I have presented, and which will ever, I believe, militate against their adoption for mercantile steamers, though the admirable arrangement of detail, precautions in regard to feed-water and facilities for repairs, together with the limited size and power of each boiler, and the considerable thickness of tubes, which the makers of the Belleville boilers have adopted for ocean mercantile steamers, will doubtless secure for them a considerable lease of life, and minimise some of the disadvantages I have pointed out. Yet these disadvantages being inherent in this type of boiler, they can never successfully compete with the cylindrical boiler.

The difficulties which have arisen in cylindrical boilers in war-ships, and which are sought to be averted by resorting to water-tube boilers, are, as I have for the last ten years been endeavouring to show, with constantly increasing proof of the correctness of my statements, not due to any defect in the cylindrical form of boiler, but to the use of an injurious system of forced draught, its injuriousness being aggravated by the proportions of boilers considered most suitable for war-ships. Had the system of forced draught which I have been offering to the Admiralty for the last ten years been adopted, it would have entirely prevented all the difficulties and damages which have taken place, and I am certain also would have entirely prevented the desire which has arisen to resort to water-tube boilers as a remedy.

The country in which water-tube boilers are most largely used is the United States of

America, thousands being at work on land, and a number, not yet large, in the river and lake steamers, chiefly of the steam launch size. It can be easily understood that in that great country, where the transport of large heavy articles inland is difficult and most expensive, if not impossible, there is a most legitimate field for the use of water-tube and other sectional boilers, consequently they are very largely in use there, and have been for many years. Notwithstanding this, I have never found any American so venturesome as to put such a boiler on board a sea-going steamer. Shipbuilders and engineers on the Eastern seaboard, like Messrs. Cramp & Sons, or the Union Iron Works of San Francisco on the Western

COMPARISON OF VARIOUS TUBULOUS AND SHELL BOILERS.

Kind of boiler and maker	Tubulous. Thornycroft.			Shell. Cylindrical Double-ended.	Shell. Locomotive.	
Where used	U.S.S. *Cushing.*			U.S.S. *Newark.*	Italian Torpedo Cruisers *Tripoli* and *Folgore.*	
Outside dimensions	10 ft. × 7 ft. × 8 ft.			13 ft. 6 in. dia. 19 ft. 5 in. long	16 ft. 8 in. × 6 ft. 4 in. × 7 ft. 6 in.	
Grate surface, square feet	38			135	28	
Heating surface, square feet	2,451			4,185	1,116	
Ratio, heating surface divided by grate surface..	64·5			30·99	39·8	
Weight of boiler, empty, tons	9			57·8	—	
Weight of boiler and water, tons	11			80·12	15·6	
Duration of trial, hours	2·5	11·5	1	8	—	—
Air pressure in inches of water	0*	3	4	2·25	3·13	4·95
Coal per hour per square foot grate surface, lbs.	7·58	40·23	66·32	40	98·3	120·8
Evaporation from and at 212° Fah.	11·9	8 84	6·51	—	6·97	6·62
Actual evaporation from and at 212° Fah. per square foot heating surface	1·4	5·51	6·7	Water not measured.	17·2	20·09
Horse-power per 100 square feet of heating surface on basis of 20 lbs. steam per hour from and at 212° Fah.	7	27·55	33·5	55·9	86†	100·45†
Horse-power per ton of boiler and water on same basis	15·6	61·38	74·65	29·2	61·52†	71·85†
Horse-power calculated from above particulars	171·6	675·18	788·15	2,339·5	959·7†	1,120·86†

* Blowers discharging into open fire room.

† By reference to Vol. XXIX. of the Transactions of the Institution, pp. 30 and 36, it will be seen that Mr. F. Marshall stated that the *Tripoli* had six locomotive boilers, of a united horse-power of 4,200, or 700 horse-power per boiler, instead of the figures given by Mr. Howden in the above table, on the authority of Mr. McFarland, viz., 959·7 and 1,120·86 horse-power per boiler. Mr. Marshall, however, stated that, owing to the vibration of the vessel, the maximum horse-power which it was ever deemed prudent to exert was 3,600, or 600 horse-power per boiler.—ED.

seaboard, who build and engine sea-going steamers, have never used water-tube boilers for such steamers. If the great advantages of this type over the cylindrical boiler, which its advocates in this country affirm belong to it, were believed in by these practical Americans, you may be assured they would have been filling their ships with them by this time.

No people are less bound by custom or tradition than Americans, or readier to adopt anything they believe to be superior to what they have been previously using. As they have had for many years plenty of examples of water-tube boilers of most ingenious and workable

COMPARATIVE PARTICULARS OF MARINE BOILERS.

Number of column	1.	2.	3.	4.	5.
Name of steamer	*X.*	*Nero*	*Polynesien*	*I.*	*II.*
Kind of boiler	Cylindrical	Babcock & Wilcox	Belleville	Cylindrical	Cylindrical
Number of boilers	4 D.E.	1	20	3 D.E.	2 D.E.
Diameter and length of boilers ..	13 ft. 1½ in. × 18 ft. 7½ in.	—	7 ft. × 7 ft. square	14 ft. 6 in. × 19 ft. 6 in.	15 ft. 6 in. × 20 ft.
Number of furnaces	24	—	20*	18	12
Heating surface, square feet.. ..	16,000	2,272	23,800	1,400	10,000
Grate surface, square feet	560	44	580	360	250
Weight of boilers with water, uptakes, funnel, and mountings, including all forced-draught apparatus ..	364 tons	41·65 tons†	380 tons	361 tons	272 tons
Space occupied on floors by boilers and stokeholds	1,904 sq. ft.	—	2,100 sq. ft.	1,597 sq. ft.	1,152 sq. ft.
Space occupied on floors by boilers only	—	—	980 sq. ft.	877·5 sq. ft.	640 sq. ft.
Indicated horse-power on trial ..	9,400	530	8,000	8,500	6,000
Economical indicated horse-power at sea	—	450	5,000	7,500	5,000
Ratio of grate surface to heating surface	$\frac{1}{28{\cdot}5}$	$\frac{1}{51{\cdot}6}$	$\frac{1}{41}$	$\frac{1}{38{\cdot}8}$	$\frac{1}{40}$
Heating surface per indicated horse-power on trial	1·7	4·28	2·97	1·64	1·66
Heating surface per indicated horse-power at sea	—	5·04	4·76	1·86	2
Indicated horse-power on trial per ton of boilers, water, &c.	25·82	12·72	21·05	23·54	22·05
Indicated horse-power at sea per ton of boilers, water, &c.	—	10·8	13·15	20·77	18·38
Indicated horse-power on trial per square foot grate surface	16·78	12·04	13·79	23·61	24
Indicated horse-power at sea per square foot grate surface	—	10·22	8·62	20·83	20

* Furnaces in these boilers are of extra large size, and require two furnace doors for each.

† This includes the weight of a fresh-water tank with its water of about 9 tons.

designs, the absence of these boilers in any American mercantile sea-going steamer is significant.

I am aware that one of the steamers of the United States Navy, the *Monterey*, has fully two-thirds of her steam power in four water-tube boilers; but I am not aware that they have as yet been put to any trial extending over many hours of work at one time. The Engineering Bureau of the Naval Department have wisely fitted in that steamer, in addition to the coil boiler, two "Scotch" boilers, as the cylindrical form is universally called in America. These two boilers have as yet, I believe, done all the cruising. Our American friends mix a good deal of common sense with their boldness. The water-tube boilers used in the *Monterey* are Ward's coil boilers, a very ingenious design, especially the feature where the steam generated in each semi-circle of the coil is relieved by vertical tubes of larger section, through which it obtains access to the steam receivers above. The boiler is, undoubtedly, among water-tube designs a first-class generator of steam, but unquestionably its proper field of action is on shore, and not on board a sea-going steamship.

I have thus endeavoured to set forth the comparative merits of cylindrical and water-tube boilers for ocean steamships; and, I believe, that all who will examine this subject without prejudice must come to the conclusion that the cylindrical is by far the most suitable.

Name of steamer … … … … … … … …	*Speedy.**	*Satellit.*
„ builders … … … … … … … …	Thornycroft	Schichau.
Number of boilers … … … … … … … …	8	4
Kind of boiler … … … … … … … …	Water-tube	Locomotive.
Average performance … … … … … … …	4,500 I.H.P.	4,792 I.H.P.
Maximum performance … … … … … … …	4,674 „	4,901 „
Total heating surface … … … … … … …	15,145 sq. ft.	8,417 sq. ft.
„ grate surface … … … … … … … …	216·6 „	185 „
Weight of boilers, with water, uptake, funnel, &c. … …	154 tons	96·1 tons.
„ boiler and water per indicated horse-power … …	75·39 lb.	44·09 lb.
Indicated horse-power per square foot of heating surface …	·29	·56
Total length of engine and boiler-room … … … … …	101 ft. 6 in.	83 ft. 8 in.

* The following letter has been received from Mr. J. I. Thornycroft, in reference to the particulars given in the above table:—

Church Wharf, Chiswick, London, W.,
June 14, 1894.

George Holmes, Esq.,
Institution of Naval Architects, 5, *Adelphi-terrace, London, W.C.*

Dear Mr. Holmes,

In reply to your letter of yesterday, I have pleasure in sending you the following particulars:—

Discussion on Mr. Howden's Paper.

A table placed on the wall by Mr. Howden was not printed in the first copy of his paper, so we had no opportunity, at the time of the discussion, of checking the figures referring to the *Speedy*.

On examination, these proved to be so inaccurate that we should be glad if you will insert a corrected table in the minutes as follows :—

Name of ship	H.M.S. *Speedy*
Number of boilers	Eight
Type ,, ...	Thornycroft water-tube
Guaranteed I.H.P. (called by Mr. Howden the "average" I.H.P.)	4,500
Average I.H.P. on official trial	4,703
Total heating surface (sq. ft.)...	14,720
,, grate area	204
Tons, of boiler with water, uptakes, funnels, and mountings	90·4
Lbs., of boilers and water per average I.H.P.	43
Average I.H.P. per square foot of heating surface	·319
Total length of boiler rooms	68 ft. 3 in.

I am, dear Mr. Holmes,

Yours sincerely,

John I. Thornycroft.

DISCUSSION ON THE TWO PRECEDING PAPERS.

Mr. A. E. **Seaton** (Member of Council): Sir Nathaniel Barnaby, Ladies, and Gentlemen, as my name occurs pretty prominently in Mr. Howden's paper, and as it is getting late, I venture to come forward to open this discussion, although in doing so I feel that I am presuming somewhat, inasmuch as, although I ventured to say what I did last year about water-tube boilers, it was rather in the guise of a prophet that I spoke than in that of an engineer. I cannot, however, allow one thing to pass unchallenged. Mr. Howden is, I believe, a Scotchman, although his name is not Scotch; I have a Scotch name, but I happen to be English. I likewise happen to be a Cornishman. I believe that a cylindrical boiler was first made in my native county, and it happens, in its primitive form, to bear the name of the Cornish boiler. I will remind Mr. Howden of what he has probably forgotten, that Messrs. Penn, in 1854, made a cylindrical boiler for H.M.S. *Malacca* for a pressure of 60 lbs., which is, to all intents and purposes, a similar boiler to those made now for 150 to 200 lbs.; the honour therefore, if it be one, of putting a cylindrical boiler into a ship belongs to London and not to Scotland. Therefore, when Mr. Howden spoke of the "Scotch usurper," I agreed with him, but in rather a different sense from what he meant. Mr. Howden appears here to-night as the champion of the cylindrical boiler, or what I may now call the old form of boiler, if he will allow me. He speaks of it in most affectionate terms. I am sorry to say I cannot match him in eloquence, or I would endeavour to do so, to convince him that he is not giving quite fair play to the other side. He speaks as if our old friend the cylindrical boiler had never given us any trouble whatever. He tells you that. He goes, bit by bit, through the construction of the boiler to show you that there is not a single thing wrong; in fact, it is very like a doctor examining an ancient gentleman of good constitution, and assuring him that he has not the slightest trace of organic disease, and might live to be 150. So Mr. Howden is telling us of the cylindrical boiler, that it may live for many years yet. I do not doubt that it will, for certain purposes. I do not doubt but what prejudice, irrespective of the merits of the boiler, will keep it alive for a very long time; but, gentlemen, I do not wish to introduce any element of prejudice into this discussion, although I would like to call Mr. Howden's attention to a few opinions as well as facts. Mr. Howden is a very busy man. He is here, there, and everywhere, and he is good enough to give us a very long paper, and a very valuable paper, as no doubt it will be found, when read carefully on publication. I am sorry he could not condense it into the regulation twenty minutes, so that we might have had more discussion; but such as it is we must deal with it. He spoke of the furnaces of our present cylindrical friend as if he were assured of perfect safety. I am sorry to say that is not the experience of everybody. I am afraid he does not always read the Law Reports, or he would have seen recently the somewhat interesting case of Palmer's Shipbuilding Company *versus* the Leeds Forge. He might also, from time to time, have heard of furnaces being repaired, and even replaced with others. But he has committed one offence to this Institution; he has not taken the trouble to read Mr. Milton's paper of last year, where he told us of the deformation of the shells of boilers. I think, had he done so, he would not have passed quite so lightly as he did over the question of the perfect safety of the shells of cylindrical boilers. He has spoken in a very jaunty way about the ease with which you can remove a tube from a cylindrical boiler, or rather stopper it. If Mr. Howden had been at sea very much with leaky boilers, I do not think he would have spoken quite so lightly on that point, because, although it can be done, and plugs do remain in for a long time, it is by no means an amusement, plugging tubes on a stormy night, particularly if you have only one boiler to supply the steam to the engines. While speaking of tubes, there is one thing I would like to remind him of, and that is, he, in discussing the tubulous boiler—the water-tube boiler rather—seems to take it for granted that, we admit it as an axiom in practical engineering that the receptive surface must be smaller than the distributing surface. If this is so, Messrs. John Brown & Co. had better cease advertising the "Serve" tube, because I take it that, the particular object of that tube is to increase the receptive surface, while the distributing surface remains constant. I will not, however, speak too much of patented articles. I will go to the paper we had to-day from Professor Lewes and the discussion thereon, where we were told distinctly that everybody had been aiming, and while aiming at success, had achieved it in some cases, by increasing the receptive surface in boilers, the distributive surface not being very much increased. Mr. Howden seems to think, too, in comparing the two systems, that in case of accident—the bursting of a tube or what not—the cylindrical boiler is the safer. He speaks about the huge quantities of water that would come from a split tube in a water-tube boiler. Now I was rather astonished at that, because in one place he claims for the cylindrical boiler that it owes its superiority to its containing larger quantities of water than the tube boiler. He compares the quantity of water to the fly-wheel of an engine, the larger it is the steadier will it work, and says the water-tube boiler will not work steadily because it contains such a small quantity of water. I thought, that being so, when we have to pour boiling water into the stokehold the less of it the better. There is another argument in favour of our friend the water-tube boiler, that is, that even in small ships it is almost invariably divided into a series of boilers, and what is familiarly known as putting your eggs all into one basket is avoided. If we take Mr. Howden's paper, he has distinctly laid down that it is a great advantage to have one big boiler in a ship, and he has told us what one big boiler can do. But he has not been quite frank, and told us what one big boiler might do if a tube gave way at sea, or on a very stormy night what might happen to the big boiler and the big ship. I am afraid, like the grandfather's clock, it might stop, never to go again. At the same time (and I hope Mr. Howden will take my remarks as they are intended —perfectly good-humouredly) I must say that I think this paper, and the discussion which will, I hope, ensue upon it, is very necessary in these times. I know of many shipowners waiting to see what is being done by the Admiralty, and waiting to see what is being done by one or two brother shipowners, before deciding what to do with some of their old ships, and before ordering new ones. I think, therefore, the time has arrived when an Institution of this kind should do its duty by the shipowning public, and without prejudice of any kind discuss the relative merits of the two systems. So far as Mr. Howden has gone, I think he has attempted to be fair to both; but from, I think, a want of knowledge of what has been done more recently with the water-tube boiler, he has not been as fair as I think he might have been. Mr. Milton spoke of the Babcock and Wilcox boiler. I am sorry to say Mr. Spear, the Superintendent of the Wilson Line, is not here to-night. If he had been, he would have told you how that boiler had worked for nine months, that he had had no serious trouble with it from the beginning—I mean since the trial, for on the trial one tube split; that was replaced with another tube, and the ship has been working steadily for nine months with very good results. I might mention—it is interesting to those gentlemen who have been engaged in water-tube boilers at very high speeds—that it has been found necessary in the case of the *Nero* to reduce the fire grate very much indeed. Originally it had the large proportions usually found in the Thornycroft and other similar boilers, but it has been reduced very considerably, because it was found that the ship was burning, if anything, rather more coal with the water-tube boiler than with the cylindrical boiler; but since the reduction in grate the economy has been marked, and it is now very satisfactory indeed. The reduction in grate has necessitated some little alterations on the baffle plates, that were carried out a few weeks ago, but with what result I do not know. When they were making these alterations some of the tubes were drawn. I saw one a few days ago, and I had it cut through; I found that although it was coated on the outside with bituminous deposit from the bituminous coals which are used in that district—in fact, it was glazed from end to end as if it had been originally painted with coal tar—the inside had a very thin deposit of mud, and on the whole it was what you would call a very clean tube. That brings me to the general design of water-tube boilers. I must confess I have a very strong preference for a straight tube, in spite of my friend Mr. Thornycroft's preference for a bent one. It may be a matter of taste, and you might say each one to his taste, but I cannot say I should like to go to sea or round the world with a boiler of that kind—not that I doubt its working well while it was clean, but I should like to know from time to time that it was clean; and therefore I confess my strong preference for a horse whose faults I know rather than one whose faults are hidden, and to having a desire for a boiler whose tubes I can see from end to end, each one of which may be taken out and replaced without very much trouble and in little time. Unfortunately, the condition of a boiler with bent tubes must always remain as somewhat doubtful in the minds of the engineers in charge of it; besides which, should one of those centre tubes require replacing, the only way to do it is by destroying a number of tubes to get at it. I also do not believe in what I call the priming boiler. There again I am at issue with Mr. Thornycroft. I do not ask you to take my opinion, although I express it, because Mr. Thornycroft is a gentleman of much larger experience on these matters than I am; but arguing on first principles—and I must say, perhaps because in my younger days I had such a horror of priming—it does not appear to my mind to be engineering, to be boiling the water and steam up together and discharging them into a receptacle at the top and trusting they will separate, one to go to the engines and the other to go down somewhere else. There is no doubt that to Mr. Yarrow and Mr. Thornycroft very great praise is due for persevering in the way they have done. That brings me to another point. Mr. Howden has spoken of this water-tube boiler as if it were something continuous from the days when Captain Trevethick put down copper tubes into granite tube plates to get high-pressure steam; but you must remember that we have now an entirely different problem from anything we had before. These water-tube boilers have been designed and intended to give the maximum amount of steam with the minimum amount of material, both of water and brickwork. So that we are not very likely, either Mr. Thornycroft, Mr. Yarrow, Mr. Howden, or Mr. Laird, or anybody else, to do exactly what you would like to do—which I take to be the point—inasmuch as it means a large addition of weight to either the boiler itself, or to the water it contains, or to the brickwork surrounding it. So that the problems which have to be worked out by these gentlemen are of a very much more intricate and difficult nature than Mr. Howden is disposed to acknowledge. There is very little absolutely new in these boilers. I know that patents have been taken out for that form of boiler long before I was born, and also for some like Mr. Yarrow's; but that does not alter the fact that these are to all intents and purposes new ideas—the perfecting of old ideas perhaps; but in the way they have been manipulated they are quite equivalent to new ideas. We are enabled to do to-day these wonderful things which we have heard of—for I take Mr. Yarrow and Mr. Thornycroft as brother engineers. These are wonderful speeds with such light boilers. The reason why it could not be done in the old days was simply because we could not get supplies of fresh water and good tubes. To-day we can get magnificent steel tubes of almost any length or size, and of almost any degree of thinness. The steel tube-making companies are offering us at this time solid drawn tubes at the same price as welded tubes. Perhaps Mr. Milton is not aware of that, but that is so. By these means we hope to eradicate all the faults that Mr. Howden has pointed to in the old forms of water-tube boilers, and make the present ones a brilliant success, and really safer in every way than the best forms of cylindrical boilers can be.

Mr. A. F. Yarrow (Member of Council): It will be admitted by all who have heard the interesting papers by Mr. Thornycroft, Mr. Milton, and Mr. Howden, that this Society is under a great obligation to these gentlemen for the very valuable contributions they have made to the Transactions of our Institution. It was about seven years ago that we first commenced adopting straight tubes in our water-tube boilers, having been previously led away by what we believe to be the popular fallacy that curved tubes are necessary in order to allow for contraction and expansion, which, no doubt, is necessary in some designs, but it does not follow that it is essential in all. Although we have built a large number of water-tube boilers during the last seven years with straight tubes, it may be of interest to the meeting to know that we have never had a single leakage between the tube and tube-plate; proving, we believe, that there is nothing objectionable in the straight tube system; but clearly it offers many advantages both in construction and in service. Experience has shown that steel tubes, whether galvanised or not, rapidly deteriorate, and if the tubes be galvanised on the inside it causes a rough surface, retarding the circulation of the water, and also there is the possibility of portions of spelter lodging in the tubes and partially blocking up the passage, or causing such an impediment as will allow sediment to collect. So far as our experience goes, it leads us to believe that copper tubes are more durable than steel, but in the use of copper it is essential that it be very pure, and that the tube, under all circumstances, be below the level of the water and always filled, otherwise the copper may become overheated. Mr. Thornycroft has given us valuable information concerning the circulation in tubes which are drowned, and in those which lead at their upper extremity to the steam space. In spite of the possibly reduced circulation in drowned tubes, referred to by Mr. Thornycroft, the circulation is still ample for the purpose, and any more rapid circulation is unnecessary. The result of our experiments with water-tube boilers (and I may here state that we commenced them as far back as 1877, and put a water-tube boiler in a torpedo-boat in the year 1879) indicates that very small changes in design materially affect the action of a boiler; small alterations in some cases make the difference between success and failure. If portions of the boiler be rigidly secured by stays which are not subject to the same temperature as the tubes, in such cases serious strains may be set up, involving frequent bending of the tubes to meet continual variations of temperature; and if in such cases the tubes be only slightly bent it may lead to trouble, as small alterations in length involve considerable changes in the curves necessary to conform to them; consequently in cases where portions of the boiler are rigidly secured to one another it is necessary that the bends in the tubes should be considerable, so that they can easily, and without excessive strain, suit differences of temperature. Our practice is to aim at allowing the tubes freedom to expand and contract as they like, and as the contraction and expansion of a group of tubes has been found to be nearly uniform under our conditions of working, any small difference of length seems to be met by the elasticity of the material. We are satisfied on this point, having made very careful experiments to test it, and I think it will be admitted that it is most desirable, in fact, almost essential, that access be freely obtained to the interior of the tubes for the purpose of examination and for cleaning. For these reasons we are strongly in favour of straight tubes, which at the same time reduce the cost of construction, and are a convenience in actual working on account of the facility of supplying spare tubes, avoiding the large variety of different forms of spare tubes necessary with boilers where the tubes are curved to different forms. It is often asked concerning our boilers, such as we have put on board H.M.S. *Hornet*, and other previous vessels, how we manage to replace the tubes. The form of boilers adopted in the *Hornet*, and to which I am now referring, is not of the type described in Mr. Milton's present paper, and, as throwing some light on the subject, it may interest the meeting to know that, on one of the trials with this vessel (in the boilers of which there are over eight thousand tubes) one of the tubes gave way on account of faulty manufacture, and the time occupied in taking out and replacing this tube ready for expanding was only forty minutes. We were also led away in our first boilers by the idea that down-pipes were necessary to ensure circulation, and in all the boilers made by us up to three years ago we provided four down-pipes, two at each end; these down-pipes being suitably curved to allow for variations in lengths between the upper and lower portions of the boiler. For purposes of experiment we removed two of the down-pipes, and found the action of the boiler unaffected. We then ultimately dispensed with the other two with the same result; thereby saving both weight and length, and obtaining greater simplicity. Those who have had water-tube boilers of a satisfactory type under their management, as well as those of the locomotive type, will be ready to admit that it requires less skill to stoke a water-tube than a locomotive boiler; as with the latter it is necessary to keep the grate uniformly covered with fuel for fear of admitting cold air, while with the former such care is unnecessary. In order to test the effect of sudden changes of temperature on one of our water-tube boilers, when experimenting with it in our yard, we forced it to an abnormal extent, then suddenly pulled out the fire, and stripped the boiler of its casings, so as to cool it as quickly as possible. We then replaced the casings, lit up rapidly, raising steam to 180 lbs. The result of this somewhat severe treatment showed that there was not the slightest alteration in form or injury to the boiler. The results obtained with one of the boilers of H.M.S. *Hornet* may perhaps interest the meeting. The boiler weighed, complete with fittings, smoke-box, fire-doors, fire-bricks, funnel, casings, and all boiler mountings, also including water up to working level, 5 tons 7 cwt. On carefully conducted experiments in our yard it was found on a three hours' trial that 12,500 lbs. of water were evaporated from 60° Fahr. to 180 lbs. pressure per hour. In order to compare the relative efficiency of water-tube and locomotive boilers we have the following facts:—In H.M. Destroyer *Havock* we adopted two locomotive boilers, and indicated on trial about 3,500 H.P. with an air pressure of 3 in. In the *Hornet*, which is a sister ship, provided with similar engines, and fitted with eight water-tube boilers as previously described, we obtained, with a very low air pressure, averaging $1\frac{1}{4}$ in., 4,300 H.P. The eight boilers in the *Hornet* weighed 11 tons less than the locomotive boilers in the *Havock*. We had every reason to fear, from what we were told, that trouble would be experienced in working this group of small, rapidly evaporating boilers in the *Hornet;* but, as a matter of fact, we have experienced no difficulty whatever; the feed being arranged in, as it were, two stages. The feed pumps on the engines take their suction from the hot well, and deliver into a reservoir at 50 lbs. pressure, and from this the donkeys take their suction, each boiler being provided with an independent pump. By these means a very ample supply of water is always ensured on the suction side of the donkeys, and the pipes leading to them can be of moderate dimensions in consequence of the 50 lbs. pressure delivering the water readily to the suction side of the pumps. To ensure the reservoir always being well filled there is a small amount of auxiliary feed always passing into it; the surplus, beyond what is necessary for the supply of the boilers, being returned to the tank through a relief valve loaded to 50 lbs. As is well known, we have been strong advocates of the locomotive type of boiler, especially as the form we have adopted was found to work satisfactorily and to be durable; but the recent success with water-tube boilers obliges us to advance with the times and to modify our opinion, which is more particularly necessary, having in view the possible further rise of working pressures in the immediate future. The recent action of the Admiralty in, as it were, forcing on numerous contractors the adoption of water-tube boilers has frequently of late been unfavourably criticised; but I believe that time will prove that, the greatest possible credit is due to the authorities for having thus taken the initiative in the introduction, in this country, of a form of boiler which there is little doubt is destined to replace old types. I am fully convinced that, in spite of naturally to be expected failures at such a sudden change of practice, naval architects and engineers will in a few years recognise, in the action of the British Admiralty, a wise and important step in the advance of marine engineering, and I believe before very long it will be generally admitted, not only in this country, but throughout the world, that the greatest credit is due to the authorities at Whitehall for having had the boldness to act as they have done.

Mr. J. E. THORNYCROFT (Visitor): Would you allow me, sir, to point this out? Mr. Yarrow said he had tried his boiler for the effect of leakage by sudden cooling. He took the casing off, drew the fire, let it cool down somewhat, and then lighted it up again with no detriment to the boiler. In two experimental boilers which Mr. Thornycroft tried while at work, we blew all the water out, partially drew the fire, and then pumped up with cold water, and went on working, and at the same time there was no evidence of any leakage caused by this drastic treatment, and the boilers have been at work two months since this experiment. I doubt whether this could be done with straight tubes without causing serious injury.

Mr. J. H. ROSENTHAL (Visitor): Being interested in the Babcock and Wilcox boiler, mentioned in the papers this evening, perhaps you will allow me to give you a few notes on those boilers that have been constructed by us for marine purposes. I do not propose to discuss in detail the papers of Messrs. Milton and Howden, which have been read to-night, but I would draw attention to a discrepancy in Mr. Howden's tables, in which he credits the *Nero* boiler with a weight of 40 tons, while, as a matter of fact, it is below 30 tons. We are advocates of a water-tube boiler, in which the tubes are not only all straight, but in which every tube is accessible without taking down any casing, or without breaking any joints beyond bolts and nuts, or simple hand-hole fittings. We have not hitherto laid ourselves out to construct the boilers of such light weights as Mr. Yarrow and Mr. Thornycroft, although we have prepared designs of boilers of about 4,000 I.H.P. to work with forced draught, where the weight has not exceeded 13 tons per 1,000 I.H.P., and from which we conclude that, when we are required, we shall have no difficulty in satisfying modern requirements as to lightness. Our experience has been more in the direction of the requirements of the merchant service or steam yachts. What we have done hitherto has been to a certain extent experimental; but our experiments have been fairly successful. One of the first boilers that we made for marine purposes, was for the steam yacht *Reverie*, running in America. This boiler was installed three years ago, and I have some notes here of the results of her trials, which may interest you. The length of the boiler was 9 ft.; width, 6 ft.; height to top of cross-drum, 9 ft. The diameter of the stack was 2 ft. 3 in., and the height of stack above grate was 26 ft. 4 in. The type of engine was quadruple expansion. High-pressure cylinder diameter, 8 in.; first intermediate, 11 in.; second intermediate, 16½ in.; low pressure, 26 in.; stroke of piston, 12 in. Heating surface in boiler proper, 672 sq. ft.; heating surface in feed-water heater, 128 sq. ft. Total heating surface of boiler, 800 sq. ft.; total grate surface, 28 sq. ft.; ratio of heating to grate surface, 28·56. Kind of coal used, Lehigh Valley anthracite. Pounds of coal burned, 3,125; pounds of coal burned per square foot of grate per hour, 13·9. Duration of run, 8 hrs. Force of draught in inches of water, ·45 in. Temperature of escaping flue gases, 560° Fahr. Average gauge pressure of steam, 205·3. Average number of revolutions of engines per minute, 205. Indicated horse-power of main engines, 190·5. Pounds of water evaporated, 28,956. Pounds of water evaporated per hour, 3,619·5. Pounds of water evaporated per pound of coal, 9·26. Steam consumption of plant, including steam for auxiliaries and other purposes about the yacht, per indicated horse-power of the main engine per hour (in pounds), 19. Steam consumption of main engine per indicated horse-power per hour, 14·5 pounds. We have boilers in other vessels in the States, and on this side we have one in a yacht belonging to Sir Gilbert Clayton East, Bart., the *Eleanor*: it is a boiler containing 567 sq. ft. heating surface, and 19 sq. ft. grate surface. I stated that we believed in constructing a boiler with straight tubes, in which every tube was readily accessible by removing a hand-hole fitting. The boilers that we have made—those I have referred to—have nearly all different kinds of fittings. In the *Nero* the tubes are grouped, and one fitting covers four tubes. The fitting is made with an internal clamp, and an external cap, the surfaces being milled and made tight without any packing of any kind. If a bolt were to break no accident could result, because the pressure of the steam would hold the internal cap tight, just the same as an ordinary manhole would. In the steam yacht *Eleanor* there are fittings on the same principle, but instead of one large one for four tubes, each tube has its own fitting. There also, of course, the surfaces are milled, but the fittings are very small, and the inside fitting covers the hand-hole sufficiently to prevent any serious escape of steam or water if the bolt should break. In another boiler we have built for the steam yacht *Trophy*, each tube is covered by a screwed plug, and we have come to think lately that this is one of the simplest methods of giving access to the end of the tube. These plugs have the advantage of being considerably lighter than the hand-hole fittings before mentioned.

Mr. A. Morcom (Member): Mr. Chairman and Gentlemen, I have no special interest at present in the manufacture of water-tube boilers; but Mr. Milton has referred to a boiler in the design of which I took part. My partner and myself, in company with Mr. White, took out a patent for it five years ago, and we manufactured it at our works. The boiler was made with copper tubes, rolled up in rather short coils, and, owing to the short length allowed to the engine department, we were obliged to maltreat the tubes rather more than by simply coiling them, and this emphasised two or three points in connection with the manufacture that are sure to turn up in any boiler with tubes, bent or worked in any form. The big distinction between the boiler of the water-tube type and the ordinary boiler is that, in the case of the water-tube, the tubes are under tension, and if there is any split of the tube, as Mr. Howden suggests, I think there is certainly a far greater danger of the split being a big one than in the case of the old boiler, where the tendency of the pressure is to compress a crack and close it. In the manufacture of our boiler we selected from the best Birmingham firms solid-drawn copper tubes, taking the greatest trouble to determine the quality of the metal before we began, and to examine the tubes inside and out, to see that they were perfect. As in all solid-drawn tubes the lines, on the interior especially, were continually deceptive; and, although we threw back a large number of them before coiling, we had to throw away after water-pressure test about 50 per cent. of the coils on account of defects developed in coiling, and yet, when the boiler was put up, we had a further large number to pull out before we got our tubes as we wished them. I am merely referring to this now because of the difficulty with regard to these coiled tubes, and the obvious remedy. As Mr. Yarrow has observed, there are 8,000 tubes in his boiler, and necessarily there are a very large number of tubes in any type of water-tube boiler; and I think it is of serious importance that the design of the boiler should arrange for tubes the interior of which can be thoroughly examined, and especially if they are to be solid-drawn copper tubes. Anybody who has been through a similar experience will know the difficulties there are in determining defects in solid-drawn tubes. A defect may easily be latent in a bent or coiled tube, and only show itself when the boiler is in action, and then the results may be disastrous. I must, however, say a word in favour of this boiler. We fitted it to one of the 200 horse-power boats in the Navy, and I lost sight of it. I was up before the Boiler Committee, taking the part of the locomotive boiler with certain circulating arrangements as against the water-tube, and the Chief Engineer of the Dockyard at Portsmouth informed me that the boiler in question had been acting in a very satisfactory manner. The tubes are copper, and it is what has been referred to as a priming boiler. It was a very priming boiler to start with in another sense, but by the addition of a steam drum that was got over. I do not know how they have been working in the *Vernon*, but we were running the boiler with a water-level several inches below the junction of the tubes with the steam drum, and, although the tubes are copper, and the boiler has now been working for four years, there has been no trouble whatever on this account. Mr. White has improved it by putting the extra straight tubes so as to divide the flue, and getting the current of gases somewhat better than we had originally; but the defect still remains, that the coiled tubes cannot be examined for very probable defects. Mr. Howden has referred to the weight of casing necessary in the water-tube boiler. I should have thought he would have been rather pleased with the water-tube boiler in this respect, as it lends itself somewhat to a system his name is well known in connection with, *i.e.*, the heating of air before it gets into the fire. There was a patent taken out for our boiler (but whether valid or not I do not know) in connection with the casing. We put one thin casing next to the tubes, and another about $\frac{3}{8}$ths of an inch from it, and through the narrow space between, we can depend upon the cold air let in from the stockhold through none-return doors passing all over the inner casing into the fire, so heating the air and keeping the casing cool. I do not know what repairs the Dockyard has made in it since, but I have heard of none, and the boiler has lasted four years. The casing plates were something like 14 gauge, without any asbestos or other lining outside, and, as far as I know, the outside plate was cool enough to meet the Admiralty requirements.

Mr. JOHN SAMPSON (Member): There is one remark made in this paper which in fairness to our "French allies" I cannot allow to pass. Mr. Howden, referring to the feeding of the boilers, states:—"I am informed that they now use an automatic regulation of the feed water which requires only one attendant in such steamers as the *Armand Béhic* with her twenty separate boilers. If this is so, and this attendant is not assisted by others in the stokeholds, this automatic feed regulator is a marvel indeed, and the attendants must be specialists of a very high order." They are specialists —Arabs—and very fine fellows, too! Mr. Howden goes on to say, "What may be possible, however, as regards regulation of feed in these French steamers, maintaining as nearly as possible a uniform speed and power from day to day with trained specialists in charge, would be impossible and dangerous with ordinary men picked up promiscuously, as is almost invariably done among the numberless steamships at present. If one-twentieth of the steamships now running with cylindrical boilers were fitted with Belleville boilers, the casualties from this one difficulty of the feed-water would, I am convinced, be legion." Now, gentlemen, this particular steamer, the *Armand Béhic,* makes her voyage regularly from Marseilles to Australia and back without use of gauge glasses; they simply have an attendant in charge of the stokeholds, who occasionally tries the lever of the automatic valve to see that all is free. The French engineers prefer to run without the gauge glasses in action. My experience of these boilers is that they are practically as inexplosible as possible. During a trial trip I made on board a vessel fitted with these boilers in Russia, two gauge glasses broke, and, naturally, one's first impulse was to replace them or draw the fires, but Messrs. Belleville's representative was by no means concerned, and assured me that there is no cause for anxiety when the gauge glasses give out. I think the difficulty as regards feeding has been quite overcome by Messrs. Belleville's ingenious apparatus. No copy of this paper has been sent to me, which I regret, as I should much like to have said more upon the subject, but in the absence of notes it is difficult to speak. However, after what Mr. Seaton and Mr. Yarrow have said, I think, perhaps, water-tube boilers have been sufficiently well supported.

Mr. MARK ROBINSON (Member): Sir Nathaniel Barnaby and Gentlemen, I would like to ask Mr. Thornycroft, before he speaks again, for one explanation, which would add to the obligations we are under to him for his exceedingly interesting paper to-night. Can he give us the actual figures of the dryness of steam from his boiler? I ask that question because lately I have been concerned a good deal with the trials of two other water-tube boilers. I approached those trials in no friendly spirit, believing little in water-tube boilers, and not at all in their giving dry steam, but the results have astonished me. One of the boilers under trial was a Babcock boiler, built for a yacht, already referred to this evening by Mr. Rosenthal. The results as regards dryness were exceedingly good, the moisture present being only about ½ per cent. The other boiler was the Niclaussé boiler, spoken of in Mr. Milton's paper, and that has given results practically the same. The dryness of steam was something extraordinary. We forced the Niclaussé boiler to more than double its rated evaporating power, *i.e.*, to nearly 5,000 lbs. of water against 2,200 lbs., and still there was considerably under 1 per cent. of moisture in the steam, tested with great care by the salt test, and by other tests as well. Mr. Milton referred to the method of taking out the tubes of the Niclaussé boiler, and to the short time in which it can be done. I have several times tested the time required. Having from 180 lbs. to 200 lbs. pressure in the boiler, the order has been given to draw the fire, blow out the boiler, and remove a tube for examination, and invariably, within thirty minutes, we have had one or more tubes lying on the table for inspection. When the drawings and models were first shown to me, I thought it was impossible that the two cone joints, in two separate seats on opposite sides of the header, could always be relied upon to keep tight, owing to the apparent possibilities of unequal expansion; but as a matter of fact the boiler has been under trial for more than six months, and has been put to very severe tests in many ways, and yet, so far as I know, there has never been a weeping joint. The tubes have been repeatedly taken out and put in again to show how it could be done, not, one would think, without great chances of grit and dirt getting into the cone joints, yet there has never been a leak. I will not say more about these trials, because I am personally interested in the result; but the boiler is now under test by engineers whose verdict will be altogether independent. Some time since I was in Mons. Niclaussé's factory in Paris, where there is a boiler, of which one end of the drum and the side of one of the headers are partially made of plate glass, and I was invited to see steam got up. As the circulation commenced, there was rapid foaming on the surface of the water in the drum, over the upcast of the header (which, of course, is "drowned," to use Mr. Thornycroft's phrase); but as the pressure rose to 5 lbs. the foaming grew much less, when it went up to 10 lbs. there was but little. At 15 lbs. it was scarcely perceptible, but I then thought it time to go somewhere else, because of not having so much faith in plate glass windows in boilers as they have at Chiswick. The experiment brought home to one admirably, how the reduction in the size of the steam bubbles, pushing their way up through the water as the pressure increased, lessened their tendency to break up the surface of the water, and to carry the water up with them into the steam space. In other words, the higher the pressures you deal with, the less should be the troubles from foaming, and the smaller may be the disengaging surface for the escape of a given weight of steam from the water. Of course this does not apply to Mr. Thornycroft's boiler, where the discharge of foam into the steam space is intentional, and where dryness of steam can only be obtained by subsequent separation of the water from the steam, rather than by its absence from the steam space in the beginning. But as regards the class of water-tube boiler of which I now have experience, the bugbear of wet steam is at an end for me. Apparently the Niclaussé water-tube boiler gives dryer steam than any boiler we have ever had at Thames Ditton, though the Babcock boiler, with which it happens to have been compared, gives results, in this respect, substantially as good.

Mr. J. I. **Thornycroft**, F.R.S. (Vice-President): Sir Nathaniel Barnaby, Ladies and Gentlemen, I will answer what Mr. Robinson has just now said, because that is immediately in our memories, and in doing so I will also answer Mr. Seaton's remarks. Mr. Robinson asked as to the dryness of steam. Mr. Seaton said he did not like priming or foaming boilers. Now, I would like to say one or two words with regard to the priming boiler, as bearing upon the dryness of steam. The Diagrams 3 and 4, Plate XLIX., represent two experimental boilers we have been working with lately, in which we made special experiments as to the dryness of steam. I feel a little hesitation in saying anything very definitely about this. I think Mr. Robinson has been experimenting longer on this subject than I have, and therefore he perhaps will have more to say about it. So far as we could make out in the boiler, shown in Fig. 3, which is very small, and therefore, I take it, is unfavourable to dryness, the percentage of water when working hard, that is evaporating 10 lbs. of water per square foot of surface per hour, was about two per cent.

Mr. J. E. **Thornycroft**: 14 lbs.

Mr. J. I. **Thornycroft**: I beg pardon, 14 lbs. Of the two boilers there shown, Fig. 4 has what are described as drowned tubes. Now, I must say, in order to remove the impression that Mr. Seaton probably gave to the meeting, that I found that the boiler with the drowned tubes is the greatest primer; it primes more than the boiler where the tubes come in at the top. The diagram of the boiler with above water delivery does not show the curved plate protecting the steam pipe from the shower of water which comes down, and, I think, there is some probability that in this shower of spray there may be some explanation of the fact that Mr. Robinson has stated, that is, that these boilers gave really dryer steam than could be expected. And I think it may be due to the fact that the vapour in the boiler is, as it were, bombarded by a number of particles which pick up from the steam the particles of moisture there. In my own mind I got, I think, the best notion of the way to dry steam from considering the effect of a tree in a fog. If you notice when there is a mist in the air, and it passes through the small branches of a tree, although the mist will not fall in particles of itself, yet in its passage through the branches of the tree it is condensed on the surface, and you get the appearance of rain underneath the tree. I think, in the passage of the particles of water through the space in the steam chamber, they pick up the small damp in the mist in the same way as the tree does, and that accounts, I take it, for the dryness of the steam. Mr. Yarrow likes straight pipes, and I prefer, at present, curved ones, and there we agree to differ. With regard to the curved pipes, they have this advantage, that you are able to get a longer length of pipe available for heating in a given space. There is an advantage in that. You also get this advantage, that the tubes with considerable curvature adapt themselves to the most sudden changes of temperature with great ease, and—the point on which I have already laid stress—the water cannot return down them. The whole of the feed water cannot get into the hot pipes. I think that is an important point which Mr. Yarrow has overlooked. With regard to the downtakes which Mr. Yarrow has found it practicable to discard in the boiler which you see before you, I have tried the experiment of plugging up the down tubes, and I can corroborate what Mr. Yarrow says, that it works well without the down tubes; but there is this great disadvantage to my mind—you have in the circulation a matter of uncertainty. You have some tubes where a current of steam is coming up, and others where a current of water is coming down. Then you must have other intermediate tubes where there is a certain amount of uncertainty, and you get a certain amount of foam, which does not know whether to go up or down, and I think that is likely to cause trouble. If Mr. Yarrow does not have any trouble from this cause, I will only say he is fortunate, that is all. With regard to the doors, the advocates of straight tubes say that through the doors they can get at all these tubes. I beg to call the attention of the meeting to the fact that in the boilers I have been constructing the access to all the tubes is got in the new type through two doors; every tube end in the boiler is accessible through two doors; the manhole door which we are adopting now is the same door as is used in the boiler which Mr. Howden so much admires. It is put on internally, and when the steam is up it will stop there. I think that is preferable to any other door. If you can use two doors of that kind you can open your boiler in five minutes, and get at all the tubes. In the Babcock and Wilcox boiler you cannot get at all the tubes in that time. I think there is a great advantage in being able to use a simple mandril for expanding the tubes into the plate. I admire the facility for the removal of tubes afforded by some of the straight tube boilers which Mr. Robinson has described, but I am afraid that is a quality that must wear out. In a new boiler you can have perfect fittings, and have a boiler, practically engine-worked, which is so well fitted that everything will take to pieces in a moment; but

I am afraid that will not last long. The boiler described is a modification of the field boiler, and although it has straight tubes it has the same good quality that the field boiler had, that the expansion is allowed for although it is straight, because only one end of the tube is attached to the boiler. If you have a straight tube boiler that is of importance, but it necessitates this trouble, that instead of having one you must have two tubes. You have one tube to get steam, another to convey the water down, and therefore that cannot be a very light boiler. The boiler that Mr. Yarrow and myself are fighting for is a very light one, and I am afraid Mr. Yarrow is taking liberties with his boiler, and is taking away one part which I consider essential.

Mr. Leslie Robinson (Visitor): Sir Nathaniel Barnaby and Gentlemen, it is with some diffidence that I rise at this late hour to make a few remarks. I should first like to allude to one or two points in reference to the Thornycroft boiler. I had the pleasure and privilege of being associated with Mr. Thornycroft, and of representing his firm for some time in France, where I had under my charge the construction of a large number of Thornycroft boilers, with men who had never seen this type of boiler before and who were perfectly green to the work, and I may add that the boilers were turned out with great success and with great credit to Mr. Thornycroft. There is one point which I think has been rather overlooked, that is to say, that you cannot under any circumstances explode these boilers. During some trials which were conducted in this country when Messrs. Thornycroft were experimenting with various kinds of tubes and metals, two or three tubes gave way in the innermost row next the furnace, and the stokers in the stokehold never knew that anything extraordinary had happened, until the deck hands informed them what had occurred. Another case which illustrates remarkably well the inexplosibility of this type of boiler is one which occurred abroad where a boiler was put into the hands of men who did not understand it; they allowed the water level to run down and down until there was practically no water left in the boiler, the tubes got so hot that the steel of which the tubes were composed began to melt and trickle down the outside of the tubes and some of the tubes ultimately burst, but nothing further happened. That is in itself, where we are dealing with high pressure, a tremendous argument in favour of the tubulous boiler which we cannot afford to overlook. There is another point which I think has not been quite sufficiently emphasised—I speak with due deference to Mr. Howden—and that is, that we can get up steam very quickly in these boilers. I do not pretend that we should put boilers like these into an ocean tramp—they are designed for special purposes, and I think, in the discussion, gentlemen have rather wandered from the point in this direction. The tubulous boiler is designed for special purposes, amongst others for raising steam quickly and for making a spurt at any moment which may be most valuable in action. I think Mr. Thornycroft can give us figures more recent than I can, as to the ability and facility with which you can get up steam, not only in his boilers, but in any tubulous boiler. There are one or two questions I should have liked to have asked Mr. Thornycroft, but as time is so advanced now I will not do so this evening. I thought these few practical details would be of interest, and it was that which led me to rise at this late hour. In connection with these tubulous boilers economy is a matter of considerable importance to my mind. I may be wrong, but in a boat where we have only a limited amount of coal on board and where the boats may be called upon to steam long distances, which is especially so in our own Navy, it is a matter of great importance that we should be able to have a large radius of action, and Mr. White emphasised that to us so strongly yesterday that I need say no more on that point now. I think we might be more careful than we are in this direction, and get the full advantage of using economical boilers. What I mean is this: Mr. Yarrow in his *Hornet* has got most splendid results. If I am right—and he will correct me if I am not—with the coal allowance he has, it should take 35 lbs. to drive his boat one knot. Under the present conditions of contract, whether he uses 25 lbs. or 35 lbs. is, I believe, a matter of indifference. Now, supposing Mr. Yarrow, instead of using 35 lbs., only used 25 lbs., and in his contract one of the conditions was that he had to put on board sufficient coal to drive the vessel at full speed about 2,000 miles, I need not say what tremendous saving of weight, and consequent gain in speed and radius of action, Mr. Yarrow would obtain, if, instead of using 35 lbs., he used only, say, 30 lbs. I think I may fairly say for the tubulous boiler that the economical results it has given are one of the strongest points in its favour, and I need not do more than draw the attention of the meeting to the results obtained by Professor Kennedy in his trials of the Thornycroft boiler, and the remarkable results obtained by M. Normand, which have been published in the technical papers. That we get speeds combined with economy, when using the tubulous boiler, that could not be obtained with any other known type of boiler, is well illustrated by the splendid results recently obtained by M. Normand. In one of his 36-mètre boats, with 76 tons displacement, M. Normand has obtained with the use of his boiler a speed of 24·5 knots per hour for a continuous run of two hours. The full weights and complete armament were in place, and sufficient coal, at 10 knot speed, to steam 1,800 knots. These results, considering the size of the boat and the severity of the trials, must speak for themselves, and need no further comment on my part.

Mr. J. Huddart (Associate): Mr. Chairman, I wanted to say, as a non-expert, assuming that all the experts had spoken, that I came here to see if I could get any light thrown on this subject for practical purposes, and I must confess that I have not got much light. I am sure that every heart knows its own bitterness, and every shipowner knows his own boiler troubles. It is not considered wise to advertise one's boiler troubles, but I have never met a man yet who has not had them. I think there are a great many who will agree with me that the sooner the present cylindrical boiler is at the bottom of the deep Atlantic the better. If you can show us a boiler that will give us less trouble—I suppose we shall always have trouble, we must all admit that—we should be perfectly willing to adopt it. I would ask you, as a friend of Mr. Howden, not to take his paper too seriously. You know Emerson says, you should always treat your friend as kindly as you would treat a good picture; put him in the best light. He certainly does not appear in the best light in his paper to-night. He is going back on his own experience to a large extent. He is one of the most progressive men in this room, and he is trying to laugh out of existence a thing that may be coming to the foreground. I looked to Mr. Sampson as the one man in the room who would have helped us with regard to those water-tube boilers in ships that are running to Australia. This would be a splendid opportunity of giving us the data. We shall get some information from Mr. White, as representing the Admiralty, by and by, as I hear they are trying the water-tube boilers on a large scale. I desire to say, as a practical manager, that up till this moment I have had very little assistance from the discussion here to-night.

Mr. W. H. White, C.B., LL.D., F.R.S. (Vice-President): Sir Nathaniel Barnaby and Gentlemen, I came into this meeting very late, and had not the opportunity of seeing Mr. Howden's paper until a few minutes ago. I know Mr. Howden's views on this subject very well. It is probably no unfair criticism of this paper to say that in it Mr. Howden has displayed the courage of his opinions. At all events, he has not spared the water-tube type of boiler, in which he does not believe. I greatly regret that my friend, the Engineer-in-Chief of the Navy, is not here to-night to speak for himself as regards the action which has been taken by the Admiralty before deciding to adopt water-tube boilers, on a very large scale, in the two cruisers *Powerful* and *Terrible*, which are now being built for the Navy.

Incidentally I shall be able to oblige Mr. Huddart with some information—not of a detailed nature—in regard to the steamers fitted with water-tube boilers which he mentioned as trading to Australia. For many years past—thanks, in great measure, to the work done by Mr. Thornycroft, and subsequently by Mr. Yarrow—the Admiralty has had in its own possession torpedo-boats fitted with water-tube boilers; and has been able to gain experience—on a small scale, it is true, but still experience—as to the efficiency and working qualities of these boilers. Some years ago Mr. Thornycroft came before this Institution and made a very powerful plea in favour of the extension of water-tube boilers to larger ships. That plea did not result in any immediate action. The Admiralty was endeavouring, within the means it had, to solve a good many problems before going further. Two years ago, when I was in France, and visited a great many French ships, my mind was impressed by a very notable circumstance, to which Mr. Howden makes no reference whatever in his paper, so far as I am able to see. If I am mistaken he will correct me. Two years ago there was not building for the French Navy any vessel—from the largest ironclad down to the smallest torpedo-boat—that had not water-tube boilers. Now, I am not aware that we are accustomed to regard our French colleagues in shipbuilding and engineering as lacking either in intelligence or caution, and they are certainly not wanting in knowledge of their profession. How comes it that Mr. Howden says nothing about that very striking fact? He says but little either, as far as I have been able to gather, about the experience in actual working in many French mercantile ships with water-tube boilers. Mr. Sampson has told us (and he can speak with far greater authority on this point than I can) that the difficulties which Mr. Howden has pictured with regard to feed arrangements are non-existent in practice. I put it to this meeting whether such a contradiction as that, on a matter of fact, coming from competent authority, does not somewhat weaken the faith we shall be disposed to put in Mr. Howden's conclusions on other points. Before the Admiralty took action, the fullest consideration was given to experience gained with water-tube boilers at sea. An engineer officer of considerable ability and experience took passage to the East and back in a ship fitted with Belleville boilers. He saw the working of these boilers out and home, and his report was of an entirely satisfactory character. We had information also as to what was being done with other types of boilers in France, and we had our own experience in the torpedo-vessels which had been fitted with water-tube boilers. Our latest experience was that of the *Speedy*, a vessel where nearly 5,000 H.P. had been developed, built and engined by Messrs. Thornycroft. Having these experimental facts—not opinions, but facts—before them, the Admiralty were convinced that many advantages were obtainable, without undue risk, by using water-tube boilers for the new cruisers, on the side of the economy of weight for power developed. The tactical advantages resulting from the quick raising of steam in water-tube boilers were also considered important. On these grounds, it was determined in these large cruisers to adopt the type of water-tube boiler which, so far as I am aware, has been most thoroughly tested in sea work, namely, the Belleville type. That is a plain statement of facts. Anyone reading Mr. Howden's paper, and noting comparative statements like those which occur on pages 323, 324, as to fuel space, weight, and so on, requires to be cautioned against accepting the figures therein as final or conclusive. I am disposed to question their accuracy in some instances, but cannot deal with them in detail now. There are obviously many circumstances that must be taken into account in ships of different types and different forms, when comparing cylindrical and water-tube boilers. Underlying Mr. Howden's figures for cylindrical boilers, through which I have only been able to take a hasty glance, as far as I can see there will be found Mr. Howden's own estimate of what can be achieved with his own system of forced draught. I do not wish now to enter into the discussion of that point, but I may recall to mind the fact that in previous discussions in this room Mr. Howden's claims have not been universally admitted, and in some respects have been challenged. We are all the better for having both sides of the question put clearly in the present discussion. For my own part, I am glad that Mr. Howden has had the opportunity of publicly expressing his views, and of putting as strongly as he may feel his doubts as to the wisdom of adopting water-tube boilers; but I am inclined to think that, his somewhat unpleasant experience years ago may have given him a bias in dealing with a type of boiler which a great many other engineering authorities than himself look to for progress in the advancement of steam navigation, whether it may be for war or for commerce.

Mr. J. T. Milton (Member of Council): Sir Nathaniel Barnaby and Gentlemen, I will only keep you a minute. I am very sorry indeed that no one has been able to enlighten Mr. Huddart upon the economical point of view of the water-tube boiler. I have not made inquiries on this point from all the makers of boilers, but if Mr. Huddart looks in my paper he will find some statements there as to the economy of the D'Allest boiler, a boiler which is not described in this paper, but which is referred to as having been described in the Cardiff paper. He will find that the D'Allest boiler is an exceedingly economical boiler. He will also find in the Cardiff paper that the D'Allest boiler has had a great many years' use at sea, and has proved to be a very safe boiler. That is an important point. If Mr. Huddart possesses a book which I have here, and if he does not, I am sure Mr. Sampson, of Maudslay's, will be glad to give him one, he will find in that book the statement of results of some trials made at Nice on the Belleville boiler. From those trials it would appear that the Belleville boiler is a satisfactory boiler. If he refers to the paper I read at Cardiff he will find there stated—if he does not know it already through travelling to and from Australia—that the Belleville boilers are fitted in the large Messageries boats. One of these at least has been in use for some years. The owners of these vessels have repeated them, and are repeating them now; and unless they had been commercially successful with these boilers I do not think it is likely that they would have repeated them. In my paper also I have given the result of an economy trial made with the Anderson and Lyall boiler. I have only one or two other points to mention. Mr. Rosenthal pointed out that Mr. Howden's paper was inaccurate as to the weight of the *Nero's* boiler. I daresay that Mr. Howden labours under the disadvantage that most other people do to-day, of not knowing all about these matters, and gets his information from some source which is not reliable. When it is stated that the weight of the boiler is 40 tons when it is actually under 30 tons, there is a very large difference. With regard to one of the other boilers as referred to by Mr. Howden, I do not know whether accuracy lies with Messrs. Maudslay or with Mr. Howden. In Messrs. Maudslay's pamphlet the weights are given of the P. & O. Company's *Himalaya's* boilers. They were fitted with Mr. Howden's forced-draught system. I do not know what the indicated horse-power on trial is, but it is not much more than 8,500. I do not think there is much more than 7,500 indicated at sea in those boats. He gives the weight of the boilers and all the fittings for 7,500 at sea as 361 tons. Messrs. Maudslay give the weights of the *Himalaya's* boilers without the forced-draught fittings or uptakes as 546 tons. There is an enormous difference there, and I really do not know where accuracy lies. I think I have nothing further to say, except to thank you for your indulgence.

Mr. J. Howden (Member): Sir Nathaniel Barnaby and Gentlemen, at this advanced hour of the evening it is not possible for me to reply to the many criticisms and remarks which have been made on my paper. I wish, however, to call attention to the great difference in the effect of the distinctive principles of the cylindrical and water-tube boilers on their evaporative power. In the cylindrical the heat is inside the water, and in the other the water is inside the heat. To show the great difference in effect of these different modes of application I point again to the Table given in my paper, on page 328, which is copied from one given by Mr. McFarland of the United States Navy in connection with the discussion of one of the papers read at Chicago last year on "Water-tube Boilers." In that Table Messrs. Thornycroft's boilers give the highest results at sea of that class. You will find there that the actual evaporation from and at 212° per sq. ft. of heating surface is 6·7 lbs., in the Thornycroft water-tube boiler at 4 in. air pressure and 20·09 lbs. per sq. ft., in the locomotive boilers of the Italian torpedo cruisers *Tripoli* and *Folgore* at 4·95 in. air pressures.* This gives an evaporation of 3 to 1 in favour of the locomotive boiler, which is similar in principle, as regards the application of the heat to the cylindrical boiler. In the line immediately above, in the Table, you will find the water evaporated per lb. of coal from and at 212° in the water-tube boiler is 6·51 lbs., and in the locomotive boiler 6·62 lbs., showing that even when the latter is evaporating three times the weight of water per square foot of heating surface of the water-tube boiler, the locomotive boiler with the heat inside is more economical than the water-tube with the heat outside. These examples, I think, prove clearly that having the heat inside and the water outside is the proper method of applying heat to a steam boiler. The extraordinary difference, as shown in these examples, of having a more economical evaporation with the locomotive boiler when using only one-third the heating surface required by the water-tube boiler, is surely onclusive on this point. If the amount of heating surface per indicated horse-power used in the water-tube boiler was used in a locomotive or cylindrical boiler, the economy of fuel in them could never be approached by any water-tube boiler. It is only where the heating surface of the water-tube boiler is 4·5 or 6 times more than is required for equal power in a cylindrical boiler that any approach to economy is made by the former. Now with regard to weight, which is supposed to be the great point in favour of the water-tube boiler, I refer to the table on page 330 showing the comparative particulars of power, weight, space occupied, &c., of Messrs. Thornycroft's water-tube boilers in the *Speedy* and the locomotive boilers of the *Satellit* built by Schichau, of Elbing, for the Austrian Government. These particulars, which have been given me by Herr Ziese, managing director of the Elbing establishment, show that in the *Speedy* the indicated horse-power per square foot of heating surface is ·29 I.H.P., while in the locomotive boilers of the *Satellit* the indicated horse-power per square foot of heating surface is ·56, or nearly double that of the *Speedy*.† Taking the respective weights of the boilers of the two steamers, including water, uptake, funnels, &c., the boilers of the *Speedy* are 154 tons, and those of the *Satellit* 96·1 tons, which is greatly less than the water-tube boilers. The respective powers are:—Maximum performance of the *Speedy* 4,674 I.H.P., average performance 4,500 I.H.P.; maximum performance of the *Satellit* 4,901 I.H.P., average performance, 4,792 I.H.P. The space occupied by the water-tube boilers, with their engines, in the *Speedy* is 101½ ft. in length, and by the locomotive boilers, with their engines, in the *Satellit* 83 ft. 8 in. These particulars show that in every point, including weight and space occupied, locomotive boilers when worked properly are superior to the water-tube boilers, even when the latter are specially constructed for lightness and power, a class of boiler unfitted for sea working. A water-tube boiler fit for sea-going must be made after the manner of the Belleville boilers, with large water-tubes. In the Belleville boiler these tubes are 5·4 external diameter and from ⅜ in. to ¼ in. in thickness. Such tubes will, of course, last for a considerable time, but if you make a water-tube boiler to be capable of working at sea, it must be much heavier and will occupy much more space per indicated horse-power than those of the *Speedy* type. The water-tube boilers for large power must also be much subdivided in a sea-going steamer. In the Messageries steamers there are twenty water-tube

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* The figures given in Mr. McFarland's table are erroneous. See footnote, page 328, and also Mr. F. Marshall's statement in Vol. XXIX., pages 30 and 36.—Ed.

† Mr. Thornycroft disputes the accuracy of these figures. See his letter, pages 330 and 331.—Ed.

boilers for a power which can be obtained from three double-ended cylindrical boilers, not very large. The difficulties of the feed-water, when a large number of boilers are used, are also much increased, though this has been spoken of to-night as a mere bagatelle. In the regular voyages of the Messageries steamers to Australia, where the speed is maintained at a uniform rate from day to day and there are trained men in attendance, the feed may be regulated without much trouble, but in ordinary steamers, such as tramp ships, which go knocking about over the ocean at various speeds, feed regulation in water-tube boilers would be very difficult indeed. Under conditions of great regularity it can be done, but under greatly variable conditions difficulties with the feed-water would at once appear. The amount of water in the boiler also is most important. The more water the safer the boiler and the less troublesome. If the water is little, the safety is little, and the greater the trouble.

The **CHAIRMAN** (Sir Nathaniel Barnaby, K.C.B., Vice-President): Will you pardon me one moment. Mr. Howden has made some statements which it is thought desirable to challenge for the purpose of getting the proceedings right. Mr. Thornycroft wishes to put a question.

Mr. J. I. **THORNYCROFT**, F.R.S. (Vice-President): I should like to ask some questions about the table on page 330. From the position I was in, in the room, I could not quite read your table, and I must apologise for asking a question at this time. That table contains an account of some records which were reported, I believe, in the newspapers some time ago, as to the relative performances of the *Satellit* and the *Speedy*. At the time that record was challenged, and I believe the weights there given are, at any rate, misleading, although they may be correct in some sense. What I should like to know is the number of boilers used and the air pressure used, and some particulars of the trial. What I know is this, that in the one case the boilers were amply up to their work, and could do it easily, and I think that is proved by what was done. I know, in the same ships and in the same space, locomotive boilers have been built by a number of very competent engineers, and it was found with those particular dimensions it was not possible to make satisfactory boilers, and I think that accounts for the boilers found in the *Speedy*. The locomotive boilers shown in the same space illustrated by this diagram were not found to do the work well, not the very best work. Perhaps Mr. Howden has some secret for making his boiler do more than the other boilers can. I take that table to be misleading, and if Mr. Howden would kindly supplement it I should be greatly obliged to him.

Mr. J. **SCOTT**, C.B., F.R.S.E. (Member of Council): While we are on this point I should like to ask Mr. Howden to reconsider and revise one or two points in the historical part of his paper, because I see what I consider to be a few variances in it which I should be glad to point out.*

Mr. J. **HOWDEN**: With regard to Mr. Thornycroft's remarks, I wish to say that I will place the table of the particulars of the *Speedy* and *Satellit* in his hands for rectification in any point which may be found necessary. I would not wish anything to be put into the Transactions which is not quite correct.† Referring to what Mr. Scott has said as to some corrections required on the historical part of my paper, I have to mention that I wrote to Mr. Scott to ask for any information he could give me in regard to the boilers of the *Thetis*, the only steamer about which I was not in possession of full particulars, but Mr. Scott mentioned that he could not give any information regarding these boilers, as they had no drawings of them. If Mr. Scott can correct me on any point, I will be happy to make

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* See page 349.

† See page 330.

these corrections. Before concluding I would like to refer to the performance of the locomotive boilers under forced draught. Their efficiency depends greatly on the system of forced draught used. In this country and others the locomotive boilers in torpedo-boats have been worked by closed stokehold forced draught, which does fairly well in such boilers up to a certain point; that is, they are not so easily injured as some other kinds of boilers with this system, but when a high air pressure is used difficulties immediately appear, and the efficiency is much less than with a system analogous to mine, such as is used by the Schichau firm. They inform me that they obtain about 30 per cent. more power from the same boiler with their system of forced draught than can be obtained from the closed stokehold. Referring now to the question of weights, there have been some remarks made in regard to the weight I give of the *Nero's* boiler. The weight I indicate is given from data obtained from those who should know, but I have not yet obtained complete particulars, and was therefore unable to give the exact weight, but I had sufficient data to show it could not be under 40 tons. I will endeavour to get the exact weight.*

Mr. W. H. **White**: What about the weight of the *Himalaya's* boilers?

Mr. J. **Howden**: I am glad Mr. White has called my attention to the *Himalaya's* boilers. These boilers are not at all in usual proportion of weight to power, being very large for the size of furnaces, and have very large water spaces. They are made to suit the ideas of the Company's officials, as, when the steamer is not for carrying deadweight, it is supposed that a hundred tons, more or less, in the boilers does not matter much. This may be, but I am sure the time is coming when much more attention will be paid to this question of unnecessary weight in cylindrical boilers, and they will be made much lighter, in proportion to power, in all steamers. With regard to the figures on the tables on page 329, giving the relative powers of cylindrical boilers of various sizes worked on my system which have been challenged by Mr. White, I can assure him that these figures are based on what is, and has been, obtained at sea for some years in the American steamers, the *Pennsylvania*, and others, to which I have more than once called attention.

Mr. W. H. **White**: I in no sense challenged Mr. Howden. I simply said I understood Mr. Howden to be representing here claims in relation to his system—the comparison is made between the water-tube boiler and boilers working under this system of forced draught. I called attention to the fact that it has not been admitted, but personally I expressed no opinion at all.

Mr. J. **Howden**: Without going further into the particulars of these diagrams, what I wish to emphasise is, that in comparison with a water-tube boiler safe to work at sea, the cylindrical boiler for same power will occupy less space, and be of less weight, and certainly be more economical in fuel. With regard to the example of the French Naval authorities, I would not follow their example, but look to the Mercantile Marine for guidance, for it is in the mercantile service alone that boilers are properly tested, as there they have to pay for their mistakes. It is the Mercantile Marine, therefore, that will decide the boiler question, and not the Navy. I will not say more now, but I have to thank you for listening at this late hour to my remarks.

The **Chairman** (Sir Nathaniel Barnaby, K.C.B., Vice-President): On the part of the meeting I offer our sincere thanks to Mr. Milton and to Mr. Howden for their papers.

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* See footnote on page 329.

June 27, 1894.

DEAR SIR,

In reference to the observation which I made at the close of Mr. Howden's reply, on the historical part of his paper, I beg to say that I notice, among others, the following points in error.

I was the owner of the *Thetis*, which was built by me entirely for experimental purposes. The compound engine with Mr. Craddock's arrangement of slide valves proved an entire failure, and the cylinders were replaced by others at the Greenock Foundry. No alteration was made in the boilers. It is not a matter of much importance, but in many details the sketch of this boiler which Mr. Howden has "made up" is not correct, either in the form of construction or in the arrow indication of the direction of the travel of the gases.

The tubes were of 2½ in. diameter. The *Thetis*, after a very continued series of experimental trials, ran for nearly six months in the trade between the Clyde and Liverpool, making about twenty double voyages, and thereafter traded for six months in the Mediterranean. The tubes failed ultimately from internal corrosion.

I am,
Yours obediently,
JOHN SCOTT.

GEORGE HOLMES, Esq.,
Secretary, Institution of Naval Architects.

The Council have received a reply from Mr. Howden to the above letter which is too long for publication. The only points which appear to be in question are:—(1) The details of the boiler of the *Thetis;* (2) the length of time which this boiler ran before giving out. Regarding the *Thetis* boiler, Mr. Howden states that he applied to Mr. Scott for the particulars, that Mr. Scott was unable to supply them, no drawing of the boiler being in existence, and that consequently he (Mr. Howden) had to rely on information supplied by Mr. Robson, a late Board of Trade Surveyor at Glasgow, who had watched the construction of the boiler. Regarding the length of time the boiler ran, Mr. Howden accepts Mr. Scott's correction.

FURTHER INVESTIGATIONS OF THE VIBRATIONS OF STEAMERS.

By Herr Otto Schlick, Member.

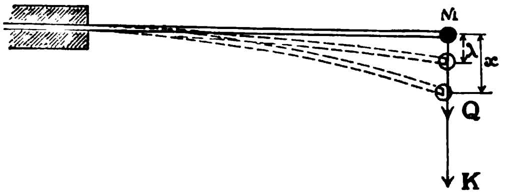
[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 16th, 1894; Admiral the Right Hon. Sir John Dalyrmple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

The paper which I had the honour to lay before you at the last year's meeting of the Institution of Naval Architects appears to have been sufficiently interesting to the members to encourage me to communicate to you now the results of my further investigations on the same subject.

It is no doubt very desirable to have a reliable formula for determining, with some degree of accuracy, the number of revolutions which the engines of a steamer should make in order to avoid altogether, or at least reduce to a minimum, the violence of the vibrations inherent in ships themselves, and in the distribution of the weights in them. Such a formula I had already worked out some time ago, but before publishing it I took care to test and correct the co-efficients occurring in the formula, by applying it to a number of steamers already doing service.

This was not an easy task for me, as I had not the opportunity of ascertaining, with accuracy, the critical number of revolutions of the engines above referred to, excepting in the case of a very limited number of steamers in the merchant service. Many vessels vibrate violently when running under steam, but in most cases the revolutions of the engines cannot be increased to the number necessary to bring about a decrease of the vibrations; so that this critical number of revolutions can ordinarily not be ascertained.

The mathematical formula for the period of vibration of an elastic rod or girder is very complicated, but in the case of a ship's hull its compilation is comparatively simple. Let an imaginary, weightless, elastic rod be firmly secured at one end, while at the other end let the mass M be attached and the force Q applied. The latter will bend the rod, and move the mass M through a distance λ from its original position, to which M will return with a certain acceleration, when the force Q is withdrawn.



If the acceleration at the distance 1 from the horizontal position of the rod is called q, then the time of oscillation of the rod will be found by the well-known formula—

$$t = \frac{\pi}{\sqrt{q}} .$$

If now the force K is applied to the free end of the rod, and the distance through which M is moved downwards by this force is equal to χ, then—

$$\frac{K}{Q} = \frac{\chi}{\lambda},$$

that is, the distances through which the free end of the rod is moved by the bending forces are proportional to these forces.

If the acceleration given to M by the bending force K at a distance χ is called p, then—

$$p = \frac{K}{M} = \frac{Q}{M\lambda} \cdot \chi .$$

If χ is put equal to 1, then will be,

$$q = \frac{Q}{M\lambda},$$

λ signifying the distance through which the rod is bent by the force Q, and $\frac{\lambda}{Q}$ being a constant quantity, λ_1 may be put for λ in the case of the bending of the rod having been caused by the weight of the mass M alone. We can, therefore, put

$$Q = Mg,$$

g signifying the acceleration of gravity. Therefore the time of oscillation is—

$$t = \pi \sqrt{\frac{\lambda_1}{g}} \quad . \qquad (1)$$

The distance χ through which an elastic, prismatic rod is bent by the force K, the weight of the rod being neglected, may be found by means of the formula—

$$\chi = \frac{K \,.\, l^3}{3 \,.\, E \,.\, T} \qquad (2)$$

l signifying the length of the rod, E the modulus of elasticity of the material, T the moment of inertia of the section of the rod.

If now, in the formula (1), instead of λ_1, the value of χ from the formula (2) is put we have

$$t = \pi \sqrt{\frac{K l^3}{3 \,.\, E \,.\, T \,.\, g}} . \qquad (3)$$

The direct application of this formula for calculating the time of oscillation in the case of a ship's hull is, however, only admissible on the supposition that the weight of the ship is concentrated in one point. Therefore $\frac{L}{2}$, half the length of the ship, must not be substituted at once for l in formula (3). It is, however, admissible to suppose that the weight of half the ship, the same being divided by the midship section into two equal parts lengthways, is concentrated in one point at a certain distance from the midship section, and that the time of oscillation in this imaginary case is the same as in that of a real ship, in which the weights are distributed in the usual way along the whole length.

This imaginary distance may be expressed by $\alpha \times \frac{L}{2}$ (α being smaller than 1), but need not be taken into consideration at present.

Upon this supposition the formula (3) may be used at once to determine the time of oscillation for a ship.

If D signifies the displacement (weight) of a ship, then is the time of oscillation expressed by the formula—

$$t = \pi \sqrt{\frac{\frac{D}{2} \cdot \left(\alpha \frac{L}{2}\right)^3}{3 . E . T . g}}$$

The joint value of all the factors in this formula being put equal to ξ, we have

$$t = \xi \sqrt{\frac{D . L^3}{T}}$$

From which follows, if the number of vibrations of a certain type of ship per minute be

$$N = \frac{60}{t},$$

$$N = \phi \sqrt{\frac{T}{D . L^3}}$$

If in this formula D is expressed in English tons, L in English feet, and, for the calculation of the moment of inertia, the sectional areas in English square inches, and the distances of the centres of gravity from the neutral axis in English feet, then the co-efficient will be, for

Vessels with very fine lines, such as Torpedo-boat Destroyers... $\phi = 156850$;
Large Transatlantic Passenger Steamers with fine lines .... $\phi = 143500$;
Cargo boats, with full lines................................ . ... $\phi = 127900$.

This formula gives generally reliable values, and even alterations in the distribution of weights do not materially influence the result.

In order to adjust the co-efficients to exceptional cases, it is only necessary to bear in mind that a removal of the weights from the ends and the middle of a ship, viz., an accumulation of the weights near the nodular points of vibration, will increase the number of vibrations, and, *vice versâ*, that this number will decrease when the weights are accumulated near the ends and the middle of a ship.

It would, of course, be more correct to take account in the formula of the distribution of the weights in the longitudinal axis of the hull; but, as this would require a very tedious calculation, which would, moreover, not always be reliable, and as I consider it particularly important to construct a formula which easily adapts itself to practical use, I have thought it better to employ only the co-efficient ϕ, which I ascertained from results obtained with reference to existing ships. After more experience has been gained, it will be possible to find perhaps more correct co-efficients for the ordinary types of steamers in which the distribution of the weight is analogous.

In order to avoid vibration with perfect certainty the normal number of revolutions must, as is known from experience, be at least from 10 to 12 per cent. less, or else considerably greater than the number of vibrations. In case the number of revolutions should be only inconsiderably greater, there could arise the possibility that even a small diminution of the steam pressure, hardly always to be avoided in practice, would immediately cause vibrations of great violence.

A ship's vibrations have until now never been closely examined with regard to the influence exercised by the position of the engines in the ship, and I myself touched this subject only superficially in my previous publications. Although it is comparatively easy to find out the consequences of shifting the engines in a ship by argument, yet the attempt to prove the conclusions arrived at by practical tests on a steamer will remain very costly and difficult. I therefore had recourse to a model to show the results caused by shifting the engines of a ship in a fore and aft direction.

This model, represented by Figs. 1 and 2, Plate LXV., consists principally of a plank P P about 8 feet long and 11 inches broad, suspended horizontally by ten helical springs S S.... arranged in two rows lengthways near the edges of the plank. These helical springs are attached to a frame F F, the construction of which is immaterial.

Along each edge of the plank P P are also arranged, in two rows, a number of weights W W . . ., which can be easily shifted. This plank represents a ship's hull, and by means of it the origin of vibrations in a ship may be demonstrated, by applying to it forces, in a similar way as they would occur in reality in a ship. If, for instance, at one part of the plank a pressure is exercised, the plank will give way in the direction of that pressure either up or downwards until, through the increased tension of the respective springs, equilibrium is re-established, similarly to the action of increased buoyancy in the case of a ship.

The plank suspended as above described can thus easily be made to vibrate in the manner shown at Fig. 3, Plate LXV., by a regularly repeated impulse of the hand either at the middle or at the ends. These vibrations will be called in future, vibrations of the 1st order in distinction from vibrations of another kind. Everyone who has been on board a violently vibrating steamer will acknowledge at once the perfect analogy of the vibrations of the plank with those of a steamer.

A model engine, as shown at Fig. 4, Plate LXV., serves for further investigations. The shaft has four cranks, which can be easily adjusted at any angle with each other, by a screw arrangement. The pistons are represented by four different weights p_1, p_2, p_3, p_4, which can be easily removed and exchanged for others, to show the effect produced by the use of pistons of different weights. This model engine is placed, as shown at Fig. 1, on the plank P P, and made to revolve by the turning-gear G in connection with the spindle *a*, *a*, which is furnished at each end with a universal joint and also with a telescopic sliding arrangement, so that the engine E can work perfectly freely.

Another model engine of similar construction, but with three cranks, is used to explain the influence of ordinary triple-expansion engines on the vibration of steamers.

In the first place, let the pistons, piston rods, and connecting rods of two cranks of the three-crank engine be removed, so that the model may represent a tandem engine—viz., an engine with only one crank. When the apparatus in this state is set in motion, only forces acting alternately upwards and downwards in a vertical direction will come into action, without any rocking couples being formed in the vertical plane through the longitudinal axis of the ship.

If the model engine be placed at C, the middle of the plank representing the ship (see Fig. 3), and be made to work, first slowly, and then gradually faster, it will be observed that the plank will remain at rest until the revolutions have reached a certain number, when violent vibrations of the form $A_1 C_1 B_1$ and $A_2 C_2 B_2$ (see Fig. 3) will make themselves manifest. The violence of these vibrations will, however, decrease again to perfect rest when the number of revolutions of the engine is gradually increased. Exactly the same will be observed when the model engine is shifted to O or Q near the end of the plank. When, however, the engine is placed exactly over one of the nodular points N or N_1, then the plank will remain at rest, or nearly so, at any number of revolutions that the engine may be worked at. The vibrations, as shown at Fig. 3, will be replaced by others of a higher order, having more than two nodular points, depending on the number of revolutions the engine is worked at.

For further investigations, the cranks belonging to the cylinders I. and IV. of the model engine shown at Fig. 4 are placed exactly opposite to each other—viz., at an angle of 180 degrees. The weights of the two respective pistons p_1 and p_4 are made exactly equal, and the two connecting rods and piston rods of the cylinders II. and III. are removed altogether. With such an engine with two cylinders the algebraical sum of the forces will always be zero—viz., they will be perfectly balanced in a vertical direction at any position. However, during the first half of a revolution a couple will be created having the tendency to lift the engine bed abaft, and during the second half a couple with the exactly opposite tendency.

When such an engine is placed exactly in the middle of the ship, vibrations of the 1st order, as shown at Fig. 3, cannot be produced, but the ship will remain at rest. Only small vibrations will occur when the engine is placed near the end of the plank, considerably abaft the nodular point. Both assertions can be proved by experiments with the model.

When, however, this engine is placed with its two cylinders equidistant from the nodular point (that means when one cylinder is placed at the same distance after the nodular point as the other one is placed before it), very violent vibrations of the 1st order will be produced as soon as the revolutions of the engine have reached the critical number. This can easily be gathered from Fig. 3, considering that during the first half of a revolution a downward force at *n*, and an upward pressure at *m*, will take place simultaneously, and that these pressures will be reversed during the second half of the revolution. Vibrations will also still be produced when the engine is placed with its cylinders not equidistant from the nodular point.

If, for an instance, one of the cylinders is placed exactly over the nodular point N_1, Fig. 3, and the other towards the middle of the ship over *r*, the thrusts of the piston acting exactly over the nodular point will have no effect in producing vibrations, while the thrusts of the other piston acting at a distance from the nodular point will cause violent vibrations.

In shifting the engine gradually towards the middle of the ship, the vibrations will decrease in the same measure, until they entirely disappear as soon as the engine has reached the middle position.

The following rules, based on the above-described experiments and observations, may be laid down for the construction of a ship's engines, so as to avoid vibrations:—

(1) In the case of engines that are placed exactly at the middle of the ship or near its ends, the algebraical sum of the vertical forces generated by the reciprocating masses must be made equal to zero. Rocking couples, which may possibly arise, need not be taken into consideration, as their influence in producing vibrations of the 1st order is but small.

(2) In the case of engines that are placed over or near one of the nodular points, rocking couples acting in the vertical plane through the longitudinal axis of the ship

must be avoided, in order to do away with vibrations. It is, however, less important that the algebraical sum of the vertical forces be equal to zero.

The second case only will come into consideration in practice, as it is impossible, under ordinary circumstances, to place the engine in the middle of the ship. On the contrary, it will be requisite for the proper arrangement of the boilers to place the engine considerably abaft, near to the nodular point.

In designing the engine, special care must therefore be taken to avoid rocking couples.

The usual arrangement of a three-cylinder engine is that the high-pressure cylinder is placed foremost, the middle-pressure cylinder in the middle, and the low-pressure cylinder at the after end.

Considerable rocking couples will always be produced with such an arrangement, and, moreover, the alternately upward and downward forces at the after end of the engine bed will be greatly in excess of similar forces at the fore end, because the weight of the low-pressure piston is naturally greater than that of the high-pressure piston. An ordinary triple-expansion engine may therefore be used, when it is placed before the nodular point in question, because then the greater pressures are applied nearer to that point than the smaller, and the engine will therefore work better.

But when the engine is placed abaft the nodular point, as is generally the case with tank steamers, then the greater force will act also at a greater distance from the nodular point, and cause, therefore, more violent vibrations. The usual position now given to triple-expansion engines in tank steamers is therefore, as regards producing vibrations, the most unfavourable. The low-pressure cylinder of the engine should be placed foremost, and the high-pressure cylinder abaft.

Moreover, the rocking couples, inherent in a triple-expansion engine, would be considerably reduced if the low-pressure cylinder were arranged between the high and middle-pressure cylinders, because then the greatest pressures produced by the reciprocating masses would act nearly in the centre of gravity of the engine. With such an arrangement, not only the violence of the vibrations would be reduced, but also the strain on the engine bed, which often causes loosening of the fastenings.

It is therefore to be recommended, for any engine of the three-cylinder type, that the low-pressure cylinder should be placed in the middle between the two other cylinders. In the case of an engine with five cylinders and three cranks, viz., one cylinder for the middle crank, and a pair of cylinders for each of the outer cranks, very great rocking couples are produced, as the piston weights for each pair of the outer cylinders are considerably greater than that of the middle cylinder. These engines will, therefore cause especially violent vibrations.

An ordinary triple-expansion engine, with three cranks, if erected in a particular manner, would also not be able to put the body of the ship into a state of violent vibration. To make this clear, refer to Figs. 9 and 10, Plate LXV. Let the line A B represent the axis of the ship. Let N be the aftermost nodular point; let B be the stern, and A about the middle of the ship. Let it be also assumed that the engine, as is usually the case, is placed somewhat in advance of the nodular point. When the revolution of the machine takes place in the direction indicated by the arrow in Fig. 10, and the cranks occupy, for example, the position shown, the weight of the piston of cylinder No. III. will generate a considerable upward force, while the pistons of cylinders Nos. I. and II. generate forces in the opposite direction. If, now, the distance x of the engine from the nodular point N be such that the moments of these forces about the nodular point N be equal to zero, no vibrations of the first order can take place.

As, however, the weights of the moving parts of the separate cylinders of an ordinary triple-expansion engine generally stand to each other in the ratios of 1 : 0·82 : 0·73, we have, in order that no vibrations may take place, the simple calculation that the distance x of the low-pressure cylinder, must be about five times a, the distance apart of the cylinders from centre to centre. It results also that wherever the engine be erected in the steamer, an engine with three cranks can be designed which renders it possible to avoid vibration, on condition that the weights of the different pistons are correctly chosen.

By properly balancing rocking couples, as well as vertical forces, vibrations may be avoided altogether. The use of counter-weights is, however, not expedient, when the same have to be too heavy, and is almost inadmissible for very large engines. For instance, for a triple-expansion engine of 7,000 indicated horse-power, the counter-weights required would amount to 44 tons, if the stroke of the eccentrics for moving these weights were 20 in. at one end and 12 in. at the other end of the engine. It is, therefore, by all means necessary to reduce the counter-weights to a minimum, or better still, to do away with them altogether. This may be carried out partially, by giving the engine a proper construction or position in the ship.

With this object in view, the weights of the three pistons for a three-cylinder engine have been made exactly equal. With such a construction the algebraical sum of the vertical forces is equal to zero for any position of the cranks, and if such an engine be placed exactly in the middle of the ship, no vibrations could be produced, as has been demonstrated before. But as soon as such an engine is placed near one of the nodular points, which is nearly always the case, violent vibrations will be caused by the large rocking couples inherent in the construction of the engine.

These couples are even greater than those inherent in an ordinary triple-expansion engine, because the small weight of the high-pressure piston at the fore-end of the engine is replaced by the much greater weight of the low-pressure cylinder. However, these difficulties may be overcome entirely, or at least greatly reduced, by adopting engines with four cylinders and four cranks. Two methods of construction, which differ chiefly in the relative positions of the cranks to each other, come here into consideration. In one of these methods the cranks are so arranged that in each pair at each end of the engine they form an angle of 180 degrees, viz., stand exactly opposite each other, while the two pairs themselves stand at an angle of 90 degrees. The two small cylinders are placed at the ends, and the two large cylinders between them in the middle of the engine.

The construction of such a quadruple-expansion engine is represented in sketch at Fig. 5, Plate LXV. The steam enters at cylinder I., and passes through the cylinders II., III., and IV. successively. The cranks of the successive cylinders stand, therefore, always at an angle of 90 degrees to each other. The steam might also be made to take a different course through the respective cylinders; but care should always be taken that the two heaviest cylinders, or the heaviest piston weights, are placed in the middle, viz., between the two lighter cylinders.

Fig. 6, Plate LXV., represents the arrangement of a triple-expansion engine of this system with two low-pressure cylinders. The advantages of this construction are, first, that the forces produced by the reciprocating masses of any two adjoining cylinders are nearly balanced, viz., that the algebraical sum of the existing vertical forces is approximately equal to zero; and, secondly, that only very small rocking couples can be produced. In most cases counter-weights may be either entirely dispensed with, or will only require to be of such a size that there will be no difficulty in their adoption.

In case the engine is placed very near the nodular point it is very desirable to balance the couples that might be formed. As the balance weights need not be very large it is admissible to let them rotate, without any fear of injurious horizontal components being produced. The simplest way of balancing the respective forces is to fit a balance weight on the periphery of the wheel of the turning gear, with which every engine is furnished; and also a disc of suitable diameter on the fore end of the crank shaft. This disc, which also bears a balance weight on its periphery, can always be easily fitted, and offers no danger to the engine-room staff.

In order to reduce the counter-weights for these discs to a minimum, the weights which work at the two outside cranks of the cylinders I. and II., Fig. 5, must be smaller in a certain ratio than those working at the two inside cranks of the cylinders III. and IV. The determination of the exact ratio of these weights to each other mathematically is rather complicated; but supposing that the weights which act on the crank II. are in the same proportion to those which act on the crank IV., as the weights which act on the crank I. are to those which act on the crank III., and further supposing, for the sake of simplicity, that the counter-weights are arranged at the same distance (*a*) from the centre-lines of the outside cylinders as these cylinders are distant from each other, then the weights of the moving parts of the outside cylinders must be 0·823 times the corresponding weights of the adjoining inside cylinder.

If the counter-weights for a four-cylinder engine of this construction of 7,000 indicated horse-power are calculated according to this rule, the respective weights will be 2·68 tons and 2·45 tons. It is, however, here supposed that these counter weights are fitted at a distance from the centre of the crank-shaft equal to the radius of the crank. Although these weights are considerable, yet they might be applied to an engine of the above size without hesitation.

In the case of an engine with four cranks, the counter-weights might, however, be avoided altogether, and all possibly existing forces and rocking couples be balanced, if it be not made a condition that all the four cranks are placed at an angle of 90 degrees. This arrangement will suffice for all requirements of a completely balanced engine. The masses acting on the outer cranks form, so to speak, the counter-weights for the forces acting on the inner cranks. If, therefore, the weights of the piston for the outer cylinders are chosen rightly, and their respective cranks are put at the proper angles, such an engine will always work without producing vibrations in the ship. The position of the four cranks to each other might vary considerably. For instance, the position of the two inner cranks may be chosen optionally, and the weights of the pistons of the outer cylinders as well as the position of their respective cranks be arranged accordingly.

The two inner cylinders must in this arrangement be furnished with the heaviest pistons, and it will be therefore best also to place the largest cylinders in the middle. If the cranks for the two cylinders III. and IV., Fig. 5, are placed at an angle of 90 degrees to each other, the arrangement shown at Fig. 7, Plate LXV., might be adopted for the cranks. The relation of the moving weights for each cylinder are marked at each crank in brackets, as shown.

The moment of the forces acting on the crank-shaft during one revolution will, in this arrangement, vary more than would be the case if all the cranks were placed at an angle of exactly 90 degrees to each other. These circumstances are, however, not so unfavourable as might at first appear, and differ but little from those of three-cylinder engines, if the cylinders have only the proper diameters. The cranks belonging to the cylinders I. and II. might also be placed at an angle of 90 degrees to each other.

The arrangement of the remaining cranks consequently required will be seen in Fig. 8, Plate LXV.

Any number of arrangements similar to those represented at Figs. 7 and 8 might be made and used in practice. It will be easily seen that, if the angle at which the cranks of the cylinders I. and II. are placed to each other is made smaller, the angle for the cranks of the two other cylinders will also have to be smaller.

In the case of a triple-expansion engine with four cylinders, as shown at Fig. 6, the relative positions of the cranks to each other will be symmetrical, and therefore the motion of the engine will be still more even. This principle may also be applied to engines with three cranks only, when the moving parts of an imaginary fourth cylinder are replaced by a counter-weight at the after end of the engine. This counter-weight may, as already proposed for four-cylinder engines, be attached to the wheel of the turning gear. By using such a counter-weight and adopting the proper angles for the cranks, the vibrations of existing steamers can be greatly reduced or even entirely obviated.

The above investigations refer principally to merchant steamers where vibrations only of the 1st order occur, and those of a higher order will very seldom be observed. In war-vessels, where the number of revolutions of the engine is generally great, vibrations of a higher order will often be observed, and, consequently, in such cases we have to deal with more than two nodular points, and the influence of the position of the engine is therefore different from the deductions given above. Nevertheless, the following rule will hold good in any case, independently of the fact whether two or more nodular points exist; viz., to prevent vibration, the algebraical sum of the moments of the moving parts in relation to the intersection of the tangents which touch that point of the curve of the deflected axis of the ship where the engine is situated, must be equal to zero.

If the engine is erected exactly in the centre between two nodular points, the tangents will intersect at an infinite distance, and, consequently, vibrations can only disappear if the weights of the reciprocating masses were perfectly balanced in the vertical direction. For instance, in a triple-expansion engine, if the weight of the three pistons were equal.

When the distance between the engine and the nodular point is small, the tangents will almost exactly intersect each other in the nodular point, and this supposition has been adopted by me for the sake of simplifying the above demonstrations.

It is important to state that the engine proposed by me can not only be perfectly balanced in a vertical, but also in a horizontal, direction, by choosing the weights of the parts working horizontally, *i.e.*, principally the connecting rods, so as to be in the same proportion to each other as the vertically moving masses. For the smooth working of this engine does not depend on the absolute weights of the moving parts, but only on the proportion of these weights.

From the foregoing observations it will easily be seen that in designing a ship it is of the greatest importance to determine in the first place the position of the nodular points.

If the weights of a ship were distributed equally in the direction of the longitudinal axis, and the moment of inertia of any cross section at any distance from their common axis were always the same, then the position of the nodular points would be 0·2242 times the ship's length distant from its ends. This value is, however, greatly influenced by the more or less equal distribution of the weights, and I may perhaps have the honour to lay before you the results of my experiments and observations on this head on a future occasion.

DISCUSSION.

Mr. W. Worby Beaumont (Visitor): Sir John Hay, I take the liberty of asking to be allowed to say a few words on this subject, because I have been for some months spending a good deal of time upon it, not so much in connection with the balancing of ships' engines and the vibrations in ships, as in connection with other classes of machinery; but of course the balancing that may be effective with any other kind of machinery bears to a very great extent upon the class of machinery to which the author of this paper has been drawing our attention. We have to thank him, I think, for teaching us a very great deal, not only upon the effect of varied disposition of the reciprocating and rotating parts of the marine engine, but upon the varied effect of those same loads and same dispositions on a vessel which has purposely, or accidentally, varying nodal points. Remembering the ten minutes in which I have to make what remarks I wish, I would, without saying anything further upon those points, like to ask the author a few questions, namely, whether he has observed the effect of the changing of the springs which he uses, so as to have springs of different periods, and whether he has observed the effect of the vibratory period of his springs as changed by the vibratory period of the plank carrying the engine. It will be observed that his plank will have one period, the spring another, and those will at some speeds of the rotation of his engine completely mask each other, and it is of course essential that it should be found whether those two things, coupled with the shifting of the weights to the different parts of his plank, do not tend in some cases to mislead. He may have made, and I suppose he has made, experiments on all those parts, and I have no doubt he will be able to assure us concerning them. In the paper the author has developed certain formulæ which relate to the period of vibration of an elastic parallelopiped. I find in connection with certain palometric experiments that the vibrations brought about by any influence in such an elastic rod are interrupted by exceedingly small causes. To take a rough example, in connection with a paper which I had the honour to read recently in this room, I showed one model in which there was an elastic bar set in motion by means of a very small unbalanced rotating weight. When the model containing, as the chief part, this elastic bar is placed upon a rigid foundation, or upon a rigid table, the period of vibration as affected by different weights and different speeds of rotation of the unbalanced weight, was very marked, and a very small weight, when rotating at the speed corresponding with a period of elastic flexure of the bar, would make it bend through a range almost unbelievable until it was shown. I had this model placed upon the table which is at the other end of the room, which is covered, as you will see, with some green baize. I do not know whether there was anything under that green baize, but the cushion which that afforded was sufficient to make a very great difference in the period, and in the range of flexure of this elastic bar. I mention this as one illustration of the effect of upsetting one period by means of another. Further, with regard to the author's formula (valuable as it is in connection with the subject), I am afraid that it would be found impossible to predetermine, with anything like accuracy, the nodal points in a ship when we remember that, not only is the elastic flexure of any period so upset every hour, and that the framing is of various degrees of rigidity, but it is of course upset constantly by the loading of the ship. The author has, however, shown us that it is possible even with a three-cylinder engine to meet a good many of these changes by a system which results really in balancing an engine, and I may remark at once that what he has shown us with regard to the change of the position of the cranks is really in effect a balancing of one set of things by means of another, all the things being parts of the engine. I think in some cases it will be found that the movements that are set up might be prevented by permitting movements in the things which set up those vibrations. In some cases I have been able to make use of that, and in connection with the vibration set up in some classes of machinery I have been able to employ the work that has hitherto been wasted and harmful work, that which used to set up vibrations in a building, and so on, and make it do the work that was intended by the machinery employed. That is to say, by avoiding all attempts in certain classes of machinery to balance the things, and on the contrary to purposely put it out of balance, I have been able, by shifting the point of application of these things, to make use of the forces that were hitherto destructive forces. The other points I would like to mention would be, to ask the author if he will, when the discussion is over, show us the effect of the rotation of either of his models when he has placed them at one of the nodal points, removing the whole of the weights, or as many of the weights as he can, from the board. I think we may perhaps in that way be taught something that will be not that which has already appeared to us, but which will confirm some of the remarks I have already made. I have some models which show some of the effects of vibration of rotating and unbalanced parts, and I am sorry I was not able to bring them here to-day; but some of them will be exhibited at the Royal Institution to-night. I would like to point out that the balancing which the author has secured is partly obtained by getting a concentration of the weight of some of his cranks. It will be seen, if we have several masses rotating about a centre and disposed as in Fig. 7, Plate LXV., the cranks I. and II. will act in unison with greater effect as against the disturbing influence of the cranks III. and IV. and of the parts connected to them than if separated by 90°. The question very largely resolves itself into one of reducing vibration by means of engines that are now usual, by a redisposition of the rotating parts or by balanced weights, as against the use of four-crank engines. Four-crank engines, we know, are being used much more than they were; but the question is whether it is not possible to arrive at the same result with existing engines, and by means of engines with less than four cranks.

Mr. A. F. **Yarrow** (Member of Council): Sir John Hay and Gentlemen, I should like to compliment Mr. Schlick most heartily upon his very valuable paper. With reference to a paragraph in which the author states that special care must be taken to avoid rocking couples, which is the essence of the problem, I question whether the marine engineer gives this subject sufficient attention, as there are many reciprocating parts in a complete engine, such as the air pump, feeding pumps, for example, which are worked from the main engine, the positicns of which, and the reciprocations of which in relation to those of the engine itself, should be carefully considered so that such reciprocating parts be arranged with a view to reduce any rocking motion. This I believe is a point mostly altogether disregarded. As a rule, their design is determined quite regardless of their effect on the vibration of the machinery; but, although these parts may not be of any considerable weight, when it is remembered that they may be so placed as to either augment the rocking motion or diminish it, it clearly becomes important that in the design this question should be kept in view. Further on the author states that rocking couples would be reduced if the low-pressure cylinder were arranged between the high and middle pressure cylinders. I think that everyone would probably agree with this statement, and I have often myself been greatly astonished that this distribution of the cylinders has not been more extensively adopted, for the advantage from a vibrating point of view is self-evident. The author mentions that for a triple-expansion engine of 7,000 I.H.P. the counter-balance weights required would amount to 44 tons. This weight seems to me to be altogether excessive. As a matter of fact, with the engines my firm constructed, indicating from 3,500 to 4,000 horse-power, counter-balance weights are reckoned not by tons but by a few cwt. This is the first time that my attention has been drawn to the different effects in causing vibration due to varying the position of the machinery. This is a most interesting point, but although, from a vibrating point of view, certain positions might be desirable, and Mr. Schlick has shown them to be so, no naval architect would like to have the position of his machinery determined wholly on this basis, because its place has to be settled with reference to numerous considerations, and there is not, as a rule, very much latitude left to the designer as to the position the machinery is to occupy. At the same time, what Mr. Schlick has indicated as regards the effect of varying positions, in increasing and diminishing vibration of the hull, should constantly be borne in mind in determining a design. It is probably somewhat difficult to indicate exactly where the nodes in a freshly designed vessel may be, and, moreover, these nodes vary according to the distribution of the load. I believe the simplest way of balancing is to fit a balance weight at each end of the crank shaft, which might consist of rotary weights only, or partly rotary and partly reciprocating weights, as I had the honour of describing to the Institution on a former occasion. This system I believe to be the most applicable to existing arrangements, and it was adopted in H.M. "Destroyers" *Havock* and *Hornet*, which have extremely lightly constructed hulls, provided with an abnormal power (rotary weights only being used in these vessels), and on the trials of these "Destroyers" the vertical vibrations were practically obliterated at all speeds; but a small amount of side vibration, as expected, was set up, owing to the rotary balance weights, necessary to neutralise the effect of the vertical moving parts, setting up a side motion, which was only noticeable at the extreme ends. I would point out, however, that a hull is much stronger sideways than vertically to resist such a vibration, and, moreover, there is, as it were, a wall of water on each side of the vessel to further retard any movement. On the whole I believe this method of balancing will be found to thoroughly meet all requirements, the weights being placed at the two ends of the crank shaft, as far apart as convenient, so that the minimum weight may produce the desired result; and I do not deem four-cylinder engines necessary for the sake of avoiding vibration when the simpler engines with three cylinders can be so designed as to answer every purpose.

Mr. J. I. **Thornycroft** (Vice-President): Sir John Hay and Gentlemen, I feel the paper which we have before us is most instructive, and I have great pleasure in making some remarks upon it. I am afraid the last speaker somewhat missed the point. This paper deals with a subject in a manner which commends itself to us. It starts with mathematical deductions, and very soon arrives at a formula only involving one constant, which for different classes of vessels only varies to what I consider a very limited extent. So that we may hope to be able to compute, after a little experience, the speed at which engines of ordinary construction should not be run. But this paper goes very much further. Taking the engines as they now stand, with the high-pressure, intermediate, and low-pressure cylinder of different weights, it shows us where these engines must be placed in a ship, so that, although not balanced, they will not cause vibration. I think this is what shipowners have been desiring for a long time. We owe to one of our neighbours in France, Mons. Normand, the idea that, in engines with three cylinders, the pistons should be equal in weight, and Mons. Normand considered (I hope I am not misinterpreting him) that the engine might then be put in the ship and cause no vibration. But Mr. Schlick has shown us that, if the engine is put in a particular part of the ship—that is, equally distant from two nodes—it would cause no vibration in the ship; but that the same engine put on the node would shake the ship violently. I think that is a most important point. There is this further: Mr. Schlick shows us that, in a tank steamer, where the low-pressure cylinder is usually put furthest from the node, the engine will cause vibration; but, by turning the engine round about, and making the product of the disturbing force multiplied by the distance from the node constant, the unbalanced engine would not then shake the ship. The point of the varying elasticity of the springs in the board that was put before us, I do not think is a point which influences the deductions that have been made. I think this paper, carefully read through, nearly exhausts the subject, and that we are now in a position to know what ships should vibrate and what ships should not. I cannot do more than express my great satisfaction at this paper, and I think the Institution is greatly indebted to Mr. Schlick for what he has laid before us.

Mr. A. Mallock (Visitor): Sir John Hay and Gentlemen, I should like to compliment Mr. Schlick on his very sound paper, and on the excellent model he has shown us. The few notes I have made on this paper I will now refer to as quickly as possible. In the first place, I think he might explain a little more clearly the excellent proposition with which he starts about the length of the "equivalent pendulum"—a proposition which is most useful and far reaching. Perhaps the simplest way to arrive at it is as follows:—Take the two well-known formulæ connecting the time in which any system oscillates and the constants of the system. They are

$$T = 2\pi\sqrt{\frac{M}{F}}, \qquad \text{and} \quad T = 2\pi\sqrt{\frac{l}{g}}.$$

In the first of these, M is the effective inertia of the system, and F the force with which the system tends to return to the equilibrium position when displaced through the unit distance. In the second, l is the length of the pendulum, which, oscillating under the action of gravity, has the period T. If then we put

$$\sqrt{\frac{M}{F}} = \sqrt{\frac{L}{g}}, \quad b = \frac{Mg}{F}.$$

Now, $Mg =$ weight of the system × unit of length, so that $\frac{Mg}{F}$ is the displacement of the system caused by a force equal to its own weight. As an example, I will take the case of a stick with one end loaded, floating upright in water. What will be the period of the vertical oscillations of the stick? The proposition shows at once that, since a weight equal to the weight of the stick acting upwards will just raise it out of the water, the period of the oscillation will be that of a pendulum whose length is equal to that of the immersed part of the stick when at rest. In place of the formula, Mr. Schlick employs to connect the period of a ship with its dimensions, I prefer this:

$$T = C\frac{L^2}{K}\sqrt{\frac{w}{w_s}}.$$

Here C is some constant, L the length of the ship, K the radius of gyration of the midship cross section about a horizontal axis, w is the total weight of the moving structure, and w_s the weight of the hull (or as much of it as contributes to the elastic reaction). Putting the formula in this shape makes it easy to examine the changes caused by various distributions of load. Mr. Schlick in his paper only refers to that form of vibration which has two nodes, though, of course, he is well aware of the existence of others. In merchant ships, no doubt, the vibration with two nodes is the important vibration; but this is not the case in our war-ships, where the engine speeds are high. The vibration with three nodes is generally the troublesome one on these ships, and if the engines are put in the positions which Mr. Schlick points out as being proper to avoid the two-node vibration, they will be nearly in the most efficient position to excite the three-node one, and *vice versâ*. To show the effect of the reduced mass at the ends of a ship in altering its periods and the position of its nodes, I will take the case of a bar diamond-shaped in plan.

Mr. R. E. **Froude**: Uniform thickness?

Mr. A. **Mallock**: Yes, of uniform thickness; and compare its behaviour with that of a rectangular bar of diameter of the short diagonal of the diamond. The frequency of the gravest order of vibration —*i.e.*, the two nodes—being taken as unity in both cases, the frequencies of the other orders are as follows nearly:—

	Rectangular Bar.	Diamond-shaped Bar.
2 nodes	1	1
3 nodes	2·76	2·26
4 nodes	5·4	3·7
5 nodes	9·1	5·9

It will be seen from this that the effect of reducing the mass at the ends of the bar is to increase the frequency of the graver orders of vibration as compared with the higher. In the case of a ship-shaped body this is even more marked, and the frequencies of the successive orders are nearly as 1 : 2 : 3 : 4, &c. The effect on the positions of the nodes is that, in the diamond-shaped bar, all the nodes are further from the ends than those of the corresponding form of vibration in the rectangular bar. To compute the periods of any given ship *à priori* is quite possible, though not elementary; but it is easy and simple to make an equivalent spring to represent any ship. Thus, take the curve of areas for the ship, and also the curve of moments. Now shape a plank of uniform thickness so that its width is proportional to the curves of moments, and load it so that the load at each point is proportional to the curve of areas, then from this model the position of the nodes in the ship can be at once obtained by experiment, and the periods by means of the formula before given, if the elastic constant (Jong's modulus) of the substance of the plank is known.

Mr. W. H. **White**: You say a curve of moments. Would you a little more fully define that?

Mr. A. **Mallock**: I mean the moment of inertia at each section.

Mr. W. H. **White**: Of the weight at each section?

Mr. A. **Mallock**: Of that part of the weight of each section which is effective in stiffening the structure.

Mr. W. H. **White**: May I ask Mr. Mallock, before he leaves the platform, if he would kindly tell us the maximum number of nodes ever observed in a vessel in which he has carried out his experiments?

Mr. A. **Mallock**: I have seen four nodes. There have been indications of others, but I have not been able to observe them.

Mr. P. **Watts** (Member of Council): Sir John Hay and Gentlemen, I wish to add my testimony to the excellence and value of this paper. Mr. Schlick has drawn attention to many interesting features, and illustrated them very beautifully with his apparatus. This mode of treatment will, I think, bear yet further consideration. In the fast cruisers which have been constructed by my firm during the last ten to fifteen years, the question of the vibrations produced by the engines has been necessarily a very important one, and has received a good deal of thought and investigation. This has been especially the case during the last few years. In considering the matter I have had the advice and assistance of my friend Mr. Mallock, who spoke just now. Many of our observed results have been in accord with the results which have been brought to our notice to-day by Mr. Schlick's experiments, but these investigations have not gone far enough to include conditions with which we have had to deal in the Elswick cruisers. We claim to have been very successful at Elswick in reducing the vibrations produced by the engines. In the *Piemonte*, in 1887, we adopted four-cylinder engines for the purpose of reducing these vibrations. The arrangement was very nearly what is shown in Fig. 6, Plate LXV., except that the two low-pressure cylinders were, I think, placed at the after-end. Engines of this type with some modifications have been fitted in each of the high-speed cruisers built at Elswick since the *Piemonte*. The vibrations caused by the machinery were unobjectionable in the *Piemonte*. In the 25 *de Mayo* we obtained some improvement. In the 9 *de Julio*, by a slight change in the position of the machinery the vibrations were still further reduced, and in the *Yoshino*, the 23-knot cruiser recently completed, they have been remarkably small at all speeds.

Mr. B. **Martell** (Vice-President): Sir John Hay and Gentlemen, I can only reiterate what has already been said with reference to the thanks of the Institution being given to Mr. Schlick, for keeping up the continuity of his experiments, and coming here before us and giving us an opportunity of having them entered in the Transactions of this Society. On this subject he may be considered one of our greatest authorities, I mean on this most interesting and difficult branch of Naval Architecture. He has given here the investigation of the causes, and he has likewise tabulated the results, and there is no doubt that the table he has given on page 352 will be found very useful indeed. His co-efficients, he states, have been obtained from actual experiments on vessels, which, of course, adds very much to their value, and it would be a very great benefit to the profession if Mr. White could do a little amongst his corps—the young gentlemen in the Royal Naval School—to induce them to take up this subject, and endeavour to carry on the investigations to the end. It is a most interesting subject, and very important. What Mr. Schlick has shown us with reference to the engines of tank vessels is of a most interesting character. He illustrates, to the satisfaction of engineers, and all here interested, that, by merely altering the position of the low-pressure engine, and putting a greater weight forward instead of aft, this enormous benefit can be obtained with regard to the vibration of the vessel. That is a matter of real practical benefit. I may say in connection with this, I was talking, only the day before yesterday, to one of the Directors of the Cunard Company, and he was telling me that by altering the pitch of the screw of the *Campania*, giving it a coarser pitch, and therefore reducing the revolutions, he was happy to say that the vibration so much complained of in the first place, had been entirely overcome, and that that vessel is one of the steadiest vessels in their fleet. I observe that the latter part of the paper really agrees with the paper Mr. Yarrow favoured us with last year, with which we were so much delighted. I can only again express my great thanks to Mr. Schlick for the trouble he has taken in bringing this before us.

Mr. R. E. Froude (Associate Member of Council): Sir John Hay and Gentlemen, I think this discussion ought to be left principally to those gentlemen (of whom there are many present) who have had practical experience of these very interesting and important problems which have been so ably treated by Mr. Schlick, of the effect of engines of different types, differently arranged and placed in different parts of the ship. And in reference to that point I am sorry that the curtailment of the time of the speakers, which has been necessary, has prevented Mr. Mallock giving us the benefit of the interesting propositions which he has had occasion to work out, and the convenient method of analysis of those effects which he has adopted when he has been consulted in reference to the placing and arrangement of engines. But I have great pleasure in rising to congratulate Mr. Schlick on the success of his paper, and the Institution on having received it. There are one or two small remarks, on points which have been raised by certain of the speakers, which I should like to make. Mr. Beaumont, I understood to refer to the effect of conditions to interrupt or prevent the growth of the vibrations. Of course there are such conditions, and it is very fortunate that there are; because, if there were not, the vibrations would grow until they broke everything to pieces. In the case of this model of Mr. Schlick's, those conditions are found partly, perhaps, in the imperfect elasticity of the wood and in the jumping of these weights, which you heard, when the vibration was large, and partly in the resistance of the air. In a ship, those conditions are found mainly in the movements which are impressed on the water by the ship in the action of vibrating. Now it is quite true, and perhaps this is what Mr. Beaumont was speaking of, that the smaller that extinctive action is, the more conspicuous will be the difference between the effect of those conditions of placing of engine, and the like, which tend to produce great vibration, and those which tend to produce less vibration; and there is no reason to suppose that Mr. Schlick has attempted in this model to give it a degree of extinction which would correspond to the degree of extinction which is found in a ship. If it so happens that in this model the degree of extinction is considerably less than in proportion to that in a ship, the effect will have been that the contrast between the favourable conditions and the unfavourable conditions in respect to vibration will have been more marked in the model than in a ship; and for my part, I think that, if Mr. Schlick has achieved that result, he has done a wise thing, because his object was to illustrate as conspicuously as possible, the difference between those contrasted conditions. One other remark in respect to something that fell from Mr. Mallock. It is quite true, as Mr. Mallock pointed out, that the scope of this paper is in some ways too much restricted for practical purposes, in that it deals only with the kind of vibrations which Mr. Schlick calls the vibration of the first order. For merchant ships that deficiency is perhaps unimportant. In regard to warships it is very important, because in my experience in attending steam trials of warships we often go through that first vibration while we are crawling out of Spithead, and the only vibration we have to fear at full speed is a vibration of a higher order. At the same time, if you read between the lines, as it were, of this paper and extend the principles made use of, the omission will be found less important. The reasoning is precisely the same as regards the effect of the placing of the engines to reduce vibration, provided you take due account of the new position of the nodes; only, of course, you have to remember that if you place the engine so as to be favourable to steadiness for one of the critical speeds it will be unfavourable in respect of another.

Professor J. H. **Biles** (Member of Council): Sir John Hay and Gentlemen, I merely want to emphasise one point which appears to me not to have been brought out in the discussion on this paper, and that is, that the evident object to strive for is to remove the vibrating cause from the engine completely. If the vibrating cause is removed, as has been shown to be possible, then the question of the position of the nodes is a matter of minor importance. The position of the nodes is one that may be determined. You may determine the position of the nodes for one condition of loading, or, if you have a ship, like a warship, which has a comparatively fixed condition of loading, you may determine the nodes and they may be constant. But it is evident when you get to sea, and you get masses of green sea on board, as you do occasionally, that the nodes will change, and that then, if you have an engine which will produce a vibrating cause, even if you have placed it in a favourable position, it will occasionally come in an unfavourable position. Therefore the great object to attain, as it seems to me, is to remove the vibrating cause by thoroughly balancing the engines. That seems to be very well within the reach of the engineers, and it is some satisfaction to naval architects to know that the question of the vibration of ships will be, to a very considerable extent, removed from their shoulders and placed on the shoulders, almost completely, of the engineers. I should like to add my thanks to those which have already been given for the exceedingly able and clear paper which we have had. The formula given is a very simple one, and may be of great use in recording data in connection with the vibration of ships. Most people occasionally meet with a state of affairs when there is a vibration set up with some number of revolutions, even if it is only a small one. If, for instance, the maximum number of revolutions you can obtain produces vibration, you will determine somewhere about half, which will also produce a small amount of vibration, and although you do not reduce the maximum amount of vibration you can get the actual period at which the vibration is produced at a lower number of revolutions. Perhaps it may be of interest to change the formula into a form which takes account not only of the moment of inertia of the section, which is not a very palpable thing, in one's mind or eye, but to change it to a form in which the length and depth come in. The moment of inertia of a section varies for similarly constructed ships as about the cube of the depth and as about the breadth. The displacement will vary as about the length, breadth, and draught, and taking those two things—length and breadth—into account for ships of constant draught, that is, for ships engaged in similar work, the formula works out for the number of revolutions varying as $\frac{d^{\frac{3}{2}}}{L^2}$, d being depth of ship, and L being length, so that the number of revolutions which would bring about synchronism with the period of vibration of the hull varies as the $\frac{3}{2}$ power of the depth, and inversely as the square of the length, for ships of the same draught. Another way of writing this is $\frac{d^2}{L^2 \times d^{\frac{1}{2}}}$.

Sir **Frederick Bramwell**, Bart., D.C.L., F.R.S. (Vice-President): This discussion brings to my recollection a form of compound engine which has pretty well disappeared from the thoughts of engineers at the present day; I mean that form where the one cylinder is within the other, and thus there is a central piston and an annular piston moving in opposite directions. It appears to me if that kind of engine could be so improved as to get over certain difficulties which, no doubt, have hitherto been attached to it, it is the particular form which, of all others, would be absolutely self-balancing.

Mr. W. H. **White**, C.B., LL.D., F.R.S. (Vice-President): Sir John Hay and Gentlemen, last year, in speaking on a paper which Mr. Schlick then did us the honour to contribute, I occupied a great deal more than the ordinary ten minutes. I do not propose to repeat what was then said as to my appreciation of the value of Mr. Schlick's services in this department. Mr. Yarrow has well expressed the feeling and opinion of ship designers. We have to put engines into places which are not altogether of our own choice. As a matter of fact the latitude of choice in the position of the engines is usually extremely small. Take a tank steamer, for example. We know that tank steamers have been built with machinery placed near the middle; but the balance of opinion has been distinctly in favour, for that class of ship, of putting the machinery far aft. Most of the vessels built up to date I believe have their machinery in that position. If we take warships there is a certain range of choice in some cases. In the *Bellona* class, for example, and in some of the torpedo gun-boats the boilers have been separated and the engines put in the centre of the ship. This arrangement, no doubt, tends to reduce vibration, and we certainly gained in having a better section of these finely formed ships in which to place our machinery and to construct the bearers on which the machinery stands. In ships of very fine forms, if the engines are placed entirely abaft the boilers, especially with twin-screws, there are often difficulties in constructing the bearers satisfactorily, and meeting other conditions. The great value of Mr. Schlick's paper to-day is that he first of all demonstrates how great may be the effect upon vibration of the position of an engine of given type in a ship. Then recognising, as a naval architect, that the choice of position is not a free one, he shows our friends and colleagues the marine engineers the way to arrange the engines so as to reduce the tendency to vibration. In this matter we do not want to put the burthen on either one class or the other, but working together we want to produce the best possible results. I heartily endorse every word that has been said in the way of thanks and appreciation of Mr. Schlick's labours. He is our gold medallist for the year, but he does not show his gratitude in the sense of his lively expectation of good things to come. From year to year he gives us papers of increasing value, and thus shows how highly he appreciates his connection with this Institution. Before I sit down I should like to make one suggestion on a point of detail. To call Mr. Mallock an expert on this matter is not fairly to describe his accomplishments on the side of theory and observation. I would suggest, Sir John, that we invite Mr. Mallock, not merely to complete his remarks on Mr. Schlick's paper, but at some succeeding meeting to give his own complete views on the vibration of ships.

Mr. O. Schlick (Member): Sir John Hay and Gentlemen, I have often regretted not having a better command of the English language, but I never regretted it so much as at the present moment. First I would like to tender my thanks to the gentlemen present for the kind reception of my paper, and then to answer the different points which come under consideration during the discussion. I must say I am not able to do that in such a way as I would desire. I would like to mention that the four-crank engine which I propose is balanced, not only in a vertical, but also in a horizontal direction. This is explained by the fact that the angles of the cranks depend entirely on the proportion of the weights of the moving parts. If the weights are correctly chosen in a vertical direction, and if the weights of the horizontally moving parts (that means especially the weights of the connecting rods, and of the cranks reduced to the circle of the cranks) have the same proportion, then the engine is balanced in every direction. This is the only way to check vibration, because it will not always be possible to do entirely away with vibration by placing the engine at a certain distance from the nodular points, as there will be too many such points in steamers with vibrations of a higher order, and these points will also alter their places with a change in the distribution of the weights. My idea was to design an engine which may be driven at any number of revolutions without causing vibrations, and which is balanced in such a way that it will rest quietly on the engine-seat, even without being fastened to it. Of course this is not to be understood literally, but it means that the bed-plate is secured to the engine-seat, only for the purpose of preventing its turning over by the rolling movements of the hull and to take up the twisting couple. I think my proposal shows the most convenient way to balance an engine in every direction without using any counter-weights. The construction being so very simple I could not believe that it was not already known; but, up till now, I have not found any trace of it. Some gentlemen had hesitations with regard to the weights which I use in connection with the model. These weights must be put on the plank for the purpose of making it vibrate at long periods. Without these weights the plank would vibrate so quickly that the phenomenon could not be properly observed by the eye. The distribution of the weights has especially an influence on the period of vibration. When the weights are concentrated in the middle and at the ends of the plank the model will only vibrate slowly, but when the weights are brought close to the nodular points the plank will vibrate very quickly. When making certain experiments, with the engine placed on a nodular point, the distribution of the weights must always be the same, otherwise the position of the nodular point would be altered. I thank you very much for the kind attention you have given to my paper.

The Chairman (Admiral the Right Hon. Sir J. Dalrymple Hay, Bart., K.C.B, D.C.L., F.R.S., Vice-President): I am sure a unanimous vote of thanks will be most heartily given to Mr. Otto Schlick for the excellent paper and the discussion which it has originated, and I trust it may not be long before he again produces before us the results of his further inquiries into those matters. I would also confirm from the Chair to Mr. Mallock the suggestion made by Mr. White, that he should not only complete the observations which he intended to make by adding a formula (of which we were deprived by the shortness of time) to our Transactions, but that he should also give us some further information on a future occasion by a paper on the whole subject.

Havre, March 24, 1894.

George Holmes, Esq.,
Secretary, Institution of Naval Architects, 5, Adelphi-terrace, London, W.C.

Dear Sir,

I have read with great interest Herr Otto Schlick's paper, "The Vibration of Steamers."

The most important of Herr Schlick's formulæ were given by me, with several others more complete, in a paper presented to the Académie des Sciences on February 27, 1892, and printed in the "Mémorial du Génie Maritime."

I enclose a printed copy of my paper, where the above formulæ may be found on page 85.

I have no doubt that the learned Austrian engineer was not aware of its existence.

I remain, dear Sir,

Yours truly,

J. A. Normand, M.I.N.A.

Hamburg, May 10, 1894.

GEORGE HOLMES, Esq.,

Secretary, Institution of Naval Architects, 5, Adelphi-terrace, London, W.C.

DEAR SIR,

With your esteemed favour of the 7th ult. I received a copy of Mr. A. Normand's letter addressed to your good self, and the "Mémorial du Génie Maritime," relating to the vibration of steamers, for which kindly accept my very best thanks.

I have read this paper with great interest, and am happy to see that Mr. Normand arrived at the same results as I did.

Regarding publication of this paper, I must confess that I had no idea of its existence, most probably for this reason, that it is not to be had at the booksellers.

On this occasion, allow me also to mention that Mr. Normand is mistaken in my nationality, as I am not an Austrian, but a German.

I am, dear Sir,

Yours very truly,

OTTO SCHLICK.

ON THE RELATION BETWEEN STRESS AND STRAIN IN THE STRUCTURE OF VESSELS.

By T. C. Read, Esq., Member of Council, and G. Stanbury, Esq., Member, Assistants to the Chief Surveyor, Lloyd's Register of Shipping.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 16th, 1894; Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

The effects of known stresses on vessels, and on parts of vessels, such as beams, frames, &c., are usually estimated by means of certain well-known formulæ, an investigation of which can be found in all standard text-books on applied mechanics. Of these formulæ, the most useful, as regards the parts acting as beams, under forces which tend to bend them, are generally given in the form—

$$\frac{p}{y} = \frac{M}{I} = \frac{E}{\rho} \qquad (1)$$

Where p is the stress at any particular point;
y the distance of the point from the neutral axis;
M the bending moment of the impressed forces;
I the moment of inertia of the section of the beam through the point, and perpendicular to the neutral axis, about a line through the neutral axis at right angles to the forces bending the beam;
E the modulus of elasticity of the material of which the beam is composed; and
ρ the radius of curvature of the neutral axis of the beam under the load considered.

From this formula is deduced that for the deflection of any point of the beam:—

$$\frac{d^2 y}{d x^2} = \frac{M}{E I} \qquad (2)$$

These formulæ are based on certain assumptions, and while these assumptions hold, the results will agree with those obtained by actual experiment, if the correct value of the modulus of elasticity be known.

Among the assumptions made in arriving at these formulæ, we would draw attention to that in which the material of the section of the beam is taken to be continuous, the longitudinal shearing forces between the layers into which the beam may be supposed to be divided being supposed to act continuously throughout the section. In a beam or frame of solid section, such as a Butterley beam or a Z or

Channel bar, this will be the case; but when the beam is composed of different parts riveted together this assumption is not correct, and the results obtained from calculation and from experiment may be expected to differ.

Thus, in the transverse framing of a vessel where the usual frame and reverse frame are adopted, the longitudinal shearing stresses are communicated from the frame to the reverse frame through the medium of the rivets; and, therefore, instead of a force acting on each particle of the longitudinal section at A B (Fig. 1, Plate LXVI.), it acts on the rivets only.

If each of the bars in Fig. 1 is $\frac{8}{20}$ in. thick, and the rivets are $\frac{7}{8}$ in., spaced seven diameters apart, the stress that in the composite beam is borne by one $\frac{7}{8}$ in. rivet is resisted in the Z section by an area of plate of $7 \times \frac{7}{8} \times \frac{8}{20} = 2{\cdot}45$ sq. in. Strain in the first case is, therefore, different and probably larger than in the second, and the formula will not hold rigidly in the first case.

When the stress and strain on the complete structure of a vessel are considered, regarding the vessel as a girder, it is easy to see that a discrepancy between calculated and actual results may very probably exist; and, as cases have come under our notice in which results obtained by experiment may be compared with the calculated results, we have thought the comparison may be of interest to the members of this Institution.

Commencing with the simplest cases, the following are the deflections which have actually been obtained from careful experiments with beams of the following sections, as compared with those obtained by the use of formula (2):—

(1) Steel frame ($5'' \times 3'' \times \frac{8}{20}''$) and reverse frame ($3'' \times 3'' \times \frac{15}{40}''$), riveted together in the usual manner, the ends supported, but not fixed in direction, on bearers 7 ft. apart, and loaded in the middle; sectional area 5·15 sq. in.

Actual deflection under a load of 10 tons	·87 in.
Deflection as calculated by formula (2)	·7 in.

(2) Iron frame ($5'' \times 3'' \times \frac{8}{16}''$) and reverse frame ($3'' \times 3'' \times \frac{7}{16}''$), tested as in first case; sectional area 6·18 sq. in.

Actual deflection under a load of 10 tons	1·1 in.
Deflection as calculated by formula	·64 in.

(3) Steel Z frame ($5'' \times 3'' \times 3'' \times \frac{8}{20}''$), tested as in case 1; sectional area 4·54 sq. in.

Actual deflection under a load of 8 tons...	·62 in.
Deflection as calculated by formula	·6 in.

(4) Steel Z frame ($5'' \times 3'' \times 2\frac{1}{2}'' \times \frac{8}{20}''$), tested as in case 1; sectional area, 3·885 sq. in.

Actual deflection under a load of 6 tons...	·5 in.
Deflection as calculated by formula	·51 in.

(5) Steel channel bar (6″ × 2½″ × 2½″ × $\frac{8}{20}$″), tested as in case 1; sectional area 4·088 sq. in.

Actual deflection under a load of 6 tons... ... ... ·5 in.
Deflection as calculated by formula ... ... ·37 in.

(6) Steel channel bar (10″ × 3½″ × 3½″), web $\frac{11}{20}$″, flanges $\frac{10}{20}$″; sectional area 8·45 sq. in., supported at ends, but not fixed in direction, bearers 12 ft. apart, loaded in middle.

Actual deflection under a load of 8·2 tons ... ... ·43 in.
Deflection as calculated by formula ... ... ·46 in.

(7) Steel channel bar (10″ × 3½″ × 3½″ × $\frac{11}{20}$″), tested as in case 6; sectional area 7·95 sq. in.

Actual deflection under a load of 8·2 tons ... ... ·39 in.
Deflection as calculated by formula ... . ·43 in.

(8) Steel channel bar (12″ × 3½″ × 3½″ × $\frac{10}{20}$″), tested as in case 6; sectional area 9 sq. in.

Actual deflection under a load of 10·2 tons ... ... ·43 in.
Deflection as calculated by formula ... ... ·37 in.

In each of the foregoing cases the modulus of elasticity has been taken as 10,000 tons. From the fact that some of the calculated results are greater than those obtained by actual experiment, it may be inferred that the value assumed for E was too small. It may, however, we think, be safely assumed that for solid sections, such as channel and Z bars, the calculated deflections obtained by using the value $E = 10{,}000$ tons will not differ to any appreciable extent from those obtained by experiment, and which occur in practice, provided the limit of elasticity of the material is not exceeded.

It will be noticed, by comparing the results obtained in cases 6, 7, and 8, that, as the thickness increases, the actual deflections compare more favourably with those obtained from the formula; a result which is doubtless due to the greater resistance of the section of greater thickness to tripping, and thus avoiding the stresses.

The built sections, illustrated in cases 1 and 2, as before stated, do not give such good results as the solid sections. The same modulus of elasticity was assumed in each of these cases, in one of which the material was iron, and in the other steel—and it will be seen that in each case the actual deflection was considerably greater than that obtained by calculation. It may, however, be remarked in passing, that although these built frames show a proportionately greater deflection under a given load than bars of solid section of the same depth, having the same moment of inertia, the ultimate strengths of these bars do not follow the same rule. Thus the frame in Case 1 had a deflection of ·7 in. under a load of 8 tons, as compared with a deflection of ·62 in. of the Z bar in Case 3 under the same load; the calculated deflections in these cases being ·56 in. and ·60 in. respectively. The load, however, in Case 1 reached 12 tons before failure occurred, when the deflection became nearly 3 in., while the Z bar in (3) which, it will be seen, has a moment of inertia only slightly less, had a deflection of over 4 in. under the same load. Thus, up to a load of 8 tons, the solid section showed the best results, and beyond this, the built section having practically the same moment of inertia, but a greater area of section, offered the greatest resistance to bending.

Passing now to the consideration of the relation between the actual deflection and the estimated deflection of loaded vessels, we have particulars of two cases in which it has been possible to make this comparison, the vessels having been carefully sighted before and after loading, and full details as to the weights and positions of the loads taken on board noted.

The first of these is a vessel of the following register dimensions: 347 ft. by 45·6 ft. by 27·2 ft.; and the load amounted to nearly 5,000 tons, placed mainly in the midship part of the vessel. A diagram *a a a* showing the position of this load, is given in Fig. 2, Plate LXVI., while the line *b b b* in the same diagram, shows the corresponding buoyancy curve, being the difference between the light and load displacements of the vessel. On account of the broken character of the weight curve, it was found more convenient to estimate the bending moments due to the load and buoyancy separately at different parts of the length, than to construct a curve of shearing force, and integrate it in the usual manner.

The load moment curve is shown by the line *c c c*, Fig. 2, and the buoyancy curve *b b b*, integrated twice in the usual manner, gives the buoyancy moment curve *d d d* in the same Fig. The difference between these curves (*c c c* and *d d d*) at any point represents the actual bending moment on the vessel at that point. It will be noticed that as the deflection due to the load only—and not the total deflection due to the weight of vessel and load—was obtained by sighting, the bending moment dealt with is only that due to the load and the buoyancy between the light and load lines.

The moments of inertia of sections of the vessel at different points of the length were then estimated; and, the results being plotted, a curve was obtained, from which the moment of inertia of any section could be found.

In estimating the moments of inertia of the different sections, a modification from the usual practice was necessary, in that the stiffness of the vessel was being estimated, and not the stress at any point. It is the common practice, in making this calculation, to reduce the area of such parts as are in tension by one-seventh, to allow for the reduction of area due to rivet holes in way of the frames. In the case under consideration, the reduction was not made; for, of the 24 in. spacing of frames, less than 1 in. was of this reduced area, the remainder being of unpunched plating, except at the butts. The slight error here introduced, of neglecting the reduction in the area of plating at the framing, is more than compensated for by the omission of that part of the deck at the middle line between the hatchways, and also the casings, &c., in the 'tween decks. These items would not be considered in an ordinary strength calculation, as the weakest section would be clear of them. On the whole, therefore, the moments of inertia used were somewhat less than they should have been; but the percentage error from these approximations would be very small. The values to be given to thin iron or steel plating and wood decks were taken from the Board of Trade Load Line Memorandum as representing the opinions of the Board's officials and of the different Register Societies, and are probably not far from the truth. Having on these assumptions obtained the curve of moment of inertia, each ordinate of the moment curve was divided by the corresponding ordinate of the moment of inertia curve, and the results plotted, as shown by the line *a a a*, Fig. 3, Plate LXVI. If the ordinate of this curve be designated by the variable z, then—

$$E\frac{d^2 y}{d x^2} = z. \qquad (3)$$

showing that the second integration of this line will give the deflection of the vessel at each point of its length.

Its first integration is given by the line *d d d*, the ordinates of which give the actual curvature of the vessel at each point; and the integration of this line is shown by the line *e e e*, which, on an exaggerated scale, is the estimated form of the vessel under the load considered.

To measure the actual deflection, it is necessary to introduce the integration constants.

Thus, the second integration of 3 can be written—

$$E y = \int\int z\, d x^2 + a x + b \qquad (4)$$

Now, $y = 0$, when $x = 0$, and when $x = l$, the length of the vessel. Hence

$$a = \frac{-\int\int z\, d x^2}{l}, \text{ and } b = 0. \qquad (5)$$

If, therefore, a line be drawn from A to B, as shown in the diagram, the ordinates of this line represent the correction, and the actual deflections of the vessel are to be measured from this line.

The deflection of the vessel between the points P P was, from careful sighting, found to be 2·31 in., and the deflections measured from the line *e e e* in the diagram are as follows:—

With modulus of elasticity assumed to be 12,000 = 2·18 in.
,, ,, ,, 11,000 = 2·38 in.
,, ,, ,, 10,000 = 2·62 in.

It will be seen that with the value 11,000 for E, a close agreement occurs between the deflection of the vessel as sighted and that obtained by the method here described.

The second case we have considered is of a vessel of the following register dimensions—300 ft. by 41·6 ft. by 21·2 ft.

The load in this case consisted of about 2,300 tons; but, at the time this was being taken on board, about 500 tons of water ballast were pumped out, leaving a net load of about 1,800 tons. The disposition of this load is shown in Fig. 4, Plate LXVII., by the line *a a a*, the part below the base line representing the weight removed, and the part above the weight added. The method employed in this case was similar to that of the previous one, and the corresponding curves are similarly marked in Fig. 4 and 5, Plate LXVII. The actual deflection as sighted amounted in this case to ·62 in., and the estimated deflection as follows:—

With modulus of elasticity assumed to be 12,000 = ·48 in.
„ „ „ 11,000 = ·53 in.
„ „ „ 10,000 = ·58 in.

These results practically confirm those obtained in the first case; and although we should have felt more confidence in our results had we been able to investigate the cases of several vessels, yet there appears to be good reason for supposing that the actual deflections of a vessel do not differ greatly from those which are obtained by calculation.

It is interesting to notice that the calculated deflection of the vessel 300 ft. long, under the most strained conditions at sea, assuming that the bending moment amidships is the displacement multiplied by $\frac{1}{35}$th of the length, would be about 2 in., and that the deflection of her screw shaft, 125 ft. long, under these circumstances would be less than $\frac{3}{8}$ in. This amount of deflection, seeing that it would only be momentary, and would very seldom occur, could be borne by the shaft without damage, a result which experience shows to be the case.

The information supplied by Professor Biles relates to an Atlantic liner 525 ft. long, 63 ft. broad, and 42 ft. moulded depth. The lines *a a*, *d d*, and *e e*, Fig. 6, Plate LXVI., correspond with those similarly marked in the previous figures, and the result of this calculation is that, neglecting the effect of the promenade deck, the deflection when the vessel is across the crest of a wave of its own length is slightly more than 6 in. measured over the extreme length of the vessel.

Allowing full value for the moment of inertia of the promenade deck, the deflection of this vessel, taking the superstructure into account, is about 4·3 in. The actual deflection probably falls within these values as limits.

It is interesting to notice that the amount of curvature as shown by the line *e e e*, over a length of 200 ft. at the after end, is only about ½ in. when the total deflection of the vessel amounts to over 6 in.

In estimating the moments of inertia of the sections of these vessels, it has occurred to us that in making a strength calculation it would be nearer the truth to allow the full value to the area in tension, and then increase the results obtained by one-sixth. Thus, assuming the rivet holes were 1 in. in diameter, and a 24-in. frame spacing, it is evident that the 23 in. of solid plating would determine the position of the neutral axis, and the disposition of the stress in the plating of the vessel, and that at the frames, where the plating was perforated by rivet holes, the stresses would adjust themselves to the reduced area. As this method is also slightly shorter than the usual one, it appears to us preferable.

We have been led to make these calculations in view of the opinions that are sometimes expressed as to very considerable bending having occurred in vessels, while loading in still water, with unexceptional distribution of cargo. The results we have obtained tend to prove that errors have occurred in the sighting when excessive sagging has been alleged, for we are convinced that well-built vessels, in which the continuity of longitudinal strength has been well preserved, do not under any ordinary condition of loading in still water sag to any serious extent, and the small deflections actually observed by Mr. T. Phillips, and recorded in his paper in the Transactions of the Institution for 1891, we think, can be accepted as representing the general condition of ordinary cargo-carrying vessels.

DISCUSSION.

Professor J. H. Cotterill (Associate Member of Council): Sir John Hay and Gentlemen, I think it is generally recognised that the modulus of elasticity of a built-up beam or a flanged beam of any kind—calculated in the usual way—will be less than that of beams of rectangular or circular sections. Rankine in his "Civil Engineering" gives an average value of 17,500,000 pounds, or about 8,000 tons as compared with 10,000, the value on which Messrs. Read and Stanbury base their calculations. Either value is much less than the modulus of elasticity of the metal itself, and the reason of that difference is very clear. As the authors of the paper point out, there is first of all the imperfect union occasioned by the riveting, and besides this the shearing stress, being chiefly concentrated on a thin web, the deflection, due to the shearing, forms an important item in the total deflection produced. The deflection produced by this cause depends upon the ratio of depth to span, whereas the deflection due to bending is proportional to the cube of the ratio of depth to span, and therefore the error, consequent upon the neglect of the deflection due to shearing, will be much greater in short lengths than in long lengths. Hence we may anticipate that, if the authors of the paper had made their experiments with shorter lengths than 7 ft. or 12 ft. as the case might be, they would have got an even smaller value of the modulus. I think, therefore, the results obtained by the experiments on flanged beams are quite in accord with what one would have expected. There is one point I should like to make a remark upon, which is not so clearly stated as it should be in most books, and that is that the error in the equation $\frac{p}{y} = \frac{M}{I}$ quoted in the paper, consequent upon the effect of the distortion of the central parts of the beam, takes effect in altering the stress due to bending only when the total shearing force on the section varies. The reason of that is plain to be seen, and has been confirmed by means of elaborate mathematical calculations. The reason is that when the shearing force on all the transverse sections of the beam is the same, the warping of each section consequent upon the shearing force is also the same. If now the demonstration of the formula is looked into, it will be seen that, although it was originally supposed that there was no distortion, yet it will hold equally good if the distortion be the same, for each of the pairs of sections considered. Hence it appears that the formula in question will not fail, even though the distortion consequent upon the shearing be considerable, provided that the shearing force is constant. As regards the second part of the paper, in which the authors compare theory and experiments with regard to the deflection of a vessel, it seems to me most interesting and valuable, as showing that the results of the equation of bending, as commonly assumed, are really reliable for the case of a vessel; the results of calculation being, as the authors remark, very much what might be expected. It shows that in an ordinary vessel, when well constructed, there is no reason to anticipate that the distribution of stress, for given values of the shearing force and bending moment, will differ materially from that indicated by the usual equations. Hence the discrepancy between theory and experiment pointed out by various high authorities on the strength of vessels cannot probably be accounted for by errors in the equations. Any difference which cannot be ascribed to incomplete data must, it would seem, be due to shearing, which, in addition to the direct action calculated by the late Professor P. Jenkins and others, has also the effect of increasing the stress due to bending by an amount which in girders with thin webs is known to be very important.

Professor J. H. **Biles** (Member of Council): Sir John Hay and Gentlemen, I should like, in the first place, to thank Messrs. Read and Stanbury for the very able and clear paper which they have given on this most interesting question. Mr. Read is well known to us as one who takes a persistent interest in the question of stress and strain of ships, and he has advanced our knowledge of this question one step further by calculating the actual deflection upon an existing ship. The value of his paper is still further enhanced by the theoretical calculation being compared with and confirmed by actual experiment. The finding of the moments of inertia of sections varying throughout the length of the ship is something that has not been frequently done before. In a paper which I read in Glasgow at the end of last year I published the stresses derived from taking account of the variation throughout the length of the bending moment for some large ships, and I think it would be of interest if Mr. Read would take those results, and from them deduce the actual deflections upon larger ships. In those results the stresses due to the ship being upon a wave of her own length, and one-twentieth of that length in height are also given, so that the results that are given there I think fairly conform to what actually exists in the ship at times, and with those bending moments, deduced on these assumptions, the deflection can be readily determined. It would be interesting to see whether the deflection upon a large Atlantic liner is very considerable. It is interesting, not only from a scientific point of view, but from a general point of view, because I have on more than one occasion heard passengers who have crossed in Atlantic liners say that the ships "whip," as they express it, and that the two ends go up and down nearly 18 in. I have heard that expressed as the result of actual observation. Mr. Read perhaps will be kind enough (there is not much work in it) to add the results of his calculation of the bending moments I have given, and of the deflection due to those bending moments to this paper, and he may be able to confirm, or otherwise, the observation of the all-knowing passenger.* There is one great value in this paper, apart from the fact that it represents new matter in relation to the deflection, and that is, that for probably, I think, the first time we have a real value for the modulus of elasticity upon the actual structure of a ship. Now, in listening to the paper that we had this morning on the vibration of steamers, and on looking through the formula there given, it occurred to me that one difficulty in making use of that formula was that, the modulus of elasticity was a comparatively unknown thing, as applied to a composite structure like a ship. That difficulty has been removed to a very considerable extent by the results given us to-day by Mr. Read and Mr. Stanbury; and a further application of the use of that modulus of elasticity at once suggests itself in addition to the question of vibration, and that is that, when we are able, as we may be, and as we are now to some extent, to measure deflections under given conditions, we shall be able to pass from those deflections, with the value of the modulus of elasticity which has been determined for us, to a determination of the actual force that causes those deflections. At the present moment we calculate the strength of a ship upon a wave (which is an assumed wave), but the waves come and act upon the ship independently of our assumptions. If, however, we can find the actual strength of a ship with the aid of this modulus of elasticity, we may be able to find out more about the forces that are brought to bear on the ship by the waves than we know at present. There is one point in Mr. Read's and Mr. Stanbury's paper that it may be worth while making a remark upon. It has been customary to take the factor of $\frac{1}{35}$th for the ratio multiplied by the length for ships of considerable size. Now we have had sufficient calculation in recent times, I think, to make us modify that factor, and there are opportunities that arise for making use of that factor of $\frac{1}{35}$th, which may sometimes lead us into considerable error. I think, therefore, it should be stated now, and it would be well perhaps if Mr. Read would say something about it, that this factor of $\frac{1}{35}$th is too low. Mr. Denny read a paper, and gave us the results of a very long series of investigations, in which I think the $\frac{1}{35}$th was modified to $\frac{1}{24}$th to $\frac{1}{30}$th, and in the paper which has been already referred to, which was read last year by me, the factor of proportion of displacement multiplied by length is as low as $\frac{1}{20}$th in a large ship with ordinary distribution of weight and buoyancy; therefore, I think, any deductions based on $\frac{1}{35}$th should be modified so to bring them up to date. Perhaps Mr. Read would be kind enough to add to the value of this paper by stating in what way the loads were applied to the sections of material that were tested. That is a matter of some importance in measuring the actual deflection which comes upon a tested bar, and it would be interesting to have the information complete on that point.

Mr. W. H. White, C.B., LL.D., F.R.S. (Vice-President): Sir John Hay and Gentlemen, I wish to express my sense of the value of the work that has been done by Messrs. Read and Stanbury. Those of us who have made similar calculations know that there is a great amount of labour and thought behind the results stated in the paper; and that in the determination of the deflection of ships by the method here employed there is a distinct advance on anything that has yet been done in that direction. There are two points of great practical importance which occurred to me on reading the paper. The test as between "built-up" girders and girders produced by the steel-maker in finished sectional forms are very striking in themselves. But if the authors had tabulated out the

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* This has been done by the authors. See page 377, and Fig. 6, Plate LXXVI.

weights per foot of the various girders (and I would suggest in publishing that this be done, and the weights per running foot given for the several girders*) it would be seen not merely that there was less deflection with solid girders, but that less weights bore the loads with less deflections. Of course that is a most important matter in relation to construction. We have been greatly helped by our friends the steel-makers in the production of finished sections which we wished to use. In the Admiralty service we have been long accustomed to use such sections, even although they involved greater first cost. With regard to the Mercantile Marine the same principle is largely applied, and it is illustrated by the paper in a very remarkable manner. The second point to which I would refer is that mentioned by Professor Biles. A calculation and an observation of deflection have been compared by the authors, and found to be in practical agreement. We know the gross, nc doubt unintentional exaggerations often made in statements as to the bending of ships. In a discussion at the Civil Engineers of the accident to the shaft of the *Umbria*, it was deliberately stated that excessive bending of the ship had broken the shaft. In another case a naval officer of considerable experience came to see me after being afloat in one of the new cruisers. He spoke generally of the ship in the highest terms, but, he said, "her elasticity is quite alarming." In reply to my request for more detailed information he said: "I do not think the movement at the extremities was more than 18 in." When it was asked, "Did anything happen to the bearings?" he said "No." "To the shaft?" "No; that was quite in order." Still in his own mind this officer contemplated the possibility of a vertical vibratory movement of 18 in.! Observations such as the authors of this paper deal with, and the calculations which they make, confirm what we know must be the facts of common experience. They will probably lead in the long run to a more modest estimate, on the part of those on board ships, of what the movements of structures may be without damage.

Mr. B. **Martell** (Vice-President): Sir John Hay and Gentlemen, I am sure that you all appreciate the services of those gentlemen who prepare papers of this character, particularly when we know that their duties are very heavy, as I know in this instance they have been, and therefore that they have very little time to spare, considering the degree of elasticity left in them after they leave their ordinary duties. I think we are very much indebted to Messrs. Read and Stanbury for preparing this very excellent paper. You all know, of course, that in making calculations of the strength of ships, there are certain assumptions to be made of certain kinds, while at the same time there is a very important point to be considered, and that is, the material of which the structure is built. We are placed in a very much better position now than we were formerly with regard to the use of mild steel, because its character is so uniform as to quality, compared with the old description of iron, that the general and uniform elasticity of it may be relied upon very much more than we could rely upon the material that we had some years ago. But it is rather surprising that, notwithstanding we have this beautiful material, up to the present paper being read I do not know of any experiments that have been made which have enabled us to arrive at anything like a correct modulus of elasticity for steel in structures. I may say that the results of these experiments which have been made, and which are embodied in Messrs. Read and Stanbury's paper, have been felt to be so valuable that, we are at the present time engaged in making an extensive series of experiments and calculations of this kind, so that we may do all we possibly can to add to the value of such knowledge as this to the naval architects of the country and to the Institution of Naval Architects in particular. Now, of course, the only way of testing the fair reliability of the assumptions, that you have to make in those calculations, is by comparing the results obtained from calculations and those that are obtained from experiments;

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* The sectional areas have been added by the authors. See pages 373 and 374.—Ed.

and it is very gratifying indeed, as Messrs. Read and Stanbury point out, that the results of their calculations should compare so fairly with the actual results that have been practically ascertained by experiment. As Messrs. Read and Stanbury have said, with the various sections and frames that we have to use at the present time, of course it is very necessary that we should know their relative strength, in order to determine how their size should be apportioned, and it will be seen in this paper, as they remark, that the Z bar and the channel bar under small stresses come out, in the experiments that have been made, better to a certain extent than the ordinary section of the frames. When you go up to greater stresses, then these sections are more equal to each other. I think what Professor Biles has said bears very largely upon this, and, as I said before, we shall endeavour to gain more information on this subject by a larger number of experiments which we propose making; in fact, we have them in hand at the present time. With regard to the deflections of ships, when loaded, that of course is a matter of very great importance, and I can bear out what Mr. White said before, and I think I have mentioned it in this room, that we were very much concerned some time ago, when a shipowner in London engaged a gentleman to make some experiments, or investigations, on board of one or two of his vessels that, he said, sagged a great deal. The consequence was that in loading them to the proper draught of water the freeboard disc was found to be under water, and consequently the ship would not carry so much, by I do not know how many tons. The gentleman undertook to make the experiments, and the result obtained by him was quite alarming. I believe the ship deflected a foot amidships, or something very excessive. I may say at once we did not believe anything of the kind, and told him so in those words; but, at the same time, it was necessary that the owner should have, not only our *ipse dixit* for it, but that we should prove to him clearly that this investigation by the gentleman he had engaged was really unreliable. I daresay it was not intentional; but it was, as Mr. White says, that in taking his sights he evidently did not understand how to do it, and, somehow or other, got into a muddle with it, and there was the result which I have stated. Messrs. Read and Stanbury refer here to the paper read in 1891 by Mr. Phillips, one of my colleagues. You know that was a very important paper, and was appreciated very highly, because he took three ships—he had sights placed before they were launched and observed the extent the vessels broke in launching; then as the weights were put in them he continually took sights, and ascertained at each step what the vessels did break. It was, of course, infinitesimal compared with the results previously stated. The very outside in one case, if I remember rightly, was 1½ in., and in the other, perhaps, 2 in. That, of course, was very satisfactory to us, as I suppose it would have been said, if it had come out otherwise, that all Lloyd's surveyors and the professional advisers of Lloyd's Society were a set of idiots, and anything they might do in the way of framing rules would be altogether different from what it ought to be. The amount these vessels broke was very small, and that is a gratifying thing for one to feel who has had anything to do with framing rules for ship construction. I may say at once, with regard to obtaining the actual deflection of vessels at sea, we have not been able, up to the present time, to get at any quantitative results, and until that is done, even although the method of calculation suggested in this paper might give results so near to those obtained by measurement in still water, we must and can only use it for a comparison until we get at some method by which such deflection can be accurately obtained, and I fancy that will not be for some time to come yet. With respect to what Professor Biles was saying as to altering the factor $\frac{1}{35}$th, which we have always been accustomed to use in estimating longitudinal stresses, I think it was Mr. John, our late colleague, who first brought that forward in this room. He wants to alter that, because Mr. Denny read a paper here and he came to the conclusion that it should be altered to $\frac{1}{24}$th or $\frac{1}{30}$th. But it must be borne in mind that Mr.

Denny took the ships that he considered under the very worst possible circumstances. All the coal amidships had been consumed, the vessel was taken under the very worst circumstances that you could possibly take her under, and therefore I can quite understand that the stress on that, as he said, was much more than we should take by the $\frac{1}{35}$th; but for purposes of comparison I cannot see much difference whether you take $\frac{1}{30}$th or $\frac{1}{35}$th. The calculation does not profess to give the quantitative results of stress. It is for purposes of comparison, and for that purpose it is as good to take $\frac{1}{35}$th as any other factor. I beg to express my thanks, and I am sure we shall all do so, to Mr. Read and Mr. Stanbury for the labour which they have bestowed on this paper.

Professor J. H. **Biles**: May I be allowed to make one remark. I think Mr. Martell is under a little misapprehension on the question of the $\frac{1}{35}$th. Mr. Read and Mr. Stanbury have not deduced any deflections based on $\frac{1}{35}$th; and, I think, if Mr. Martell would re-consider that, he would not leave the meeting under the impression that anything they have done has in any way confirmed the $\frac{1}{35}$th.

Mr. J. **Hamilton** (Member of Council): Sir John Hay, I have nothing to say but to express my admiration for this paper. Mr. Read in giving the deflection here on page 376 as 2·38 in. with a ship 347 ft. long, incidentally mentioned, as I take it, that the stress was 7 tons. I should like if, in his reply, he would say something about that. I should like to know whether that was the stress on the upper part of the girder, when this deflection was taking place, calculated by taking $\frac{1}{35}$th of the length for the bending moment. We ourselves have had a case where with 10 tons stress on the upper part of the girder in a ship about 400 ft. long, and sighted before docking, we found there was a permanent deflection (I am talking off the book) of about 4 in. It was known to be a very weak ship, and the calculated stresses she was supposed to be undergoing were worked out at 10 tons per square inch on top of the deck, taking about $\frac{1}{35}$th of the length for the bending moment.

Mr. H. A. B. **Cole** (Member): I should like to ask one question as to the fulness of these ships. Mr. Read says the load amounted to 5,000 tons, or nearly 5,000 tons, and I think it would be interesting to know whether the ships were what they call modern tramps, or whether they were fairly fine ships. I think that would be an interesting point, because, if they were of the unmitigated cargo type, and there had been a contract to carry the last half ounce, to the last half inch, they must, with a deflection of 2 in. or thereabouts, which, no doubt, is nothing out of the way, lose a certain number of tons of displacement.

Mr. T. C. **Read** (Member of Council): Sir John Hay and Gentlemen, I must first thank my old teacher in applied mechanics, Professor Cotterill, for his remarks on this paper. I am sure that when they are printed in the Transactions they will materially increase the value of the paper. Professor Biles and Mr. White have suggested some additions which I think might well be made before it is printed. If Professor Biles will let us have the particulars he has already obtained for these Atlantic steamers it will be an easy matter to construct an additional diagram, from which the deflection of these large vessels at sea can be estimated. As regards this factor of $\frac{1}{35}$th used in determining the bending moment at sea, the only purpose for which it is used is to make a rough shot at the deflection of the screw shaft of a vessel when in the most strained condition at sea. In the case we took, this deflection amounted to as little as between $\frac{1}{4}$ and $\frac{3}{8}$ths of an inch over a length of 125 ft. It did not matter under these circumstances whether there was a 25 or a 30 per cent. error in the assumption as to the value of the bending moment, and we certainly did not put the factor $\frac{1}{35}$th forward as actually representing anything that would happen, but merely because it is a factor commonly used. Professor Biles in speaking of the values $\frac{1}{24}$th to $\frac{1}{30}$th that Mr. Denny used in the last paper he read here, I think has overlooked the fact that, when Mr. Denny arrived at these factors, he neglected the variations of the pressure in the waves that the vessel was supposed to be on. That was rather an important omission, and Mr. Denny's $\frac{1}{24}$th or $\frac{1}{30}$th would certainly come up to $\frac{1}{35}$th if the variation in pressure were taken into account. Professor Biles also asked how the load was applied to the bars of which we gave the deflections. We endeavoured to apply the load as far as possible exactly at the middle of the length of the bar in each case. There was a large scale plate specially constructed on which the weights were placed, and it rested on a rounded edge about half an inch in diameter, and was placed, as before stated, as nearly as possible in the middle of the bar.

Professor J. H. Biles: I suppose that is the channel bar. If that comes exactly on the point there is not much chance of its deflecting the flange, but if it presses in that way (illustrating) it would.

Mr. T. C. Read: The edge through which the weight was applied was at right angles to the length of the bar, thus (illustrating on the blackboard). The bars at first went down without distortion, then the channel bars began to tip up before they finally settled and turned right away from the knife edge. As regards this load of 5,000 tons to which Mr. Cole referred, I may say that it was a load put in the ship for a special purpose, and was not a cargo. It was a question of getting the ship down to her load line for trial purposes, not an ordinary condition of loading, and it was not intended for the vessel to go to sea in that condition. Mr. Hamilton referred to a remark I made as to the maximum stress in the case of the first vessel investigated. Seven tons was the actual stress per square inch at the gunwale of that ship when she was in her most strained condition, that is to say, when she had this full load of 5,000 tons in her. I do not see anything inconsistent in the figures Mr. Hamilton gives for the vessel to which he referred. He said this vessel with 10 tons stress at the gunwale had a deflection of 4 in. The vessel we dealt with was 350 ft. long with a stress of 7 tons, and had a deflection of 2½ in. The two cases seem to me to run on all fours very well. I think there is nothing more I have to say, except to thank the meeting generally, on behalf of my colleague as well as myself, for the indulgence with which they have listened to our paper.

The Chairman (Admiral the Right Hon. Sir J. Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): I am sure you will desire me to express the thanks of the meeting to Mr. Read and Mr. Stanbury for the valuable and interesting paper which they have given us.

ON SHIP-SHAPED STREAM FORMS.

By D. W. Taylor, Esq., Naval Constructor, U.S.N., Associate.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 16th, 1894; Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

Doubtless the day will come when the naval architect, given the lines and speed of a ship, will be able to calculate the pressure and velocity of the water at every point of the immersed surface. That day is not yet, but the present state of our knowledge of the mechanics of fluid motion is such that we can determine completely, under certain conditions, the pressure and velocity in a perfect fluid flowing past bodies whose lines closely resemble those of actual ships.

I need scarcely point out that the relative motion of body and fluid and the pressure in the fluid are unchanged, whether the body be fixed and the fluid flow uniformly past, or the fluid at rest and the body move steadily through it.

Imagine a ship-shaped vessel afloat, to be surrounded by a sheet of rigid smooth ice, forming upon the water a thin surface coating which extends to an indefinite distance in every direction. Suppose that the bottom of the vessel is flat, and the sides vertical, so that all water-lines are alike. Imagine that at the level of the flat bottom there is a second sheet of thin smooth rigid ice indefinite in extent. Suppose that the ship is held at rest while the water between the two sheets of ice flows steadily past in a fore and aft direction.

While the changes in velocity and pressure over the immersed surface of such a vessel will differ in many respects from those found upon an ordinary ship floating upon the surface, they will have, speaking broadly, so many points of resemblance that a discussion of the phenomena appearing under the restricted conditions described above will, I hope, be not without interest, even from the point of view of practical application.

I shall have occasion to use a few well-known principles and formulæ of hydro-mechanics, which I shall not attempt to demonstrate, as they are to be found in any elementary modern treatise upon hydro-mechanics. For instance, we know from hydro-mechanics that under the conditions set forth above, the flow past our ship-shaped vessel will be in plane stream-lines only—that is to say, while a moving particle of water will change its velocity and direction of motion, it will remain always in the same horizontal plane. This simplifies our work a great deal, since the methods and formulæ for dealing with stream-lines in two dimensions (or one plane), are much simpler and shorter than those for stream-lines in three dimensions.

Referring to Fig. 1, Plate LXVIII., suppose the plane of the paper to represent a plane between two horizontal parallel smooth or frictionless sheets of glass very close together and unlimited in extent. Suppose the space between the sheets full of water, and that in some way, as, for instance, through a small hole, water is steadily added at the point O. Then the point O is called a "source." The water will diverge in straight lines in all directions from the source O, and, being introduced at a constant rate, the motion throughout will be "steady." In "steady" motion, though a moving particle may change its velocity in passing from point to point, the velocity and direction of the flow at any fixed point do not change with time. The lines traversed by particles, such as the radiating straight lines of Fig. 1, are called stream-lines. For plane steady stream-lines the motion is completely determined by either one of two functions or expressions called the "velocity potential," denoted usually by ϕ, and the "stream function" denoted usually by ψ.

It is more convenient to carry out my present investigations with the aid of the stream function only, it not being necessary to use the velocity potential except for motion in three dimensions, for which in general there is no stream function.

The stream function ψ is an expression involving variables. By giving it a definite value we obtain an equation between the variables which represents a definite stream-line corresponding to the value of ψ. The stream-lines from a source, as in Fig. 1, are best expressed in polar co-ordinates. We have for the motion in this case $\psi = s\,\theta$, where s is an arbitrary constant, and θ, as usual in polar co-ordinates, is angular distance in circular measure from a fixed straight line or axis, such as O X in the figure.

Then the stream-lines from the source O in Fig. 1 are all expressed by $\theta = \frac{\psi}{s}$, suitable value being given ψ.

Suppose, for instance, $s = 2$. Then, for $\psi = 0$, we have $\theta = 0$. This is the equation to the axis O X, which is a stream-line. If

$$\psi = \cdot 7854, \text{ we have } \theta = \frac{\cdot 7854}{2} = \cdot 3927.$$

Now $\cdot 3927$ in circular measure $= \frac{\pi}{8} = 22\frac{1}{2}^{\circ}$. Then O A, Fig. 1, making an angle of $\frac{\pi}{8}$ with O X, is the straight line denoted by $\theta = \cdot 3927$. So for every point on O A the stream function has the same value, namely, $\cdot 7854$.

The arbitrary positive constant s is a measure of the strength of the source O, being proportional to the rate of supply of fluid from the source. We may suppose that instead of fluid being steadily introduced at O, it is steadily withdrawn.

In that case O is called a "sink." The lines of flow will be straight lines converging toward O. The strength of the sink will be denoted by a negative quantity, $-s$, for instance. Then, for the system of stream-lines corresponding to a sink of strength $-s$ we have $\psi = -s\theta$.

Suppose next that we have two sources as O_1 and O_2 in Fig. 2, Plate LXVIII. Assuming for convenience that they are both of unit strength ($s_1 = s_2 = 1$) and that the angle θ is measured from the line $O_1 O_2 X$. Let the stream function for the source O_1 be denoted by ψ_1 and that for O_2 by ψ_2. Let us consider the point A at which

$$A O_1 X = \cdot 2\,\pi\,; \quad A O_2 X = \cdot 7\,\pi.$$

Then at A

$$\psi_1 = \cdot 2\,\pi.$$

$$\psi_2 = \cdot 7\,\pi.$$

We naturally ask if there is not a single stream function corresponding to the combination of the two sources O_1, O_2. There is such a function. It is an elementary result in hydrodynamics that stream functions can be combined by simple addition, the value of a compound stream function at any point being simply the sum of the component functions. Thus in the case shown in Fig. 2, if ψ denotes the compound stream functions, we have $\psi = \psi_1 + \psi_2$.

At A

$$\psi = \cdot 2\,\pi + \cdot 7\,\pi = \cdot 9\,\pi.$$

Next draw

$$A O_1 B = A O_2 B = \cdot 1\,\pi.$$

Then at B

$$\psi_1 = B O_1 X = \cdot 1\,\pi.$$

$$\psi_2 = B O_2 X = \cdot 8\,\pi.$$

$$\psi = \psi_1 + \psi_2 = \cdot 9\,\pi \text{ again.}$$

Then the value of the stream function is the same for both A and B; hence every particle which flows through B must also flow through A. By repeating the process by which the point B was determined, we can locate as many points as we please, for which

$$\psi = \psi_1 + \psi_2 = \cdot 9\,\pi\,.$$

Then a fair curve, such as O_2 B A, drawn through these spots will be the stream-line along which $\psi = \cdot 9\,\pi$ due to the two sources.

Drawing E O_2 such that E O_2 X $= \cdot 9\,\pi$, we know that the line $\psi = \cdot 9\,\pi$ must reach O_2 tangent to E O_2. For, as we approach O_2 along E O_2, ψ_1 approaches the limiting value 0, and ψ_2 retains the constant value $\cdot 9\,\pi$.

In Fig. 2, A and B are at opposite corners of the four-sided figure A C B D, a fact which makes it easy to determine any number of stream-lines corresponding to two equal sources. We have simply to draw through each source an equal number of radial lines, containing equal angles, and draw the resulting stream-lines through the proper corners of the four-sided figures formed.

Fig. 3, Plate LXVIII., shows a series of stream-lines thus determined for the two sources O_1 O_2. For convenience the lines on one side only of O_1 O_2 have been drawn. They are, of course, perfectly symmetrical on the other side.

A natural complement of Fig. 3 is Fig. 4, Plate LXVIII.

This shows in full lines the compound stream-lines corresponding to a *source* O_1 and a *sink* O_2 of equal strength.

The radial lines indicating the component stream functions are the same as for Fig. 3, but the resultant stream-lines are drawn through different corners of the quadrilaterals.

For this case, measuring θ_1 and θ_2 from O_1 O_2, we have

$$\psi_1 = \theta_1$$

$$\psi_2 = -\theta_2$$

$$\psi = \psi_1 + \psi_2 = \theta_1 - \theta_2.$$

Now $\theta_1 - \theta_2$ for any point is simply the included angle at the point between radii from the point to O_1 and O_2. Along a compound stream-line due to the sink and source combined

$$\theta_1 - \theta_2 = \psi = \text{a constant.}$$

Now, a series of points for which $\theta_1 - \theta_2$ is constant simply make up an arc of a circle through O_1 O_2. It follows that the curved stream-lines of Fig. 4 are all arcs of circles.

We can compound graphically sinks and sources of unequal strength, if the interval between the radial lines from the sinks and sources be made inversely proportional to the strength of the sink or source. Thus, if O_1 (Fig. 4) had been a source of twice the strength of the sink O_2, we would have only to draw through it twice as many radii as through O_2, and then proceed as before.

In this case the compound curves would not be arcs of circles, and half of the curves diverging from O_1 would not come back to O_2, as in Fig. 4, but would stretch away to infinity.

If we are compounding two sinks or sources, or one sink and one source, it is best to proceed graphically as above. While in theory any number may be compounded thus, it becomes necessary in practice, if proceeding graphically, to make a number of steps, handling but two simple or compound functions at each step.

The labour involved soon becomes prohibitive.

In addition to the radial system of stream-lines corresponding to a sink or source, I shall have occasion to use another elementary system.

This is the system found in a uniform stream, as indicated in Fig. 5, Plate LXIX. Here the stream-lines are all parallel straight lines, as shown. In the figure the direction of flow is taken parallel to O X, the axis of x. Hence the stream-lines are all parallel to O X.

We know from hydrodynamics that, for a uniform stream as above, the value of the stream function at any point is $v_0\, y$, where v_0 is the uniform velocity of the stream, and y is the ordinate of the point, or its perpendicular distance from O X.

A uniform stream may be compounded with a sink or source system, or with any number of them. Fig. 6, Plate LXIX., shows stream-lines resulting from the combination of a radial system from the source O with a parallel system corresponding to a uniform stream flowing from left to right. The component straight-line systems are shown dotted, and the resultant curves full.

The gain of stream-function value in passing from one parallel to the next is, of course, the same as the loss in passing from one radius to the next. Then the resultant stream functions at opposite corners of the quadrilaterals formed by the dotted component lines are equal, and the curved resultant stream-lines are drawn through such opposite corners as before.

It is evident from Fig. 6 that the line A A A is a boundary-line between the water of the uniform stream and that introduced into the uniform stream from the source O. Then if the moving water inside A A A were solidified, A A A being frictionless, no change could result in the stream-lines outside. Hence the stream-lines outside A A A are those which would be found in a uniform stream, if a frictionless solid A A A were introduced therein in the position of the figure. The practical possibilities of a thoroughly artificial conception, that of sinks and sources, now begins to appear. It is evident that we must evolve a system of sinks and sources such that, when injected into a uniform stream, the bounding curve between the water from the sinks and sources and that of the stream may closely resemble a ship's water-line.

It is convenient to give a definite name to boundary-curves, such as A A A. For lack of a better designation I shall hereafter call them stream forms.

Now the stream form A A A, in Fig. 6, is not even a closed curve, and so bears but a very remote resemblance to a ship's water-line.

Suppose, next, that, instead of combining a single source with a uniform stream, we combine with the uniform stream the compound system of Fig. 4, composed of a sink and a source of equal strength. Fig. 7, Plate LXIX., shows the result, the dotted circles showing the system due to the source O_1 and sink O_2, the parallel dotted straight lines representing the uniform stream, and the full curves the compound stream-lines. B B B, in Fig. 7, shows the stream form in this case. Fig. 7 shows a system of stream-lines very fully dealt with analytically by Rankine many years ago. It is difficult to handle this question analytically where several sinks and sources are involved. Though Rankine discussed a system where, in effect, two sources and two sinks were combined with a uniform stream, I believe he did not carry the matter further.

The pressure and velocity of the water at any point of the stream form B B B can be calculated for a given speed of stream without much difficulty.

The shape of this stream form is, however, very different from that of a ship's water-line; while, by suitably fixing the sink and source strength, we can change the proportions of this stream form as desired, we can never give it, even approximately, the shape of a practical water-line. It is necessary, then, to adopt a device which appears entirely justifiable in view of what has gone before.

We have seen that the resultant stream function for any number of systems of stream-lines is simply the sum of the stream functions of the component systems. Suppose that, instead of using one, or three, or ten sinks or sources, we adopt an indefinitely large number of sinks and sources, of small strength, not necessarily all of the same strength, extending at equal intervals for a definite distance along a straight line parallel to our uniform stream.

Thus upon a given base-line, such as $X_1 X_2$ in Fig. 8, Plate LXX., we can plot a curve C C C C, such that the ordinate above any point, as B A above the point B, is proportional to the infinitesimal strength of the sink or source at the point B. While the sink or source at any point is infinitesimal, the combined effort of an infinitely large number of such will produce a finite effect.

The line C C C C is called a sink and source line or curve, a source being indicated by a positive ordinate—above $X_1 X_2$, and a sink by a negative ordinate—below $X_1 X_2$. Now arises the question: How are we to determine for any point in the plane of the figure the value of the stream function corresponding to a sink and source line, such as C C C C in Fig. 8? The process is not difficult.

Referring to Fig. 9, Plate LXX., we see that the curve C C C C of Fig. 8 is repeated. Let us suppose that we wish to determine the value of the stream function at the point A.

Let $d\,x$ denote an elementary length of the axis $X_1 X_2$, and k an arbitrary constant. Then let the strength of sink or source at a point upon the axis be denoted by $k \times d\,x \times$ (the ordinate of sink and source line). Take the point B for instance. At this point the strength of the source is $k\,.\,\mathrm{BD}\,.\,d\,x$.

Join A B. Measure the angle A B X_2. It is equal in the figure to 2·215 in circular measure. Then the element of the value of the stream function at A corresponding to the source at B is 2·215 k . B D . dx.

Set up above B to suitable scale 2·215 . B D = B E.

Determine a sufficient number of spots, such as E, and plot through them the fair curve H G O F E K.

The area of this curve multiplied by k is evidently equal to the value of the stream function at A, corresponding to the sink and source line C C C C. For it is the sum of the elementary small stream functions at A, corresponding to the infinitely numerous small sinks and sources. The stream function corresponds, of course, to the net positive or negative area of the curve—area above $X_1 X_2$, such as O F E K, being reckoned positive, and area below, such as O G H, negative.

Put into symbols, the deduction above is very simple.

Let s denote the ordinate of the sink and source curve.
Let θ denote the angle such as A B X_2.
Then strength of source = $k . s . dx$.
Element of stream function at A = $k . s . \theta . dx$.
Stream function at A $= \int k . s . \theta . dx = k \int s \theta \, dx = k$ S, say, the integration extending the length of the sink and source curve.

The principle to be applied is comparatively simple. The work of application is laborious, and methodical procedure is necessary.

Less work is required if we adopt symmetrical sink and source lines, that is, lines such that if a source of strength, $+ s$, is found at a distance, $+ a$, on one side of the centre, a sink of strength, $- s$, is found at a distance, $- a$, on the other side. The sink and source line of Figs. 8 and 9 is symmetrical, O being the centre.

Fig. 10, Plate LXX., repeats the symmetrical sink and source line and the other curves of Fig. 9. Then, from E the point on the curve H G O F E K corresponding to B, is set down E L = $B_1 E_1$, the ordinate of the same curve at B_1. (O B = O B_1).

After determining a sufficient number of points, such as L, the fair curve O P L R is struck through.

The area O P L R is equal to the difference between O F E K and O G H, and hence is proportional to the stream function at A.

Now, B E = B D . θ ; $B_1 E_1 = B_1 D_1 . \theta_1$; and B D = $B_1 D_1$. Whence B L = B D . $(\theta - \theta_1)$.

But $\theta - \theta_1$ = B A B_1 = ϕ, say.

Hence $BL = BD \cdot \phi$.

It is evidently simpler to determine values of ϕ, and multiply them into values of B D, in order to determine O P R, rather than multiply θ and θ_1 separately, and plot the full curve H G O F K.

I shall discuss from now on, symmetrical sink and source lines only. If it is desired to handle unsymmetrical lines, care should be taken that the net area is zero, or area on source side equal to area on sink side. Otherwise there will not be equality between the water supplied by the sources and withdrawn by the sinks, and the resulting stream forms will not be finite closed curves.

We have seen how to determine, at a given point, the value of the stream function corresponding to a given sink and source line. By the systematic application of this result, we can plot results from which the stream function at any point can be readily determined without computation.

Fig. 11, Plate LXX., shows to scale a symmetrical sink and source line 200 ft. long, and varying in strength from $+10$ to -10.

To gain a proper account of the value of the stream function at any point, due to this sink and source line, it is sufficient to determine curves of values of the stream function as we go out from the axis along a suitable number of perpendicular lines, such as those marked A A in Fig. 11.

The determination of spots for these curves is materially facilitated by a table, such as Table I.

This is a table of values, in circular measure, of the angle θ of Figs. 9 and 10, the tabular "ordinate" corresponding to A T and "abscissa" to T B. When the source or sink is to the right of the foot of the ordinate, as in Figs. 9 and 10, the abscissa is reckoned as positive; and, conversely, when the source or sink is to the left of the foot of the ordinate, the abscissa is reckoned negative.

The range of Table I. is such that for a sink and source line 200 ft. long the stream function can be readily determined along twenty-one ordinates, beginning at the centre of length of the axis, and extending to a distance of 100 ft. beyond the end of the sink and source line. The range outward from the axis is 50 ft. Since the stream-lines are symmetrical in the four quadrants, we can thus readily determine the stream function from a sink and source line 200 ft. long over a space 400 ft. long and 100 ft. wide. This is ample for practical purposes.

As an illustration of the use of Table I., I show by Table II. and Fig. 12, Plate LXXI., the determination of the stream function corresponding to the sink and source line of Fig. 11 at a point P, 40 ft. out on the ordinate at station 60.

TABLE I.

Values of Angle O.

Abscissa Ord.	100	90	80	70	60	50	40	30	20	
0	3·142	3·142	3·142	3·142	3·142	3·142	3·142	3·142	3·142	0
5	3·092	3·086	3·079	3·071	3·059	3·042	3·018	2·977	2·897	5
10	3·042	3·031	3·018	3·000	2·977	2·944	2·897	2·820	2·678	10
15	2·993	2·977	3·957	2·931	2·897	2·851	2·783	2·678	2·499	15
20	2·944	2·923	2·897	2·864	2·820	2·762	2·678	2·554	2·357	20
30	2·851	2·820	2·783	2·737	2·678	2·602	2·499	2·357	2·159	30
40	2·762	2·724	2·678	2·623	2·554	2·467	2·357	2·215	2·035	40
50	2·678	2·635	2·583	2·522	2·447	2·357	2·246	2·112	1·952	50

Abscissa Ord.	10	0	− 10	− 20	− 30	− 40	− 50	− 60	− 70	
0	3·142	1·571	0	0	0	0	0	0	0	0
5	2·678	1·571	·464	·245	·165	·124	·100	·083	·071	5
10	2·357	1·571	·785	·464	·322	·245	·198	·165	·142	10
15	2·159	1·571	·983	·643	·464	·359	·291	·245	·211	15
20	2·035	1·571	1·107	·785	·588	·464	·380	·322	·278	20
30	1·893	1·571	1·249	·983	·785	·643	·540	·464	·405	30
40	1·816	1·571	1·326	1·107	·927	·785	·675	·588	·519	40
50	1·769	1·571	1·373	1·190	1·030	·896	·785	·695	·620	50

Abscissa Ord.	− 80	− 90	− 100	− 110	− 120	− 130	− 140	− 150	− 160	
0	0	0	0	0	0	0	0	0	0	0
5	·063	·056	·050	·046	·042	·038	·036	·033	·031	5
10	·124	·111	·100	·091	·083	·077	·071	·067	·063	10
15	·185	·165	·149	·136	·124	·115	·107	·100	·093	15
20	·245	·219	·198	·180	·165	·153	·142	·133	·124	20
30	·359	·322	·291	·266	·245	·227	·211	·198	·185	30
40	·464	·418	·380	·349	·322	·298	·278	·261	·245	40
50	·559	·507	·464	·427	·395	·367	·343	·322	·303	50

Abscissa Ord.	− 170	− 180	− 190	− 200	− 210	− 220	− 230	− 240	− 250	
0	0	0	0	0	0	0	0	0	0	0
5	·029	·028	·026	·025	·024	·023	·022	·021	·020	5
10	·059	·056	·053	·050	·048	·045	·043	·042	·040	10
15	·088	·083	·079	·075	·071	·068	·065	·063	·060	15
20	·117	·111	·103	·100	·095	·091	·087	·083	·80	20
30	·175	·165	·156	·149	·142	·136	·130	·124	·120	30
40	·231	·219	·207	·198	·188	·180	·172	·165	·159	40
50	·286	·271	·257	·245	·234	·223	·214	·205	·198	50

Abscissa Ord.	− 260	− 270	− 280	− 290	− 300					
0	0	0	0	0	0	0				
5	·019	·019	·018	·017	·017	5				
10	·038	·037	·036	·035	·034	10				
15	·058	·056	·054	·052	·050	15				
20	·077	·074	·071	·069	·067	20				
30	·115	·111	·107	·103	·100	30				
40	·153	·147	·142	·137	·133	40				
50	·190	·183	·177	·171	·165	50				

TABLE II.

1	Stations	± 0	± 10	± 20	± 30	± 40	± 50	± 60	± 70	± 80	± 90	± 100
2	Abscissæ of Stations: Sources...	– 60	– 50	– 40	– 30	– 20	– 10	0	+ 10	+ 20	+ 30	+ 40
	Abscissæ of Stations: Sinks ...	– 60	– 70	– 80	– 90	– 100	– 110	– 120	– 130	– 140	– 150	– 160
3	θ for Sources	·588	·675	·785	·927	1·107	1·326	1·571	1·816	2·035	2·215	2·357
4	θ for Sinks	·588	·519	·464	·418	·380	·349	·322	·298	·278	·261	·245
5	Values of ϕ	0	·156	·321	·509	·727	·977	1·249	1·518	1·757	1·954	2·112
6	Sink and Source Strength	0	1·9	3·6	5·1	6·4	7·5	8·4	9·1	9·6	9·9	10·0
7	Ordinate of curve for value of Stream function	0	0·30	1·16	2·60	4·65	7·33	10·49	13·81	16·87	19·34	21·12

In Table II., line 1, are entered the stations in pairs. Line 2 contains the abscissæ of the stations, as measured from station 60. Lines 3 and 4, values of θ, are readily filled out from Table I., for ordinate = 40, and abscissæ ranging from + 40 to – 160. Line 3, ranging from + 40 to – 60, corresponds to the sources from station 0 to 100; and line 4, ranging from – 60 to – 160, corresponds to the sinks from station 0 to – 100.

Deducting line 4 from line 3, we have in line 5 values of ϕ, corresponding to the various pairs of stations, plus and minus. Line 6 contains the corresponding sink and source strength. Multiplying the quantities in line 5 by those in line 6, we have in line 7 data for ordinates of the curve O A B (Fig. 12), whose area is proportional to the stream function at P.

We have seen that the stream function at a given point is denoted in symbols by $k \int s \, . \, \theta \, . \, d\, x = k\, S$.

The area of O A B, in Fig. 12, which is easily determined, is the value of S. Repeating the above determination for a sufficient number of spots upon the ordinate at 60, we determine data to plot a complete curve of values of S along the ordinate. It should be noted that the value of S at the axis where the ordinate = 0 is simply the area of the sink and source curve to the right of the ordinate multiplied by π, or 3·1416.

By choosing a suitable number of ordinates between 0 and 200, and calculating values of S at suitable intervals, data were obtained to plot Fig. 13, Plate LXXI., which refers to the sink and source line of Figs. 11 and 12.

Fig. 13 affords information for the determination of stream-lines corresponding to this sink and source line above. We wish, however, to investigate the stream-lines resulting from a combination of this sink and source line with a uniform stream flowing from right to left. The stream function corresponding to the uniform stream alone we have seen to be very simple, being denoted by $-v_0\,y$, where v_0 is the velocity of the uniform stream in feet per second, and y is distance from the axis. Denote this stream function by ψ_1. Let ψ_2 denote the stream function from the sink and source line, and ψ the compound function due to the combination of the two. Then $\psi_2 = k\,S$, where k is an arbitrary constant. We have then—

$$\psi = \psi_1 + \psi_2 = k\,S - v_0\,y.$$

Now, for the stream form, or boundary curve separating the fluid of the stream from that which leaves the sources and enters the sinks, we have $\psi = 0$. The axis outside of the stream form, along which both ψ_1 and $\psi_2 = 0$, also has the stream function $\psi = 0$.

For the stream form we have—

$$\psi = 0 = k\,S - v_0\,y.$$

Now, $k\,S - v_0\,y = 0$ is the equation to a straight line through the origin in Fig. 13. This line having one point, the origin fixed, can be drawn through any other point we choose. Thus, in Fig. 13, O M is drawn through O, the origin, and M, the point on the curve of S at station 0, for which $y = 20$. Then the ordinate of the stream form at the middle of its length is 20 ft.

Also, the ordinate of the stream form at each station is identical with the ordinate in Fig. 13 of the intersection of O M and the curve of S for the station in question.

Along any stream-line other than the boundary curve, ψ has a value, being positive for lines inside the boundary, and negative for lines outside, in the stream proper.

We have, in general—

$$\psi = k\,S - v_0\,y,$$

whence

$$y = \frac{k\,S}{v_0} - \frac{\psi}{v_0}.$$

This is the equation to a straight line parallel to O M (Fig. 13), and cutting the axis of y at a point $-\frac{\psi}{v_0}$. In Fig. 13 a series of such lines are shown dotted, corresponding to successive values of ψ, differing by the quantity $5\,v_0$. Each dotted line corresponds to a stream-line past the stream form, the ordinate of the stream-line at a given station being the ordinate, or value of y, in Fig. 13, at the intersection of the dotted line, and the curve of S for the station.

The stream form and surrounding stream-lines can now be plotted from Fig. 13, as shown in Fig. 14, Plate LXXI.

In plotting Fig. 14, the ordinates at each station in the first quadrant are obtained from Fig. 13, the portions of the curves in the other three quadrants being obtained by symmetry. By drawing other lines than O M through the origin in Fig. 13, we can obtain any number of stream forms of any desired proportion of total breadth to length.

Thus the stream form of Fig. 14 has the proportion $\frac{40}{200} = \frac{1}{5}$. Fig. 15, Plate LXXI., repeats this upon a different scale, and shows also two other stream forms, obtained from Fig. 13, corresponding to the lines O M_1 and O M_2. Their ratios of breadth to length are respectively $\frac{50}{200} = \frac{1}{4}$ and $\frac{30}{200} = \frac{3}{20}$.

Given the sink and source line and the proportion of breadth to length of stream form, and the stream form is completely determined. We cannot make it more full or more fine. Variations of fulness must be sought through modifications of the sink and source line. In Fig. 11 was shown the sink and source line with which we have been working heretofore. Figs. 16 and 17, Plate LXXII., show two different forms of sink and source lines. Figs. 18 and 19, Plate LXXIII., show the resulting curves of S, the process of deduction being precisely similar to that by which Fig. 13 was obtained. Fig. 18 corresponds to Fig. 16, and Fig. 19 to Fig. 17.

Any number of stream forms of different widths can be obtained from each of the three Figs. 13, 18, and 19.

Fig. 20, Plate LXXII., shows half of the three forms corresponding to the lines O M in the three figures. It is seen from them that the more the area of the sink and source line is concentrated towards its ends, the fuller is the corresponding stream form. It is possible to determine sink and source lines corresponding to any desired degree of fulness, and desired variations of shape of stream forms can be obtained very closely by modifying suitably the sink and source lines.

It may be remarked that the co-efficients of fulness of the three lines of Fig. 20 are in order ·688, ·712, and ·745.

Having shown how to determine stream forms of any desired proportions and fulness, I propose now to discuss a method for determining the velocity past and pressure upon these forms for a given velocity of the stream. If we know either the pressure or the velocity at a point, we can readily determine the other quantity. For, in motion such as we are considering, the well-known "steady motion" formula holds. If p = pressure per square foot in pounds, w = weight in pounds of the fluid per cubic foot; v = velocity in feet per second, and g = acceleration, due to gravity in feet per second, we have along a stream-line—

$$\frac{p}{w} + \frac{v^2}{2g} = \text{constant},$$

the value of the constant depending upon the stream-line.

Now, at a distance from our disturbing sink and source line, the velocity and pressure have what may be called their normal values, and are everywhere the same, since we are dealing with a uniform stream in one plane. Denote the normal pressure by p_0, and velocity by v_0. Then along any stream-line—

$$\frac{p}{w}+\frac{v^2}{2g}=\text{constant}=\frac{p_0}{w}+\frac{v^2_0}{2g}.$$

Whence—

$$p-p_0=\frac{w}{2g}(v_0^2-v^2).$$

The quantity $p-p_0$ is the difference between the normal pressure and that where the velocity is v. If we divide it by w, the weight per cubic foot of the fluid, we obtain the difference between the pressure at a point and the normal expressed in "head" or feet of fluid.

Let the velocity parallel to the axis of x be denoted by v_x. Then, if we know the inclination of the stream-line, the total velocity v is determined by the formula—

$$v=v_x\ (\text{secant of inclination}).$$

Along the stream form the secant to the inclination to the axis can be easily determined at any point, since the inclination can be measured. A peculiar property of the stream function is now found useful for the determination of v_x. It is this: If a stream function exists, its rate of variation at a given point in a given direction is a measure of the velocity at the point perpendicular to that direction. Then v_x is proportional to the rate of variation of the stream-function ψ perpendicular to the axis of x.

We have seen that—

$$\psi=k\,\mathrm{S}$$

Now the rate of variation of ψ perpendicular to the axis of x is expressed by

$$\frac{d\psi}{dy}.$$

Then—

$$\frac{d\psi}{dy}=k\frac{d\,\mathrm{S}}{dy}.$$

Now $\frac{d\,\mathrm{S}}{dy}$ is proportional to the tangent of the inclination to the axis of y of a curve of S, such as shown in Figs. 13, 18, and 19.

The natural supplement then of these three figures are Fig. 21, Plate LXXIII., Figs. 22, 23, Plate LXXIV., which are curves of the values of $\frac{d\,\mathrm{S}}{dy}$ deduced from the curves of S in Figs. 13, 18, and 19. The station to which each curve applies is noted upon the curve.

If we express in feet of water the difference between the normal pressure and that at a point where the pressure and velocity are denoted by p and v, it is, we have seen, denoted by—

$$\frac{p - p_0}{w} = \frac{v_0^2 - v^2}{2\,g}$$

and $2\,g = 64{\cdot}32$, nearly.

The variation of pressure may now be readily calculated. Table III. shows the calculation for one of the curves of Fig. 20. The only point about Table III. calling for explanation is the determination of the quantity k. We have seen that for a stream form, $k\,S - v_0\,y = 0$. Now, the stream form we are dealing with is that determined by O M in Fig. 13. At the point M we have $y = 20$, $S = 7{\cdot}97$. Then $7{\cdot}97\,k = 20\,v_0$, or $k = 2{\cdot}5094\,v_0$.

TABLE III.

For Change of Pressure along Inner Curve of Fig. 20. Derived from Fig. 13.

$v_0 = 30$, $k = 75{\cdot}28$.

1	Station	0	30	50	70	80	90	100	110	130	160	200
2	$\frac{dS}{dy}$ from Fig. 21 ..	·0994	·0840	·0612	·0204	− 0086	− ·0620	− ·1604	− ·0798	− ·0360	− ·0224	− ·0120
3	$k\frac{dS}{dy}$	7·48	6·32	4·61	1·54	− 0·65	− 4 67	− 12·08	− 6·01	− 2·71	− 1·69	− 0·90
4	$v_0 =$	25·00	25·00	25 00	25·00	25·00	25 00	25 00	25·00	25·00	25·00	25·00
5	Velocity parallel to axis $= v_x$	32·48	31·32	29·61	26·54	24·34	20·33	12·92	18·99	22·29	23·31	24·10
6	Sec. of inclination	1 000	1·006	1·016	1·034	1·051	1·077	1·083	1	1	1	1
7	Total velocity past $= v$	32·48	31·51	30·08	27·44	25·58	21·89	13·99	18·99	22·29	23·31	24·10
8	v^2	1055	993	905	753	654	479	196	361	497	543	581
9	v_0^2	625	625	625	625	625	625	625	625	625	625	625
10	$v_0^2 - v^2$	− 430	− 368	− 280	− 128	− 29	146	429	264	128	82	44
11	Pressure from normal expressed in feet of water ..	− 6·69	− 5·72	− 4·35	− 1·99	− 0·46	2 27	6·68	4·11	1·99	1·27	0·69

It is seen that k and v_0 vary together, as might be expected, since the stronger the stream the stronger must be the sinks and sources to maintain the stream form unchanged. For the case in hand I have chosen $v_0 = 30$, thirty feet per second being nearly eighteen knots per hour. Then $k = 2{\cdot}5094 \times 30 = 75{\cdot}28$.

I wish to call attention now to Fig. 24, Plate LXXV., which shows curves of variation of pressure head at a speed of 30 ft. per second past the three stream forms of Fig. 20. Corresponding curves are lettered alike. While Fig. 24 is drawn for a speed of stream of 30 ft. per second, the variation of pressure for any other speed of stream or value of v_0 is readily determined, since it is proportional to the square of the speed.

But one other point remains to be discussed in this connection. That is the variation of pressure and velocity with variation of size. The change with change of size is readily determined by the law of comparison, as set forth by Froude. For plane stream-lines this may be formulated as follows: At speeds proportional to the square roots of their linear dimensions the pressures at corresponding points of similar stream forms are directly as the linear dimensions.

Thus, in Fig. 25, Plate LXXV., the stream form A is a reproduction of the outer one of Fig. 15, and the corresponding curve of variation of pressure head for 25 foot seconds normal velocity is readily determined. The stream form B is an enlargement of the inside curve of Fig. 15, it being expanded in order to give it the same area as A. The ratio between the linear dimensions of B in Fig. 25 and the inner curve of Fig. 15 is 1·318. Then the value of the variations of pressure head were calculated at various points on the inner stream form of Fig. 15 for a speed

$$= \frac{25}{\sqrt{1 \cdot 318}} = 21 \cdot 78 \text{ foot seconds.}$$

Then these values were multiplied by 1·318, and set off above the corresponding spots of the stream form B in Fig. 25.

I have now, I trust, made clear a practicable though somewhat laborious method of determining "completely, under certain conditions, the pressure and velocity in a perfect fluid flowing past bodies whose lines closely resemble those of actual ships. I shall conclude by a few words as to the difference between our "certain conditions" and those under which actual ships move through water.

The "certain conditions" are these:—

(1) The bodies we have been discussing were assumed to have vertical sides and flat bottoms.

(2) The water was supposed to be confined at the level of the bottom by a sheet of rigid ice.

(3) The water was supposed to be confined at the surface by a sheet of rigid ice.

Removing the first and second conditions, let us consider an ordinary ship with the water confined at the surface by a sheet of rigid ice.

The water being free to move in any direction below the surface, and not restricted to horizontal motion, the disturbance produced by a ship at a given displacement will be less, and will extend to a lesser distance, than in the case of our imaginary vessel of the same displacement and length.

The ship resembles our imaginary vessel more closely at the bow and stern than amidships. Hence we would find that the increase of pressure forward and aft would be much like that on our imaginary solid, while the decrease of pressure and increase of velocity amidships would not be nearly so great as that upon the imaginary solid.

When we remove all restrictions, and consider a ship floating on the surface, we are met by the fact that the pressure at the surface cannot change, remaining constantly that of the atmosphere. Hence at the surface there will be variations of velocity and elevation only. Below the surface there will be variations of pressure, velocity, and elevation. We may expect, then, to find near the bow an elevation of the surface, due to the stream-line increase of pressure head, which approaches the theoretical elevation corresponding to stream-line pressures. This elevation or wave, however, will spread and interfere still more with the motion as it would appear amidships upon our stream forms. The steady motion formulæ will no longer apply.

It appears, then, that conclusions drawn from stream-form work should be applicable with moderate approximation to actual ships in the neighbourhood of the bow and stern—particularly the former, but that the increase of velocity amidships and other differences upon actual ships are nothing like those upon stream forms.

Consider Fig. 24, for instance. We find at the bows of the stream forms, an excess pressure head of 7 ft. or 8 ft. Now it will, I think, be conceded that, for a ship 200 ft. long, of 40 ft. beam, and moving at a speed of 18 knots, the bow wave produced would not fall far short of 7 ft. maximum height. The decrease of pressure head amidships in Fig. 24 is something like 6 ft. An actual ship would show a tendency toward depression of the surface of the water amidships, a tendency frequently somewhat masked by the presence of waves spreading aft from the bow. The depression of the surface would, however, by no means approach the 6 ft. or so reduction of pressure head below the normal found in Fig. 24.

Fortunately for the practical application of stream-form results, the disturbances at the bow and stern in the case of actual ships are of the most importance, and their phenomena show fairly close correspondence with the theoretical conclusions to be deduced from stream forms.

Thus Fig. 25 illustrates in a remarkable manner the well-known fact that length is the all-important factor when we are considering the wave-making features of a ship.

REMARKS BY MR. R. E. FROUDE, FORMING PART OF THE ABSTRACT OF THE PAPER READ BY HIM.

THIS paper describes an extension of the method described by Rankine (among other places in these Transactions for 1870[*]), whereby the stream lines of the flow of a frictionless fluid past a stationary body are obtained by compounding the stream lines of a uniform, undisturbed current with those from one or more "sources" or points at which fluid is supposed to be supplied, and towards one or more "sinks" or points at which it is supposed to be withdrawn. The outline of the stationary body is represented by that stream line which forms the boundary between the fluid which forms part of the uniform current and that which is supplied at the sources and withdrawn at the sinks; this boundary forming a closed curve if the total quantity withdrawn equals the total quantity supplied. Such closed boundary line (termed by the author a "stream form") may be made as ship-shape as may be desired (as Rankine pointed out) by using a sufficient number of sources and sinks; but the labour of using more than one or two of each on Rankine's method is practically prohibitory, even when, as here, the flow is supposed to be confined to two dimensions. The author, therefore, supposes a continuous system of infinitesimal sources disposed along the forward portion of the middle line of the intended stream form, and a similar system of sinks similarly disposed along the after portion, such that the quantity of fluid supplied or withdrawn per unit of length along the middle line may be represented by the ordinates of a fair curve.

The stream lines proper to this supposed system are then determined by means of what is called the "stream function," ordinarily denoted by ψ, which is a value attaching to each particular stream, so that the stream lines are, in fact, what we may call "Iso-ψ lines." And if the values of ψ are determined for a sufficient number of points in plan, the "Iso-ψ lines," or stream lines, may be drawn in, much as the "Isobars" of a weather chart are drawn in from the local barometric readings.

The ψ-value attaching to a particular stream denotes the aggregate quantity of flow comprised in all the streams which lie between that stream line and some other which is chosen as a datum line. Thus, in the radiating stream shown in Fig. 1, Plate LXVIII., taking the line O X as a datum, if the total quantity of fluid per second supplied at O be denoted by s, the value of ψ attaching to the stream O A is denoted by $s \times$ (angle O A X), this being the whole quantity of flow comprised within the section of angle O A X. The aggregate ψ-value for each point in a compound system is the simple sum of the values for that point in all the component systems; hence the aggregate ψ-value for any point A_1, say, in Fig. 9, Plate LXX., near the line X_1 X_2, along which the continuous sink-and-source system is disposed, may be denoted by the area of the curve H G F E K, the ordinate B E of which for any point, such as B in the line X_1 X_2, is the product of the angle A B X_2 into the quantity supplied or withdrawn per unit of length at that point. It is in this way that the ψ-values proper to the supposed continuous sink-and-source system are determined for a sufficient number of points in plan. These are again added to the ψ-values for the uniform current by another ingenious graphic device, and the "Iso-ψ" lines, or stream-lines, drawn in.

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[*] Vol. XI. p. 175.

DISCUSSION.

Professor J. H. Cotterill (Associate Member of Council): Sir John Hay and Gentlemen, I think this paper is a very interesting contribution to the study of the stream lines proper to ship-shaped forms. Starting from methods given originally by Rankine, the author, by a method which is highly original, has, I think, succeeded in giving a considerable variety to the forms introduced. Perhaps I had better first of all recall what Rankine did, and the position in which he left this subject. He published two papers on "Stream Lines" in the Philosophical Transactions, and subsequently, in letters published in *The Engineer;* he pointed out a graphical method by means of which, from any pair of simple stream lines, you could obtain any number of other lines, however, complicated. Rankine in his first paper applied this to the case of the combination of two sets of lines radiating from points or foci, or, to use the phraseology of modern treatises, of streams radiating from a sink and source. Then he combined these with a set of parallel lines, representing the motion of a uniform stream; and in that way obtained lines which represented the motion of water past a certain oval, the proportions of the oval being dependent upon the proportion between the strength of the currents proceeding from the sink and source, and the strength of the uniform current. This method is well known to all readers of Rankine's "Shipbuilding," because you find the figure there given, which is reproduced in Fig. 7 of this paper. In point of fact, as far as Fig. 7, Plate LXIX., and as far as page 390 are concerned, it is merely a reproduction of Rankine's method. Then the author remarks that the oval, or stream form, which Rankine considered, is not suitable for the forms of ships. Of course it is not, but Rankine proposed, and no doubt intended, that you should choose for the form of your water lines, not the oval itself naturally, but some of the stream lines derived from the oval, which you can place in pairs, and so get a form resembling to a much greater degree the form of the vessel, and the motion obtained must be, not precisely, but very nearly the same as the motion given by Rankine's diagram. Then, in a second paper, in order to vary his forms, he studied the case of the combination of lines, drawn not from two foci, but from four foci. That I need not enter into, as it is less important. Practically he did not vary his forms to any very great extent. That was the position in which Rankine left the subject, except that I should say he also considered the question of solids of revolution—the motion of water passing a solid of revolution—it being supposed that the water had no rotation, so that the stream lines were still plane curves—curves lying on planes passing through the axis of revolution. Practically, the case of the surfaces of revolution can be treated with not very much greater complexity or difficulty than the case of the plane motion. Now, Mr. Taylor, in order to introduce forms which bear a closer resemblance to the forms of the water lines of the vessel, has gone a step further, and a very important step, by a method which, as far as I can see, is perfectly legitimate. He has conceived the idea of combining together, not merely a single sink and source, but a series of sinks and sources, ranging along a line forming what he calls a sink-and-source line. You must imagine not merely one hole up which water pours, and a second through which water pours down, but a longitudinal slit through half of which the water pours, and through the other half of which the water sinks, and you must combine the motion thus introduced with the motion of the uniform stream. The method cannot be made intelligible without reference to the original paper, in which it is fully and clearly explained, but the above may be taken as an abstract of what the author has done. Now, by varying the form of the sink-and-source line, you can vary the forms of the lines produced, and thus the original solid, instead of being an oval, is a solid which bears a much greater resemblance to the lines of the ship, as you will see if you look at Fig. 20, Plate LXXII., and at Fig. 15, Plate LXXI. In Figs. 14 and 15, Plate LXXI., and Figs. 17 and 20, Plate LXXII., you will see drawn very interesting curves, derived from varying forms of the sink-and-source lines. Then, assuming that you have got these curves, what use shall we make of them? What Mr. Taylor does is to find the velocity, which of course Rankine had done in his simple curves, for his own case. You can find the velocity at any point of the curve, and so show what the velocity of the water is that passes the ideal form, and then by the rules of hydro-dynamics you get the pressure, and thus you get Figs. 24 and 25, Plate LXXV., which show graphically the changes of pressure of the water passing the solid. I may remark with regard to those curves, although it is rather a hypercriticism, that actually they ought to form a cusp. If you were to draw vertical lines through the bow and stern the curves should reach a cusp on these lines at the height of about 14 ft.; but it is singular to notice how very rapidly the pressure falls off. Of course we know that would be the case in a flat-ended solid like an oval of small dimensions as regards the length, but it seems that it is also so in these forms which Mr. Taylor has drawn. The pressure is in excess only just for a very short distance at the bow and at the stern of the solid. In the remainder it is all through, a minus pressure represented by the depression. No doubt, as Mr. Taylor remarks, and it is perfectly true, the excess pressure is much more nearly represented in the case of the actual vessel than the depression amidships. The depression amidships will not be nearly so great. I see no reason why the method should not be carried out for solids of revolution, if it were worth while. As to the question of utility—as to what use this may ultimately be—that is another matter; that is to say, we do not know at present how to connect the excess pressures which are created at the bow and stern of our ideal form and the minus pressure amidships with the waves that are produced, but ultimately as a preparation for that there is no doubt it is a very interesting thing to have these curves drawn for these special cases, and to see that you can, if necessary, by varying your sink-and-source line vary your curves at pleasure. There is only one other point that I would mention. Rankine attached great importance to certain lines which possess the property of being lines of single change from maximum to minimum and back again. All the lines that Mr. Taylor draws here are cases of that kind. There is a single elevation at the bow, a single elevation at the stern, and a large depression amidships. Rankine, in his earlier paper, and in his treatise on "Shipbuilding," when dealing with lines drawn from a single sink and source, pointed out that in some of his lines there would be a double change. In those lines that lie nearest the solid, if the solid were made of small transverse dimensions compared to its length, there would be not only a single change from maximum to minimum, from elevation to depression, but a double change. He attached great importance to that point, because he thought there would be less disturbance made in the surface of the water when there was only a single change than there would be with a double change. Here in these cases, which Mr. Taylor draws attention to, there is only a single change. I do not know that I can say anything else. I think the thanks of the Institution are due to Mr. Taylor for the immense labour he has taken in carrying out these calculations. One day, not perhaps for some time to come, they will very probably have their value.

Professor J. H. **Biles** (Member of Council): Sir John Hay and Gentlemen, I think it would have been of great interest and of more value to the Institution if Mr. Froude had spoken on this paper after having read it.

Mr. R. E. **Froude**: I have an opportunity of doing so.

Professor J. H. **Biles**: I am quite aware of that; but I think it would have been of assistance to us if Mr. Froude had spoken first. As the Chairman has been good enough to call on me, I would like to make one remark; it is more in the nature of a personal remark than a discussion on the question. Mr. Taylor is an officer in the American Navy, who was educated at the Naval College at Greenwich. He is, I think I may say, the only student of that College who has contributed really valuable work on the subject of resistance. He has written a very valuable work on the question, summarising all that has been done, and accompanying the summaries with a great deal of original research. He has, further than that, now added a piece of original work—whatever we may think of its value it is certainly original—to this intricate and difficult subject of resistance. This Institution is to a considerable extent the parent of the Naval College at Greenwich, and I think it is a subject of congratulation to the Institution that we get back from the other side of the world some return for the fostering care that this Institution has always exercised over the education of students. Mr. Froude has very clearly put this very difficult paper. I have had the pleasure of reading through this paper, and of hearing Mr. Froude's summary of it, and those who read it through afterwards will appreciate most highly the value of the summary that Mr. Froude has given us. The paper, though it is clearly put, is a very difficult paper to follow in reading; but the way in which Mr. Froude has put it has helped us considerably to understand it. One obviously asks the question about an intricate paper of this kind—a question which is to some extent a common and vulgar one—what is the use of it? That is a question that Professor Cotterill has touched upon to some extent, but I am sure Mr. Froude can enlighten us very much on that point. I can only see to a small extent, at present, what can be the use of it. If we can determine the lines of flow of the water round a ship, we can determine from the sectional areas, the velocities, and the actual pressures, and from those pressures we can hope to determine the actual resistance. The work that is involved in this appears to be at the moment laborious, but if we can get any system which shall enable us to determine, by calculation, the resistance of a few forms, I have no doubt that we should very soon be able to systematise those calculations in such a way as to be able very much to reduce the amount of work, and to be able to determine the resistance of any form, either by an interpolation, or by some approximate method, so that we could have at our own command that which only Mr. Froude and those who have tanks now have. That is what Mr. Taylor has in view in doing this work; and, although the work happens to be difficult and intricate, it is deserving of all the encouragement that can possibly be given to it. I should like, although it is hardly relevant to the particular point under discussion, to again call attention to a very important part of this subject of resemblance—that of surface friction. I have already remarked in this Institution that the basis of our knowledge of resistance—of our interpretation of results—is the coefficient of surface friction. At the present moment we have direct experimental confirmation only for lengths of 50 ft., and only for a speed of 8 knots. Our ships are ever increasing in speed and length, and we have no experimental confirmation of the surface friction of ships of 500 ft. long and of 20 knots speed, and the gap between 50 ft. and 500 ft. and 8 knots and 20 knots is quite sufficient, I think, to warrant experimental observation upon that most important subject. Until we get that experimental investigation, it seems to me that all our results will be doubtful; and I think this Institution, or those who take an interest in this subject, should try and bring about a set of experiments which shall determine that important point.

Mr. R. E. **Froude** (Associate Member of Council): I think, Sir John Hay and Gentlemen, that

Mr. Taylor has every reason to be congratulated on the reception of this paper, and this Institution on having received it; and that we owe thanks to Mr. Taylor for the paper, and for the valuable remarks to which it has given rise, especially the instructive summary which Professor Cotterill gave of the history of the problem of stream lines as worked out by Rankine. I think, in giving that summary, Professor Cotterill said all that can be said in the way of further explanation of the paper. Professor Biles was flattering enough to suggest that it might have been an advantage if I had prefaced the discussion by an explanation. I think I did all I could in the way of explaining the object and method of the paper in compiling the abstract which I read. I read it a little hurriedly, perhaps.

Professor J. H. Biles: I did not mean to say an explanation; I meant to say your criticism and remarks upon the paper.

Mr. R. E. Froude: If, which I do not wonder at, a good many of my hearers did not perfectly follow the method, one must remember that this subject of the stream-line flow occupied some of the greatest minds of the age a great many years in working out; and, therefore, it is certainly not surprising that persons to whom it may not be familiar to start with should fail to understand it in ten minutes. There is one remark I might make generally about the paper, which is this: the particular advantage which this method has over that of proceeding by numerous individual sinks and sources, which is really what Rankine proposed, lies in the saving of labour; and that arises in this way—that the conditions of disturbance of flow, which consist in the inflow and outflow at the sinks and sources, are here supposed to be a continuous system, represented by a fair curve. We are therefore able to represent all the effects of those disturbing conditions also by fair curves, which can be determined without computing a great number of points. That is really the advantage of this method over anything proposed before. It in this way renders practicable what was otherwise impracticable. In reference to Professor Cotterill's remark about the shape of the curves of pressure at the two ends of the body, of course, it is quite true that, for the stream form which is here worked out, which ends with an angle, the curve of pressure taken along its end must go up to a cusp. That is because the stream form ends in an angle. Now, I do not quite know why Mr. Taylor in this paper, in choosing several different sink-and-source curves to illustrate his method, has made them all end with a definite ordinate value—the maximum value, in fact—which is the cause of the stream form ending with an angle. There is no reason at all, so far as method is concerned, why the sink-and-source curve should not be made like that (illustrating), ending tangentially with zero. In that case you would get a hollow line entrance, instead of an angular entrance, for the stream form, and then you would get a pressure curve, which would be really a curve, instead of a cusp. As to the practical value of this method, of course, what may be said is this, when we have determined these pressures on the body we have no direct way of thence determining the resistance. We know very well, without troubling to plot all these pressures, that, when we have indicated the fore and aft effects of them, we shall find the net effect is zero. For in a frictionless fluid with plane surface, as here supposed, these pressures cannot so arrange themselves as to cause resistance, therefore the practical value of the method depends on having some means by which, when we have determined these pressures, we can determine the wave-making action which will result from them when the flow is not confined to a plane, and the surface has been allowed to form waves. The lack of means of doing this is the difficulty alluded to by Professor Cotterill. I, however, am more hopeful than he is, and I believe that we pretty well see our way to a very definite and distinctly expressible relation between the waves which will be produced and the imaginary undulating outline, which represents in statistical equivalent, the head pressures at the various points proper to the supposed plane surface motion. I think I cannot attempt to explain the relation here; but I have dealt with it in a lecture which I lately delivered, and when that is published, perhaps you will be able to form your own judgment upon it. I have nothing further to say, except to thank the meeting, on behalf of Mr. Taylor, for the attentive hearing which has been given to the paper.

The CHAIRMAN (Admiral the Right Hon. Sir J. Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): I am sure it is the wish of the meeting that we should pass a special vote of thanks to Mr. Taylor for having contributed this very valuable paper for our information. I am sure, also, you will give a hearty vote of thanks to Mr. Froude for the excellent abridgment he has given of it, which has made it even more interesting than it would have been in its original form. I may, I suppose, instruct Mr. Holmes to communicate to Mr. Taylor the sense of the appreciation by the meeting of his paper. Mr. Froude is here himself to receive your thanks for reading it, and for all the other information which he has been so ready to contribute.

STEAM-PRESSURE LOSSES IN MARINE ENGINES.

By C. E. Stromeyer, Esq., Member.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 16th, 1894; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

Periods of commercial depression, however unwelcome they may be, have this advantage, that they force us to reconsider, from an economical point of view, the steps which have been taken in haste during the more prosperous times; and as true economy, both in nature and the arts, is perfection, such times as those through which we have passed may be looked upon as tending to improve engine design; and I therefore hope that this paper, which contains an analysis of the losses of pressure in steam-engines, will be welcome to those who wish to examine this subject in detail, with a view to perfecting their designs. It must also not be forgotten that accurate experiments on marine engines are of quite recent date. My original object had been the detection of the reasons as to why certain losses occur in a steam-engine, and, if possible, to suggest remedies; but at the very outset serious difficulties presented themselves which prevented any practical solution. In fact, when discussing economy, the question of £ s. d. cannot be neglected, and with it, it is not in my power to deal satisfactorily. Thus, while examining the very simple question of steam friction in the main steam pipe, it seemed that the most correct diameter, from a so-called theoretical standpoint, would be that one which would transmit the greatest quantity of steam with the least possible loss. Now, one of the losses in the steam pipe is that due to friction, whereby the available pressure is reduced; the other is that due to radiation, whereby the volume of steam is diminished, and an injurious amount of water thrown into the engines. With such dimensions as are now customary the main steam pipe is responsible for a loss of about 2 per cent. of pressure and ½ per cent. of condensed steam. By doubling the diameter of the pipe, the first of these losses is reduced to ½ per cent., and the second (on account of the increased radiating surface) is increased to 1 per cent., so that the total loss would be reduced from 2½ per cent. to 1½ per cent. Mathematically it can be shown that the larger of these two pipes is *the* most efficient; so that any further increase in diameter would increase the loss. Thus, if the diameter were increased threefold, the frictional loss would be reduced to $\frac{2}{9}$ per cent., and the condensation increased to 1½ per cent.—the total loss being 1·722 per cent. The question now arises: how is it that practical engineers have not adopted larger pipes? For, however expensive the methods may be by which practical engineers arrive at their results—and they include innumerable failures—their results are ultimately far more perfect than those attained by theory alone. The reason is not far to seek. Generally, theory, as in this case, has taken no account of the money question; but as soon as this is done, as soon as the loss of pressure is compared, not only with the loss by condensation, but also with the interest, insurance, depreciation and reduced earning power of the capital invested in the pipe and its valves, it will be found that the present practice, at least as regards steam-pipes and stop valves, is the most economical, and therefore the most perfect.

The difficulty of finding the best proportions for the steam passages of an engine is, of course, far greater. Thus, besides the question of first cost, interest, &c., there are the following: Loss of pressure due to wire-drawing at the steam ports; to bends in the valves and ports and receivers; loss of pressure, coupled with increase of volume, due to the volumes of receivers and steam passages; condensation, due to radiation, is affected by the size of steam ports and receivers, and also by the piston speed; and lastly, but not least, there are steam leakages past the slide valves and pistons.

To strike a balance between these numerous items, even if reliable information on each point were available, is a task which few would care to undertake; but, as will shortly be seen, the available information is not reliable, and all that I have been able to do on this occasion, is to submit a careful analysis of four typical trials, pointing out as to where possible errors may be hidden, and then to place the results in such a form that they can be used for a rough estimate as to whether certain customary dimensions are best suited for the special purposes intended. And, as the possible errors are chiefly due to imperfections in the indicator, the analysis which I have carried out ought to lead to improvements in engine trials, so as to enable one to obtain more reliable information.

While working at the diagram which accompanied my remarks on Mr. Edwards' paper of last year's meeting of this Institution (Vol. XXXIV., p. 226, and Plate XXV.), it was found rather difficult to harmonise the two sets of cards, the one being taken on an indicator actuated by a string attached, as is usual, to its engine; the other taken on the same indicator, but actuated by a string which was attached to the lever of the adjoining engine. Experiments, and the careful researches of Mr. H. W. Brightmore (Minutes of the Proceedings of the Institute of Civil Engineers, 1886, Vol. LXXXIII., p. 20), convinced me that this discrepancy was due to the friction of the indicator drum and the pulleys, which affected the stretch of the indicator string; and, in order to get the two corresponding indicator cards to agree, it was necessary to shift the pressure curve produced during the down stroke towards the bottom end of the card, and that produced during the up stroke towards the top end of the card, the relative displacement amounting to about $\frac{1}{10}$ in. for a five-foot indicator string, even when the drum and pulleys were well oiled. But there are other errors which were shown up during the discussion of Mr. Brightmore's paper, and of which the following is a short summary.

By puncturing an indicator card electrically while the piston was passing ten equidistant points of its stroke, spots were obtained which showed that the indicator string altered its length during the up and down stroke by about ·4 per cent. of its length. But the increase and decrease of tension, which produces this variation of length, also depends on the inertia of the indicator drum, as will be seen by the results of experiments mentioned during the discussion by Mr. Mair, and contained in the following table:—

TABLE I.

TENSIONS IN POUNDS ON INDICATOR STRINGS DURING THE UP AND DOWN STROKE.

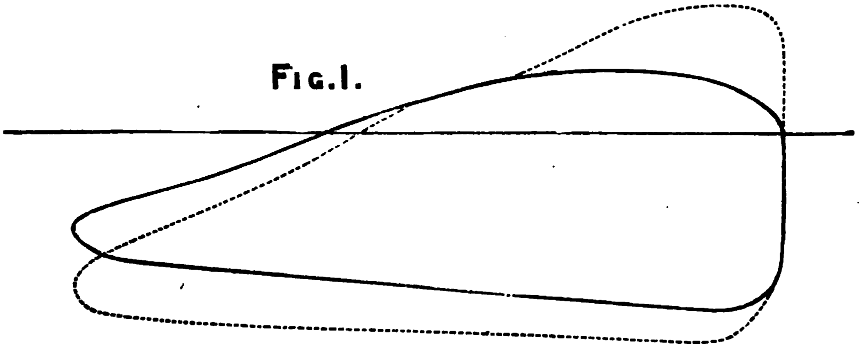
No. of Revolutions.	Slow.	90.	150.	200.	260.	300.	420.	650.
Richard's Indicator	$3\frac{1}{4}$—$4\frac{1}{4}$	$3\frac{3}{4}$—4	—	3—5	—	1–6	—	—
Crossby's ,, ...	$3\frac{1}{4}$—6	—	—	—	—	—	$4\frac{1}{4}$–$4\frac{3}{4}$	$2\frac{3}{4}$—6
Tabor's ,, ...	$1\frac{3}{4}$—$2\frac{1}{4}$	2–$2\frac{1}{2}$	—	—	—	1—3	—	—
Thomson's ,, ...	$2\frac{3}{4}$—$4\frac{3}{4}$	$3\frac{1}{4}$—$4\frac{3}{4}$	$4\frac{1}{2}$—5	—	$2\frac{3}{4}$—$6\frac{3}{4}$	—	—	—

The differences of tension in the column marked "slow" are, of course, due to the increased tension of the drum spring as it is unwound, and because the stretch of the string is proportional to this tension and also to the amount of unwinding, it follows that the drum motion is strictly proportional to the lever motion; but all this is altered, on account of the inertia of the drum, when the number of revolutions is increased, the tendency being for the drum to overshoot its true position at either end of the stroke.

Errors which are of equal, if not greater, importance than the above, are those connected with the motion of the indicator piston. Indicator springs are supposed to be graduated at a temperature of 212° F., and although this may be correct for the high-pressure cylinder, it is evidently wrong for the low-pressure one, which is sufficiently cool to be handled without burning one's self. But any allowance which might suggest itself as necessary, appears insignificant when it is remembered that a comparison amongst individual springs shows that their readings differ by as much as 4 per cent., and also that these readings are different for the up stroke and down stroke, Professor Kennedy mentioning cases during the discussion in which the difference amounted to 8 per cent. Therefore, in extreme cases it is possible that the exhaust line of the high-pressure engine is 6 per cent. higher, and the pressure line of the next engine is 6 per cent. lower than it should be, and a comparison of the two for the purpose of estimating the steam friction, is a very unreliable one.

A point which Mr. Brightmore has not discussed, is the effect produced on the indicator card by restrictions in the steam pipes leading to the indicator. This is illustrated in Fig. 1, the dotted line representing the indicator diagram taken with the cock full open, and the black line representing it with the cock partly closed. The slope of the exhaust line in the latter case suggests very forcibly that in fast-running engines part of the back pressure may after all not be due to restrictions in the exhaust passages of the engine, but to indicator pipes which are either too long or too small, or perhaps choked with grease.

FIG. 1.



The question of indicator spring vibrations was also discussed by Mr. Brightmore, who mentioned that they amount to $8{\cdot}1\sqrt{e}$ per second; where e is the number of pounds per inch to which the spring has been graduated. But in practice the oscillations are found to be about 10 per cent. fewer. In the indicator cards which I have examined these vibrations are started sometimes at either end of the stroke, sometimes near its middle. In this latter case, the only explanation seems to be, that the knock of one of the engines is their chief cause, and then, of course, there is no reason why this should not also be the cause of vibration at either end of the stroke, assisted, no doubt, by the suddenness of the steam admission or the exhaust, and, to my mind, at least, seriously aggravated by water in the connecting pipes. In fact, the vertical pipes which lead to the indicator, and particularly if the indicator is placed low, must frequently be filled with water, and in that case the pressure from the cylinder cannot possibly be transmitted to the indicator with sufficient rapidity or uniformity. It would, perhaps, be an improvement to drill the holes for the indicator pipes into the steam ports, taking care that they are inclined in such a way, that no water can collect in them, and in such positions, that the pressure readings are not affected by the reaction of the passing steam.

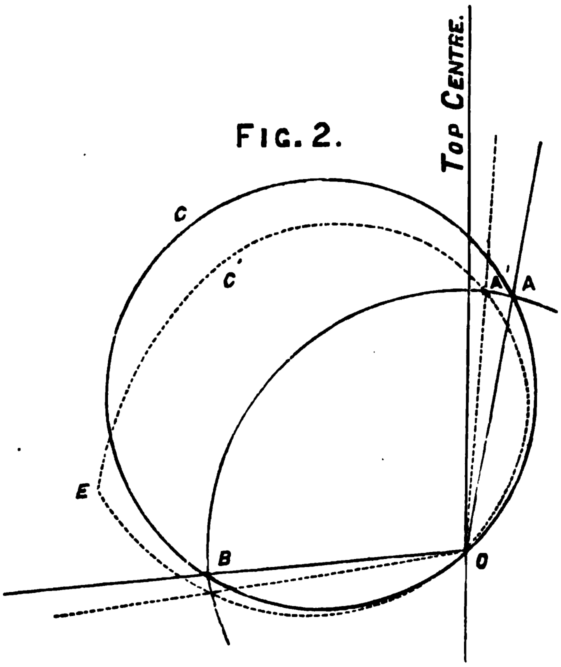
Considerable trouble has been taken to draw the curves on Plates LXXVI. to LXXX. with the greatest accuracy, and they will, I hope, be useful to those who wish to examine any particular point more in detail than is possible at present. This is true more particularly of Engine A, whose cards were taken by myself. As I have introduced several innovations which greatly facilitate the work, a short description of my proceedings is necessary.

The top curve on Plate LXXVI. represents the varying steam pressure in the bottom end of the high-pressure cylinder of Engine A (*full gear*). The scale is marked at the side; as will be seen, it is a logarithmic one, which, besides having the advantage of magnifying the lower pressures, enables one to reduce some complicated calculations to simple measurements. The second curve on this Plate represents the varying volume of the high-pressure cylinder bottom. It, too, is marked off on a logarithmic scale, shown at the centre of the diagram; but its length is 17-16ths of that of the pressure scale, and, as $p^{\frac{16}{17}} v$ is proportional to the weight of steam, all that is now necessary in order to obtain the quantity of steam for any position of the piston, is to measure the distance between the steam pressure line and the volume line. The steam weights which have thus been ascertained are represented by the lowest curve on Plate LXXVI., and this in turn has been utilised to measure the flow of steam, the weight per second being simply proportional to the tangent of the angle of inclination of the curve. Besides these three curves, the valve motions are also represented on this Plate. They enable one to see at a glance not only at what point steam is admitted, cut off, exhausted, and compressed, but the relative sectional area of any opening to its piston area is correctly represented in per cent. (see Table VI.), and all the information for ascertaining the co-efficient of steam friction is now at hand. But the work of estimating these co-efficients has only been carried out in one case, Engine A (*full gear*); (see Plate LXXVII., and Tables II., III., and IV.); because, as will be seen in the Tables or the Diagrams, the openings and closings of the steam ports, as obtained from the builders, do not agree with those points in the Diagram, at which it is evident that they have actually closed or opened. In fact, in the case under consideration, there would seem to be a very serious angular displacement of the eccentrics.

The reason is not far to seek. It is due simply to the spring of the eccentric straps, rods, links, and pins. In Fig. 2, next page, let the black lines represent part of a Zeuner's slide valve motion diagram, the travel being 4½ in. and the lap 1⅝ in. Now, supposing that the slide valve lags behind ⅛ in. on account of friction, then evidently during its up stroke its motions will be represented by the dotted half-circle $o\ a'\ c'$. For a short period the valve will now remain at rest from c' to e, until the eccentric gear has been sprung in an opposite sense, and its motion will then be represented by the dotted circle $e\ b'\ o$. The important point to notice is, that the valve opening takes place, not at a, but 6° further on, at a', and the cut-off is similarly displaced 4° from b

to *b′*, while the valve opening is reduced from $\frac{7}{8}$ in. to $\frac{5}{8}$ in., or nearly 30 per cent. The larger the lap, the greater is, of course, the apparent angular displacement of the eccentric, and that is the reason why, in the case of Engine A (*linked up*), Plate LXXVIII., the valve positions do not at all agree with the pressure and steam weight diagrams. In the absence of more reliable data, I have not ventured to adjust the valve diagrams to correspond with the curves, as this would be open to the objection that it was mere guesswork; and, as it is obviously impossible to draw any conclusions as to the flow of steam from this particular case, unless corrections are made, the calculations have been confined to Engine A (*full gear*). The results are contained in Tables II., III., and IV. The first contains the calculations of the value C_1, which is the co-efficient of steam friction between the boiler and the high-pressure cylinder, referred to the high-pressure port opening. The lower figures are evidently too high, due to the displacement of the valve motion, and a rough mean of C_1 is ·002. Table III. contains the calculations for C_2, which is the co-efficient ot steam friction between the high-pressure and the low-pressure cylinders, referred to either valve opening. Its value is a little higher than the last, say ·0022. Table IV. contains the value of C_3, the co-efficient of steam friction between the low-pressure cylinder and the condenser, referred to the low-pressure exhaust port opening. It is less than either the two others, say ·0012. Similar calculations could be carried out for the three other trials; but, as already mentioned, some very important allowances ought first to be made for inaccuracies in the slide valve motions, not only as regards their points of opening and closing, but also as regards the amount of opening.

FIG. 2.



An examination of the high-pressure bottom steam weight curves at about 180° of Engine A (*linked up*), Plate LXXVIII., reveals what appears to be a case of piston leakage. At any rate, there is an increase of the steam weight in the high-pressure bottom, and a decrease, though a slight one, in the high-pressure top. This view is confirmed by an examination of the pressure curves at the top of the plate, there being a distinct irregularity in the top end curve as it passes 180°. Perhaps this is a leakage of water, which evaporates immediately after it has passed the piston.

TABLE II.

ENGINE A. (FULL GEAR.)

VALUES OF C_1.

Position of H.P. Crank.	P_1 Boiler Pressure Absolute.	ΔP. Difference of Pressure.	a_1 Steam Port Area.	q_1 Weight of Steam per Second.	$C_1 = \frac{q_1}{a_1 \sqrt{P_1 . \Delta P}}$.
Degrees.	lbs.	lbs.	sq. in.	lbs.	
Steam from Boiler into H.P. Bottom.					
340 to 20	—	—	—	—	Excessive vibrations
30	135	1	27	·6	·0019
40	,,	3	28	·9	·0016
50	,,	3	28	1·0	·0018
60	,,	3½	26	1·3	·0023
70	,,	4	22	1·5	·0029
80	,,	4½	17·5	1·6	·0042
90	,,	6½	11·5	1·4	·0047
100	,,	10	4	1·2	·0088
Steam from Boiler into H.P. Top.					
180 to 210	—	—	—	—	Excessive vibrations
220	135	7½	19	·9	·0015
230	,,	7½	18	1·1	·0019
240	,,	8½	16·5	1·1	·0020
250	,,	9½	13	1·5	·0032
260	,,	11	9	1·4	·0040
270	,,	14	3	1·2	·0092

TABLE III.

ENGINE A. (FULL GEAR.)

VALUES OF C_2.

Angular Position of H.P. Crank.	P_2 H.P. Exhaust Pressure.	ΔP. Difference of Pressure between H.P. and L.P. Cylinders.	A_1 Area of H.P. Exhaust.	a_2 Area of L.P. Steam Port.	Q_1 Weight of Steam leaving H.P. Cylinder per second.	q_2 Weight of Steam entering L.P. Cylinder per Second.	$C_2 = \sqrt{\frac{Q_1^2 . a_2^2 + q_2^2 . A_1^2}{A_1^2 . a_2^2 . P_2 . \Delta P.}}$
Degrees.	lbs.	lbs.	sq. in.	sq. in.	lbs.	lbs.	
From H.P. Bottom to L.P. Top.							
140	86	61·8	3	46	·20	·95	·0012
150	76	53·2	10	36	1·40	1·10	·0023
From H.P. Bottom to L.P. Bottom. The curves are too irregular. (Vibrations.)							
From H.P. Top to L.P. Bottom.							
320	68	39·0	14	70	1·7	1·4	·0024
330	54	25·0	22	60	1·8	1·8	·0024
340	40	10·8	29	45	1·5	1·8	·0032
350	32·5	2·3	33	27	·9	1·7	·0062
From H.P. Top to L.P. Top.							
110	31	3·3	25	43	·40	·70	·0023
120	30·5	3·5	17	50	·35	·70	·0024
130	28·5	2·7	9	50	·40	·70	·0060

TABLE IV.

ENGINE A. (FULL GEAR.)

VALUES OF C_3.

Angular Position of H.P. Crank.	P_3 Exhaust Pressure Absolute.	ΔP. Difference of Pressure to Condenser.	A_3 Exhaust Port Area.	Q_3 Weight of Steam leaving L.P. Cylinder per second.	$C_3 = \frac{Q_3}{A_3 \sqrt{P_3 . \Delta P}}$
Degrees.	lbs.	lbs.	sq. in.	lbs.	
		L.P. Bottom exhausting into Condenser.			
50	15·4	12 4	26	·15	·0001
60	14·0	11·0	54	·80	·0012
70	11·8	8·8	80	1·40	·0017
80	10·2	7·2	104	1·05	·0012
90	8·9	5·9	104	·95	·0013
100	8·2	5·2	104	·75	0011
110	7 6	4·6	104	·55	0009
120	7·3	4·3	104	·50	·0008
130	6·9	3·9	104	·70	·0013
140	6·4	3·4	104	·70	·0014
150	6·2	3·2	104	·70	·0015
160	6·1	3·1	104	·55	·0012
170	6·1	3·1	104	·55	·0012
180	6·1	3·1	91	·40	·0010
190	6·1	3·1	63	·55	·0020
200	5·8	2·8	34	·55	·0040
		L.P. Top exhausting into Condenser.			
220 to 280	—	—	—	—	Excessive vibrations
290	5·7	2·7	104	·50	·0012
300	5·5	2·5	104	·35	·0009
310	5·2	2·2	104	·45	·0013
320	5·2	2 2	104	·30	·0008
330	5·2	2·2	104	·45	·0013
340	5·1	2·1	104	·50	·0015
350	5·0	2·0	104	·60	·0018
0	4·9	1·9	104	·30	·0009
10	5·0	2·0	96	·30	·0010
20	5·0	2·0	72	·35	·0015
30	5·0	2·0	40	·40	·0032
40	5·1	2·1	6	·20	·0102

Another serious leakage seems to exist in both top end cylinders of Engine A (*linked up*), Plate LXXVIII. At least, subsequent to the expansion period, and while the steam weight should be diminishing, it remains practically constant, the exhaust not commencing till long after the respective centres have been passed. Perhaps these irregularities are due to spring in the valve gear, or to presence of air in the condenser.

The cases of Engine B, both (*full gear*) and (*throttled*), Plates LXXIX. and LXXX., are of special interest, because of the high piston speed (855 ft. per minute), and large port opening (see Tables VI. and VII.). The disjointed nature of the steam pressure and steam weight curves (Plates IV. and V.) is due to the absence of indicator cards taken with the string attached to the adjoining engine, and no idea can be formed as to what takes place at the ends of the strokes. As might be expected, the steam weight curve is steeper for the high-pressure engine (*full gear*) than for the other (*throttled*) case. But, contrary to expectation, there is no great difference in the other cylinders. An examination of the pressure curves also shows that there is no gain as regards difference of pressure between the various cylinders by working a large-ported engine at a slow speed. This seems so contrary to expectation that I feel inclined to attribute the apparent differences of pressure between the various cylinders to the inaccuracies of the indicator, which have been already pointed out. At any rate, I would not venture to draw the conclusion which suggests itself, that the steam ports of fast running engines might be reduced. The roundness of the compression steam weight curves of this engine seems to indicate a leakage past the piston valves.

As a test of the accuracy or otherwise of this analysis, it will not be amiss to compare the steam weights of the various cylinders. This is easily done by subtracting the lower horizontal lines of the steam weight curves (compressions) (Plates LXXVII. to LXXX.) from the upper ones (expansion).

TABLE V.

WEIGHTS OF STEAM WHICH HAVE PASSED THROUGH THE VARIOUS CYLINDERS.

	Engine A.		Engine B.	
	Full Gear.	Linked Up.	Full Gear.	Throttled.
H.P. cylinder bottom	·999	·443	7·48	6·22
,, ,, top	·907	·304	7·58	5·97
,, ,, total	1·896	·747	15·06	12·19
M.P. ,, bottom	—	—	7·86	7·14
,, ,, top	—	—	7·06	6·31
,, ,, total	—	—	14·92	13·45
L.P. ,, bottom	1·047	·467	7·05	6·11
,, ,, top	·785	·283	5·87	6·07
,, ,, total	1·832	·730	12·92	12·18

With one exception, viz., Engine B (*throttled*), the loss of steam agrees fairly well with the amount which ought to condense due to the work done in the engine, and therefore it would even seem that the serious errors which I have pointed out at the beginning of this paper as being possible, have either not occurred, or have balanced each other. Possibly, too, the cards, which were selected for this paper from a number taken during one trial run, were not taken simultaneously, as was the case with the cards of Engine A. I have preferred to present my analysis in full, instead of only giving results, and trust that the discrepancies, to which I myself have drawn attention, will not be looked upon as being due to negligent work, but rather to honesty of purpose.

TABLE VI.

ENGINE A.

Cylinders	21 + 45 × 33
Ratio of cylinder volumes	4·6
	Cub. In.
Volume swept per stroke by H.P. piston	11,400
„ „ L.P. „	52,400
Receiver volume...	19,400
	Per Cent.
Volume of H.P. clearances ÷ H.P. cylinder volume	9·5
„ L P. „ + L.P. „	7·9
	Sq. In.
Sectional area of main steam pipe, 6 in. diameter, 8 ft.	28
„ „ H.P. „ ports, 1½ in. deep	33
„ „ H.P. exhaust port	88
„ „ H.P. „ passage	48
„ „ L.P. steam ports, 1¼ in. deep (double)	103
„ „ L.P. exhaust port	147
„ „ Condenser inlet	140
	Per Cent.
Sectional area of main steam pipe ÷ H.P. piston area	6·4
„ „ H.P. „ port ÷ H.P. „	9·5
„ „ L.P. „ „ ÷ L.P. „	6·5
„ „ L.P. exhaust „ ÷ L.P. „	9·2

	Revols.	Steam.	Receiver.	Vacuum.
While running (full gear)	95	120	18	24½
„ „ (linked up)	63	110	11	25

TABLE VII.

Engine B.

Cylinders	34 + 51¼ + 85 × 54
Ratio of cylinder volumes	1: 23 : 6·25
	Cub. In.
Volume swept per stroke by H.P. piston	49,000
,, ,, M.P. ,,	112,500
,, ,, L.P. ,,	306,000
M.P. receiver volume	215,000
L.P. ,, ,,	371,500
	Per Cent.
Volume of H.P. clearance ÷ H.P. cylinder volume	39
,, M.P. ,, ÷ M.P. ,,	30
,, L.P. ,, ÷ L.P. ,,	18·8
	Sq. In.
Sectional area of main steam pipe, 15 in. diameter	177
,, ,, H.P. steam ports (piston valve), 5¼ in. deep	251
,, ,, H.P. exhaust ports ,,	254
,, ,, ,, passage, 18 in. diameter	254
,, ,, M.P. steam ports (piston valve), 6 in. deep	390
,, ,, M.P. exhaust ,, ,,	415
,, ,, ,, passage 23 in. diameter	415
,, ,, L.P. steam ports, 4⅞ in. (double)	817
,, ,, L.P. exhaust ,,	1,174
,, ,, Condenser inlet	1,035
	Per Cent.
Sectional area of main steam pipe ÷ H.P. piston area	19·5
,, ,, H.P. steam port ÷ H.P. ,,	27·6
,, ,, M.P. ,, ÷ M.P. ,,	18·7
,, ,, L.P. ,, ÷ L.P. ,,	14·4
,, ,, L.P. exhaust ,, ÷ L.P. ,,	22·7

	Revols.	Steam.	M.P. Receiver.	L.P. Receiver.	Vacuum.	I.H.P.
While running (full gear)	95	140	55	12	27	5,483
,, ,, (throttled)	85	158	40	−3	27½	3,476

DISCUSSION.

Mr. J. T. **Milton** (Member of Council): I think, Sir, the least we can do is to thank Mr. Stromeyer for the paper he has put before us. It is a paper which must have entailed an enormous amount of work; but it is one which I do not think is capable of being discussed at a moment's notice. In order to fully grasp this paper, I, at least, should require some considerable time to digest it at leisure, and, as far as I can see, it is a subject which if we had had the paper a week or a fortnight ago we might have better discussed. I merely beg to propose a vote of thanks to Mr. Stromeyer for his paper.

Mr. B. **Martell** (Vice-President): I should like to endorse that sentiment, because Mr. Stromeyer being one of my colleagues I feel that, after the trouble he has taken to prepare a paper of this kind, and knowing his intelligence, which has been exhibited in the very excellent work he has recently published, it would not be showing proper appreciation of his work if someone did not propose that he should be thanked very sincerely indeed on the part of the Institution for the great trouble he has taken in preparing this paper, and bringing it before us, to enter in the Transactions. I have such confidence in Mr. Stromeyer that I have no doubt, on investigation of these tables and these results which he has prepared, it will be seen that he has contributed very largely to our information on this subject, although up to the present time members are not prepared to express an opinion upon it until they have thoroughly investigated the matter.

The **Chairman** (Admiral the Right Hon. Sir J. Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): The meeting will have heard the remarks of Mr. Milton and Mr. Martell, in which I cordially concur, and, I trust, will order me to express their thanks to Mr. Stromeyer for the very excellent paper he has just read.

SOME EXPERIMENTS WITH TRIPLE-EXPANSION ENGINES AT REDUCED POWERS.

By D. Croll, Esq., Member.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 16th, 1894; Admiral the Right Hon. Sir John Dalrymple-Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

The following experiments were undertaken with a pair of triple-expansion engines of the usual three-crank type, and of the following dimensions:—Cylinders, 13½ in., 21 in., and 35¼ in.; stroke, 21 in.; steam pressure, 160 lbs.; diameter of boiler, 11 ft. 4 in.; length of boiler, 9 ft. 1½ in.; heating surface, 1,129 sq. ft.; and grate surface, 41 sq. ft. The object was, in the first place, to determine the most economical plan of working the engines, at from 250 to 300 I.H.P.; and, secondly, to obtain data for getting the maximum results upon the full-power trial. The cut-off in the high-pressure cylinder had for practical reasons been made about 0·75, which was a greater admission than the boiler could continuously supply steam for. So, it was evident, that we should have either to reduce the boiler pressure, to throttle the steam, or to draw up the link. I have, as far as possible, given results which can be accepted as correct, and have kept back any figures which appeared doubtful; hence some data have not been given.

I wish to point out that the figures in the column giving the steam pressures in high-pressure casing are not quite reliable, owing to the oscillations of the gauge-pointer. They are given to show, to a certain extent, the degree of throttling by the stop valve. I have also to state that the trials were carried out in a comparatively narrow basin, and the state of the tide exercised a considerable influence upon the relation between revolutions and power. For the purposes of the experiments this, of course, was immaterial. I am quite aware how difficult it is to draw general conclusions from the results of a single set of engines. I think, however, that we may safely venture upon the following deductions:—

(1) Not only is the triple-expansion engine singularly inelastic, but also highly sensitive to wrong adjustment. Comparing trials Nos. 6 and 8, we find that in the one case 301 I.H.P. could be developed against 263·5 I.H.P in the other with practically the same consumption of steam. It therefore appears certain that it will pay well to supply steamers, which have to work at reduced powers, with an arrangement for

measuring the feed water, in order to enable the engineer to find the most economical adjustment.

(2) Comparing all these results with those obtained by Mr. Inglis in the case of the *Iveagh*, it appears unlikely that working triple compound engines as double compound will lead to any satisfactory result.

I have also given a table showing the percentages of feed water unaccounted for by the indicator diagrams. These percentages have been calculated for various stages of the expansion through the three cylinders. The only explanation of the cause of these enormous losses appears to be condensation and re-evaporation in the cylinders. I take it that a fairly acceptable view of this process is as follows:—Supposing a piston to begin its stroke with a temperature lower than the steam entering, it is evident that the steam will first heat both piston and cover faces, and, in doing so, deposit a film of water upon them. After the steam is cut off and the pressure lowered, the deposited water will partly become steam again; but when the exhaust is opened and the pressure still further lowered the remainder will evaporate much more rapidly, and, in doing so, cool the piston, cover, and cylinder walls, so that with the following stroke the cycle is again repeated. It is worthy of remark that in a triple-expansion engine the steam produced by re-evaporation in the high and intermediate pressure cylinders may possibly be usefully employed in the low-pressure cylinder; any water on the covers and pistons of the latter, however, is upon re-evaporation rejected as steam to the condenser.

It appears to me to be a most important point to note, that if we assume 30 per cent. of the total feed water deposited as water on the low-pressure piston and covers, the thickness of this water film will but amount to $\frac{1}{840}$th part of an inch. Having therefore, to consider films of such infinitesimal thickness, it seems worth while to inquire whether the nature of the surfaces with which the steam comes into contact may not have a considerable influence upon the amount of the condensation. As far as we know at present, the cylinder walls are best made of cast iron or steel highly polished, which allow the piston to move without, comparatively speaking, any friction. In a low-pressure cylinder of a modern marine engine, where the diameter is about one and a half times the stroke, we find that the exposed surface of pistons and covers is 50 per cent. greater than that of the working surfaces of the barrel, and it is to the former that I wish to direct your attention.

Admitting that the greater the re-evaporation, the greater will be the cooling of the surfaces, and, as a consequence, the greater the initial condensation, we must look more closely into the question whether the use of rough cast iron and steel, or polished surfaces, may have anything to do with the widely diverging results obtained from different engines of the same type, which apparently are well designed, and offer no peculiarities to account for something like 30 per cent. difference in economy.

If we wish to shape a body which will readily absorb heat, we give it as large an area as possible to be exposed to the hot gases. A familiar instance is a "Serve" tube. Also, if we wish to shape a body which will readily part with its heat to the substance which is to be heated, we do the same; for instance, the ribs and collars which are cast upon pipes for heating purposes.

Passing to the rough surfaces of cast iron and steel, we may easily conceive that an almost imperceptible difference in the conformation of the surface may make an immense difference in the area exposed to the steam. Consider an element of piston area enclosed in an equilateral triangle; suppose equilateral triangles to be raised upon each of the sides, and joined at the top to form a tetrahedron; it is evident that the area now exposed will be three times that of the original triangle. If we divide the original triangle into four equal triangles, by drawing a line parallel to the base at the half of the height, and joining the points where this line intersects the two upright sides with the middle of the base, we can raise four triangular pyramids upon each of these parts, which will each expose an area of three times their bases, and, collectively, of three times the area of the original element. This operation can be indefinitely continued, with the same result, viz., that the exposed area is three times the area of the geometrical plane. A little consideration will show that the principle involved in this rudimentary case can be largely extended if we choose to build up other forms, and make surfaces analogous to, say, coke, or even the rough, rasping surface of some steel castings.

With these considerations before me, it struck me forcibly that in my own practice the most economical results were obtained with cast-iron pistons and covers, and the worst with those made of cast steel. Upon inquiry among my engineering friends, I found that those engines which were troubled with water in the cylinders had cast-steel pistons, and in cases where covers and pistons were of cast steel it had occurred that no diagrams could be obtained through the wetness of the steam.

Personally I was troubled with a low-pressure cylinder which would hardly give cards, and I thought I should cure it by smoothing the steel piston with some kind of varnish. Having succeeded in getting a composition which was said to stand the temperature, I thought it advisable to try some experiments on a small scale, and made a hollow cube of brass sheets about $\frac{1}{16}$ in. thick. One side was polished, and the other covered with the varnish. The cube was then filled with water at different temperatures, varying from 105 degrees to 140 degrees Fahrenheit; a jet of steam was turned against the faces of the cube, and when a film of water was deposited, the steam jet was turned off, and the time noted that was required to re-evaporate the film. The mean times were, respectively, 368 seconds for the polished surface, and 128 seconds for the varnished one. The great difference in the re-evaporative power of these two surfaces was to me incomprehensible till the chemist who had supplied me with the varnish pointed out that, under the influence of the heat applied, the varnish would crack into an almost infinite number of minute fissures, and thus present an enormous surface for re-evaporation, although the varnish remained apparently smooth. However this may be, the broad fact remained, that two surfaces, apparently equally smooth, showed an enormous difference in re-evaporative power. It need hardly be said that the result did not encourage me to try the varnish on the piston in question. A more conclusive experiment appears to be the following:—A cylindrical cast-iron cup was bored out till the thickness of the metal was about ⅛th in.; part of the outer surface was left as it came from the mould, and another part opposite was polished. The cup was filled with water at temperatures from 170 to 180 degrees Fah., and it was found that the mean times required to re-evaporate the water from the steam jet condensed upon the surfaces were, respectively, 43 seconds for the rough and 83 seconds for the smooth face.

I would now summarise the argument as follows:—The greater the re-evaporative power of the material in contact with the steam, the greater will be the cooling of the surfaces, and the greater the initial condensation; the re-evaporative power of a body is increased by an increase of surface; a fairly smooth surface may, nevertheless, have a very much greater area exposed than the geometrical plane, which it is taken to represent; the total condensation in a steam-engine is a question of very thin films of water, and the structure of the surfaces exposed to the steam merits our closest attention. As far as can be seen from the above experiments, a polished surface is far superior to that of ordinary cast iron as it comes from the mould, and a rough steel casting is probably about the worst material that could be chosen; it appears, therefore, advisable to carefully turn and polish as far as possible all parts of the steam cylinder which come into contact with steam performing work.

I should have been glad, indeed, if I had been able to lay before you conclusive proof that turning and polishing pistons, covers, &c., had given the good results which I am confident may be expected from it. The difficulties connected with such experiments on marine engines are great, and I have not had cases before me in which I could carry them out to my satisfaction. I beg, however, to submit a few facts bearing on the question, and which I venture to think confirm my views.

(1) I made a disconnecting paddle engine in which each wheel could be driven by a perfectly independent compound engine. In the starboard engine I had all internal parts turned and polished, and in the port one the pistons were left rough; unfortunately no time could be given for experiments, and I had to content myself with observing at sea that, whereas we were occasionally troubled with water in the port engine, the starboard one was apparently perfectly dry.

(2) In my experience excessive condensation has always occurred in combination

with rough steel pistons and covers; in one case this was so marked that the top of piston would not give a card at all, which I attribute to the cover being of rough cast steel, and combining with the top of piston to absorb the heat of the steam.

(3) Torpedo-boat engines, which have turned and polished pistons, and in some cases polished covers, are quite remarkable for the economy of steam at nearly all powers, and, at all events, are very free from water in the cylinders.

(4) A pair of high-speed engines designed by my friend Mr. Martin, of Flushing, gave practically the same results in economy at full power, at $\frac{1}{5}$th, and at $\frac{1}{10}$th of full power. The pistons and covers were turned and polished.

(5) The highest results known to me are obtained by the carefully designed land engines of Messrs. Sulzer, of Winterthur; the pistons and covers are carefully turned and polished, and a consumption of 11·73 lbs. of steam per indicated horse-power has been obtained with their triple-expansion vertical type of engine.

These considerations lead me to the conclusion that if we wish to make really high class machinery, which will give the highest results in economy, we must turn and polish the surfaces of pistons and covers, or else seek a method of coating these surfaces with a metallic layer which will diminish their tendency to absorb and reject heat.

No.	Boiler Pressure in Lbs.	Pressure in H.P. Steam Chest.	Cut-off H.P. Cylinder.	Mean Pressure.			Mean Pressure referred to L.P.	Indicated H.P.				No. Revolutions.	Vacuum.	Temperature Feed Water.	Lbs. Feed per I.H.P. per hour.	Percentage of Feed Water unaccounted for by Indicator Diagrams (Mean of Top and Bottom Cards).						
																H.P.		I.P.		L.P.		
				H.P. Cylinder.	I.P. Cylinder.	L.P. Cylinder.		H.P. Cylinder.	I.P. Cylinder	L.P. Cylinder.	Total.					At Cut-Off.	At Opening Exhaust.	At Cut-Off.	At Opening Exhaust	At Cut-Off.	At Opening Exhaust.	Means.
				Lbs.	Lbs.	Lbs.							Ins.	Degs. C.								
1	140	35	0·75	24	7·1	3 6	9·66	26·7	19·1	27·5	73·3	73·5	26	30	20·02	—	—	—	—	—	—	—
2	160	101	0·75	52	15·8	7 8	20·52	67·5	49·5	65	182	85·3	20	60	20 02	0 225	0 20	0·20	0·21	0 30	0·229	0·227
3	160	100	0·75	52·6	16 4	7·72	21·25	71·0	53·5	71	195·5	88·6	24½	50	18·458	0·193	0·173	0·167	0·169	0·302	0·249	0·208
4	106	94	0·75	54·82	20·64	7·365	22·6	79·5	72·5	73	215	95·6	26	—	19 624	—	—	—	—	—	—	—
5	106	96	0·75	54 6	21·28	7·65	23·1	83	77	78	238	98·6	25	—	18·964	0 222	0·184	0·184	0·218	0·358	0·33	0·249
6	112	102	0 75	56·62	22·88	8·75	25·15	86	85	92·5	263·5	101	24½	48	18·216	—	—	—	—	—	—	—
7	155	117	0·75	64·2	22 3	8·65	25·9	106	89	98	293	109 2	25	—	17·512	0·15	0·108	0 14	0·163	0·33	0·30	0·198
8	146	127	0·655	61·8	22·2	9·2	26 05	104	91	106	301	111 6	25	—	15·838	—	—	—	—	—	—	—
9	155	116	0 75	63·4	22 3	8·82	25·92	109	93	108	305	113·6	25	43	16·83	—	—	—	—	—	—	—
10	152	136	0 655	63·75	22·4	9·8	26·5	111	94·5	111	316·5	115·6	25	—	15·796	0·118	0·102	0·247	0·135	0 332	0·288	0·203
11	160	130	0 75	65·0	22·1	8·92	26 67	121	100	115	336	122·8	25	—	16 0	—	—	—	—	—	—	—
12	160	148	0·625	55	22·3	9 15	25·15	100	97	118	310	119	25·8	—	15·752	0·123	0·108	0·234	0 124	0 278	0·242	0 184
13	144	137	0 69	66	24·8	11·7	30·25	132	120	160	412	131·5	24½	52	15·0	—	—	—	—	—	—	—
14	152	144	0 69	67·7	25·5	12·2	31·3	138	127	169	431	133·5	24	52	15·026	0·171	0·126	0·149	0·129	0·365	0·297	0·206

DISCUSSION.

Mr. J. Jennings Campbell (Visitor): I beg to join the members in thanking Mr. Croll for his interesting paper, which presents some novel points. The author, referring to the table at the end of the paper, suggests that, in conjunction with results laid before the Institution by Mr. Inglis in the case of the *Iveagh*, it seemed unlikely that working "triple-compound" engines as "double-compound" would lead to satisfactory results. I do not see how the table referred to leads to this conclusion, and hope for some explanation. I ask leave to make a slight digression on a point of terminology, as I think that in these scientific days terms used should be, so far as possible, scientifically accurate. A three-stage or "triple-*expansion*" engine is *not* "triple-*compound*," nor is a two-stage or "double-*expansion*" engine "double-compound." A "triple-expansion" engine is only "*double*-compound," and a "double-expansion" engine only "*single*-compound" or simply "compound." The only engine that can be correctly termed "triple-compound" is a *quadruple-expansion* engine. In some points Mr. Croll's table gives results which are rather unusual. For example, while in the high-pressure cylinder the quantity of steam unaccounted for by the cards is less at the exhaust point than at cut-off, as is usually found, in the intermediate cylinder the table shows, in many instances, the reverse to be the case. It is usually found that less steam is unaccounted for at the exhaust than at cut-off in all the cylinders, the quantity thus unaccounted for increasing as the steam passes from the first cylinder to the last. Referring to Mr. Croll's assumption that the piston commences its stroke with a lower temperature than the incoming steam, I suggest that, if full compression were given, not only would the pressure and temperature of the steam in the clearance space be brought up to that of the steam in the steam-chest, but the surfaces of metal in contact with it would also have the same temperature. (The speaker then illustrated the action that appears to take place during compression by a sketch on the black-board.) When the compression begins, the steam and metal have about the same temperature; then, as the volume is reduced, the pressure and temperature rise, causing a difference between the temperatures of steam and metal. Heat passes to the latter, causing condensation of the former, and consequent fall of pressure. So that, whatever pressure the steam was compressed up to, the metal as well as the steam should have a corresponding temperature, and, if the steam be compressed up to steam-chest pressure and temperature, initial condensation ought to be nearly, if not entirely, eliminated. The advantages of great compression have been advocated by M. Normand, of Havre, and utilised in his torpedo-boats. The surfaces producing initial condensation were the faces of the piston and cover, the counter-bore of cylinder, and the port-metal, and might conveniently be called the "initial surface." Mr. Croll, after referring to the re-evaporation during expansion, alluded to a still further lowering of pressure when exhaust takes place, with a consequent further evaporation and cooling of the cylinder walls. Why should this further lowering of pressure, &c., be permitted? I have long believed that more economy could be obtained by keeping the high-pressure and intermediate cylinders larger, and cutting off proportionately earlier, making the terminal pressures of these cylinders and the receiver pressures more nearly equal. By these means, in addition to other advantages, the condensation during admission could probably be reduced. It was instructive to divide this condensation into three parts, which, as already shown, might be eliminated by sufficient compression. Second, the condensation produced by the "initial surface" before mentioned, absorbing heat to a greater and greater depth from the surface, while the piston moved over from the beginning of its stroke to the cut-off point. This condensation would depend on the area of the "initial surface," and the time of exposure; and would, therefore, be the same whether there were a small cylinder with a late cut-off, or a larger cylinder with a *proportionately* earlier cut-off; the shorter period of exposure counteracting the increased area of surface. Third, the condensation produced by the barrel of the cylinder during admission as the piston uncovered surface which has been longer and longer exposed to the cooling action of the receiver. The barrel-surface exposed during admission in the larger cylinder with earlier cut-off would be less than in the smaller cylinder with the later cut-off, while the time of exposure would also be less. Also, the mean cooling power per unit of surface would be less. To illustrate this, let two high-pressure cylinders be assumed, one $\frac{1}{7}$ of the low pressure, and the other $\frac{1}{5}$ of low pressure, with cut-off in the former at 70 per cent. and in the latter at 50 per cent. In the former, let the barrel-surface exposed during admission be divided into seven successive rings; each successive ring would be longer exposed to the cooling action of the receiver and acquire a greater cooling power. Suppose each ring to be capable of cooling only 1 lb. more steam than its predecessor; and let the first condense 11 lbs. of steam; then the seven rings will condense $11 + 12 + 13 + 14 + 15 + 16 + 17 = 98$ lbs. In the same cylinder with a cut-off at 50 per cent., the steam condensed would be $11 + 12 + 13 + 14 + 15 = 65$ lbs.; and with a cylinder $\frac{1}{5}$ of low pressure, instead of $\frac{1}{7}$, the diameter would be as 11:13; and the steam condensed would be $65 \times \frac{13}{11} = 77$ lbs. nearly, or about 78½ per cent. of the steam condensed by the barrel-surface of the smaller cylinder with the later cut-off. Probably, however, the condensing power of successive rings of metal would increase far more than has been assumed—possibly in proportion to time of exposure—so that there would be every reason to expect that the loss by condensation during admission might be considerably reduced by the system of steam distribution suggested. The time permitted to each speaker for discussion having been by this time already exceeded I will not pursue this interesting subject further.

Mr. **Wigham Richardson** (Member): Sir John Hay and Gentlemen, I am sure I shall only be giving expression to the feeling of the meeting when I say what pleasure it is for us to hear any of our friends from abroad coming to speak to us, and having known Mr. Croll so long, I am quite sure that any opinions of his are well worthy of attention and careful consideration. I wish the last speaker, Mr. Jennings Campbell, had more clearly given his views as to Mr. Croll's theories. It will be in the knowledge of many members of this Institution that Professor Kennedy, late of the University College in Gower Street, held very strong views upon this point, and, if I remember correctly, he made experiments on the same subject. Mr. Croll, with great modesty, says he does not consider his experiments must be taken, as it were, as being more than suggestions, and sufficient to form a sort of theory for discussion. I have great hopes that many of these questions which so puzzle engineers now, may, within the near future, receive a large amount of elucidation from the experiments which are going to be conducted at the College of Science at Newcastle by Professor Weighton, on an engine of more than mere model size, the cost of which is being defrayed by the leading engineers in the north-eastern district, and I believe there will be a more complete series of experiments on the action and working of steam inside a cylinder than we ever had before.

Mr. C. E. **Stromeyer** (Member): Sir John Hay and Gentlemen, I am sure this meeting must be very thankful to Mr. Croll for the valuable experiments he has made, but I think they would be still more thankful if he would add fuller details of all the results. At present we have only got a sort of abstract of what has been done, and I think the experiments will enable us to investigate this and also other questions more fully if the full details are added. As regards the paper itself, Mr. Croll attributes the initial condensation in a steam-engine to the roughness of the cast-iron pistons and covers; but, as far as I can see, he has not experimented with polished pistons and covers, and all his cases of excessive condensation are in engines with steel pistons and steel covers. On page 423, in the last paragraph, he mentions an engine which is going to be tried in which one piston is rough and the other one smooth. It would be very valuable if, when the experiments are completed, the results were to be added to this paper, because they would then conclusively prove whether it was due to the metal itself, or to the roughness. The experiment which he made on a little tube with some varnish on the outside, shows that the oily coating really affected the radiation far more than the polishing of the surface did; and I believe the experiments of Professor Tyndall show the same thing, viz., that the least trace of oil on polished metal surfaces causes an immense amount of radiation, so that, as we cannot keep oil or moisture out of an engine—and I think moisture is as bad as oil—it may be that the condensation is simply due to their presence, and the excessive condensation in engines with steel pistons is due to the greater specific heat and conductivity of the steel. Steel conducts heat better than cast iron. Therefore it may be that it is simply a question of metal and not of roughness. If these experiments should ultimately prove that polished surfaces are better than rough ones, it will be a great advantage for the interior of engines to be made in that way. On page 421 the author mentions that about 30 per cent. of the total feed water was deposited in the low-pressure cylinder. I think that amount will be very much reduced if he will work out the indicator cards in a way which I am suggesting in a paper which I hope he will shortly read. It amounts to this, that before subdividing an indicator card for the purpose of measuring it, ⅛ in. or more—depending on the elasticity of the indicator string—has to be added to the commencement point of the pressure curve and of the exhaust curve. This correction will not seriously affect the estimated indicated power, but will add about 10 per cent. to the estimated steam weight, and the moisture referred to by Mr. Croll would be reduced by that amount. Of course the differences in the amounts of condensed steam will then appear to be far greater, and, if Mr. Croll's assumptions are correct, there would be all the more reason for substituting polished pistons and covers for the present rough ones. If this cannot be shown to be necessary, then Mr. Croll's paper undoubtedly shows that steel pistons, &c., reduce the economic effect of an engine, and in either case his experiments must be looked upon as being exceedingly valuable.

Mr. D. Croll (Member): Mr. Chairman and Gentlemen, I thought in preparing this paper that I had got a subject which was not contentious. It appears, however, that that is not the case, as it has given rise to several observations. In reference to Mr. Jennings Campbell's remarks as to these results, I can only say the diagrams showed them. What they ought to be I do not pretend to say, but there they are. I wish specially to state that my object in writing this paper was merely to introduce a subject, and to point out what I still believe to be an important point, in accounting not for 2 or 3 or even 10 per cent. loss, but for 25 and 30 per cent. of the whole feed water passing through the engine, of which none of us quite knows where it remains. I merely wished to insist upon this fact, and I thought the idea which I had might lead to some explanation of it. I anticipated to some extent what Mr. Jennings Campbell said in reference to compression and the fall of pressure at the end of diagrams; but I was very careful to point out that any re-evaporation that takes place in the high-pressure cylinder may, to a certain extent, be used again as steam in the intermediate, and so on, so that I confined all my remarks to the low-pressure cylinder, and I do not see how the re-evaporation due to fall of pressure at release is to be avoided in the low-pressure cylinder, for you must have it there. I do not know whether I am expressing myself clearly, but I will illustrate it on the board. Any re-evaporation from exhaust side of high-pressure piston is doing service as steam in the intermediate cylinder, but whatever re-evaporation takes place during exhaust of the low-pressure cylinder is lost as steam blown into the condenser. My idea is that the piston of an engine is during part of its stroke a condenser and during part of its stroke a boiler; that is to say, it is condensing the fresh steam which is entering, and it is working as a boiler and blowing it away to the condenser during the exhaust stroke. I think Mr. Stromeyer is under a little misapprehension when he speaks of the polished surfaces in the experiments of Professor Tyndall. I was careful to avoid the word radiation. I thought that was a dangerous subject to introduce. This is merely a question of the conduction of heat between the internal surfaces and the steam in contact with them. I did not quite finish what I was going to say upon the subject of the piston being a condenser during admission, and a boiler during exhaust. I think I may add that we are all agreed that to make a boiler more efficient you must increase its heating surface, and to make a condenser more efficient you must increase its cooling surface; and if the simple geometrical consideration of a rough surface, as explained in the paper, and which I think is incontrovertible, is admitted, it simply leads to the increase of the heating or cooling surface as the case may be, causing a manifest waste of steam.

The CHAIRMAN (Admiral the Right Hon. Sir J. Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): I beg to express the thanks of the meeting to Mr. Croll for the valuable paper he has just read.

ON A FLUID PRESSURE REVERSING GEAR.

By **David Joy**, Esq., Member.

[Read at the Thirty-fifth Session of the Institution of Naval Architects, March 16th, 1894; Admiral the Right Hon. Sir John Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President, in the Chair.]

When I last had the honour of reading a paper on the simplification of valve gears before this Institution I concluded by saying, "And I am continuing my investigations in the same direction, with a very tangible hope that I shall be able very shortly to take a step further in the simplification of valve gears by about 30 per cent." That was in 1886, or eight years ago, and the paper which your Council have done me the honour to accept for my reading to-night is the result of the eight years of work in that direction since that date, and I hope it will not be without interest to you.

When I made the statement quoted I had in my view the treatment of the valve gear of marine engines, which were then increasing in size and speeds of revolution with such rapid strides, on a plan on which I had long ago designed and constructed reciprocating steam and water power machinery with satisfactory success, by abandoning all direct mechanical connection between the piston and the valve, and actuating the valve directly by the motive fluid driving the engine: so arriving at about the ultimate limit of simplicity possible in this direction. Many steam hammers were made on this plan, and gave very satisfactory results, being extremely sensitive, and perfectly controllable for the most delicate blows, even to picking a wafer off a watch glass without breaking the glass. Thousands of steam pumps have also been made on the same plan, the valve being driven either by steam or water with no mechanical connection.

The great simplicity of the plan recommended it strongly for application to marine engines, and if successful promised a large field. But after some years' work in that direction I laid the plan aside, for the time only, I hope; not because of any mechanical difficulties in it that could not be overcome, but that the commercial element was not promising. It was, in fact, an advance, I think, too far in advance to find favour, a departure from ordinary practice too wide to be acceptable to either owners or builders. So taking a medium course, and, instead of driving the valve itself by fluid pressure, where the fluid would always be in active motion, I proposed to myself to take only the half-way step at once, and to adjust and retain in position the machinery for moving the valve, by the motive fluid, which would so mostly be in the condition of a static force only.

In carrying out this idea I returned, of course, to the absolute contact plan, driving the valve by a rod direct from the crank axle, but only one rod and one eccentric.

And now I shall not trouble you with the process by which I arrived at the result, but at once describe to you the machinery.

The principle of construction is simply that, in place of employing two eccentrics, set each at the proper positions F and B (see Fig. 1, Plate LXXXI.), for giving forward and backward motion, and all intermediate points of "cut off" necessitating the employment of the "motion link," and all the machinery required to move and hold it in position, I employ but one eccentric set upon the crank shaft, and arranged to be slid across it between the two points F and B (see Fig. 2, Plate LXXXI.), for forward or backward motion, and one rod direct up to the valve spindle. The method by which this sliding action is accomplished will be described immediately. By this arrangement all the requirements of the "link gear" are fulfilled, but with one-fifth of the number of parts, and giving a much more correct distribution of steam.

Referring now to the model and Figs. 1 and 2: Fig. 1 shows the cross section of the ordinary hollow crank shafts as used in the engines for war-ships, and Fig. 2 is the longitudinal section of a part of the same. A is a cast iron or steel square block, fitted on the shaft S, in the position usually occupied by the two eccentrics in link gear. This block has cast with it, on opposite sides, two small rams, B B′, the other two sides of the block being planed at the surfaces *a*, *a*, to receive the eccentric E, which is bolted together centrally in the usual way, having the surfaces *e*, *e*, planed to slide on the surfaces *a*, *a*, of the square block A. In the eccentric, and forming part of it, are cast two small cylinders, C C′, into which the two rams, B B′, fit.

We have now the eccentric mounted on a square on the shaft, and free, while moving round with and driven by it, to be slid from side to side on that square. The direction of that sliding action being on the centre line F B, arranged to be at right angles across the centre line of the crank and connecting rods, when at extreme ends of the stroke, and within the centre line of the crank shaft, towards the crank pin, if inside steam lap is to be used, as is usual with piston valves, or outside that point if outside lap is required; the movement given to the valve being equally correct either way, and whether for forward or for backward going; each extreme position being for forward or backward going, the central position being mid gear; and any intermediate position giving any variety of "cut off." The movement of the eccentric in either direction, and its control in any position, is effected by forcing in a non-elastic fluid at a pressure at either end of the crank shaft, which in this case, as for warships, is already hollow, as at S′ (or in ordinary shafts it is drilled).

The fluid is put in motion in either direction by a steam cylinder **M** operating on the piston of a cylinder N, which serves as a reservoir for the fluid, transmitting the power through the pipes *p p* for forward going, and on through the crank shaft, and so into the small cylinder in the nearest eccentric, suitable for carrying it over in the direction for forward gear, while the fluid in the opposite cylinder in that eccentric is passed on to the next following eccentric to move it over; and so on till the receding fluid finds its way by the pipes *p′ p′* to the opposite end of the fluid cylinder N. Of course, the reverse action of the steam cylinder again returning the eccentrics to the original position.

Thus the positions of the eccentrics for forward or backward motion are secured without the intervention of any mechanical combination in the form of links, levers, screws, &c., liable to wear out or break down. And by the simple arrestation of the movement of the fluid, the eccentrics are maintained in any position, so giving any required point of "cut off." The cylinder N is made of a sufficient capacity to contain a margin of about 25 per cent. more fluid than is required to fill all the eccentrics, pipes, and other channels, &c., to be able to follow up the eccentrics if required.

From this description the general principles of the system will be easily understood; and to those familiar with the designing of fluid-pressure machinery it is well known, how working through the medium of a non-elastic fluid for the transmission of power, such machinery is peculiarly sensitive to exact and certain control.

Thus this gear lends itself specially to all the adjustments required in a triple expansion engine at sea; and, though it would have made the paper far too long to go into any of the details for effecting these adjustments, it would not be complete without merely naming some of these. Thus, that while the engine is running, all the three cylinders may be "linked" up simultaneously, or each may be independently adjusted; and that while so variously adjusted, all may at once be thrown over into full gear, either forward or backward, without any manipulation of screws as in the reversing levers of link gear.

All these adjustments are effected by differentiating the amount of fluid between the two cylinders in any eccentric; and, as in the Maxim gun the recoil of the shot is made available to discharge the exploded cartridge, supply a new one, and fire it; so the tendency of each eccentric, when working expansively, to slip over into full gear is employed, by acting on a small valve in the eccentric by the motion of the engine, so allowing the fluid to change sides, under pressure of the tendency, to the amount for setting the point of "cut off" required, when it may be locked in that position also by the fluid pressure.

There is also provision made in the arrangements of the valves and pumping gear of the fluid cylinder or reservoir for reversing by hand when the steam is not on, or for refilling any of the pipes, channels, or eccentric cylinders; and finally this part of the gear may be linked up as a governor, employing the inertia of the fluid in motion and under pressure to move the valve of the steam reversing cylinder towards mid gear on the smallest increase of the speed of the engine, so linking up all three cylinders in that direction to the required amount to check the speed of the engine.

The machinery for all these adjustments is of a small and very simple character, and of a class in which I have had large experience; and for all details there are ample precedents.

The advantages of the gear are—first, its simplicity of construction and fewness of parts, all such parts also being of ordinary form commonly in use, with the further advantage that, as only one eccentric is required for each valve, that may be made of double strength and surface, if desired.

Resulting from the above, the gear is very much less costly than "link" or any other gear, fully by half, as not only are there fewer parts, but none of these are complicated and costly forgings, as motive links, requiring difficult and expensive tooling; almost all the work consisting of simple castings in steel or iron, and requiring chiefly boring and turning, the easiest and least costly operations in the tool shop. Then, having far fewer parts, it is less liable to break down; less attention and lubrication are required. Indeed, if wished, the whole of the lubrication on the crank shaft may be performed by the motive fluid itself (using oil), which may be recuperated automatically by the engine itself while in motion.

Again, it fits into the position of the "link gear" exactly, requiring no alteration whatever in the ordinary type of engine. Further, the newly designed part connected with the fluid-pressure machinery may entirely break down without destroying the efficiency of the engine, which will still continue her voyage in full forward gear; for, if the engine is working expansively, the only result of the entire failure of the fluid gear is to allow the engine to slip into full forward gear, while, if working in full gear, there is no strain at all upon that part of the machinery.

And, now, though this gear was originally and specially designed for marine engines, it is really a valve gear of general application for any class of steam-engines, and suitable to be employed wherever link gear may be used. Therefore, in selecting an engine on which to test its efficiency, I chose a locomotive, as offering opportunities for the most crucial tests to be carried out in the shortest time, as also other important advantages; as the greater ease with which experiments can be conducted and recorded on land than at sea, the freer access to the machinery by numbers, whether of workmen or of those wishing to inspect, as compared with a crowded engine-room at sea. Alterations, repairs, or additions may be readily made, variations in loads or in speed may be effected, continuous working may be maintained, independent of weather or tide; but, most of all, a much more crucial and varied series of tests may be crowded into a very much shorter time than with engines at sea. Thus the engine fitted with this gear has been at work about a year, and during that time has had the reversing gear as frequently manipulated, shifted from forward to backward going, and changed about to all degrees of expansion, as could only have occurred in a Channel steamer in six or seven years, or as in an ocean-going steamer in quite an unknown time.

With regard to the newly required constructive details, several points of interest arose, and had to be dealt with. One or two only I will name. Thus it was objected that, at the point where the stationary fluid in the pipes at either end of the crank shaft met that which was revolving rapidly in the shaft, heat would probably be generated. This never occurred, but its possibility was met by enlarging the spaces or channels at that point, so allowing room for the stationary particles to interchange gradually among those rotating rapidly.

Again it was urged that, as the fluid had to sustain the reciprocating effort of pulling and pushing the valve, a throbbing or pulsating action would be generated. This never has existed, for, whether running slowly or very fast, and even with a considerable amount of air in the pipes, the whole gear runs with the solidity of a gear of steel with no intervening fluid. The most suitable fluid to be employed has also been subjected to investigation, and if frost is not feared, and lubrication is not contemplated, then any non-elastic fluid will do; but probably one of oil, and nine of water, will be found most convenient and cheap.

For packings I, of course, used the ordinary leather cup packings, of which I have had very satisfactory experience under pressures up to 5,000 lbs. per square inch. The practice in the case of the Westinghouse break pointed in the same direction; but, thinking it well to be independent of organic material, I have been trying to get at a figure in which to employ metal, and some of the results are on the table.

Now it only remains for me to refer you to Plates LXXXII. and LXXXIII., and models, drawings, and photographs on the walls and on the table—among these, to the original machine on which I satisfied myself that the broad principle upon which I proposed to work was practicable, and cards of diagrams taken from it giving the valve stroke—and also to inform you that the locomotive on which this gear has been tested will be at the Victoria Station of the L. B. & S. C. Railway.

DISCUSSION.

Mr. A. Betts Brown (Member): Sir John Hay and Gentlemen, I have applied myself to this question, and I have had made over a thousand reversing engines. These were fitted to marine engines having the old Robert Stephenson link, a few applied to single eccentric gear and link. My engine is very similar to that shown by Mr. Joy, only I reverse by steam and use water for controlling the speed of the engine and holding the links steady. To boil down the whole of this subject, I must say that our friend, Mr. Joy, has done good work in his ordinary single eccentric valve gear, and a good many people have paid him the compliment of trying to copy him. His new departure, however, I think, is in the wrong direction; and where, I fear, he will come to grief will be on account of the use of leathers in his cylinders placed inside the eccentric. He draws a comparison between the complication of the roundabout double cylinder engine and his gear which I do not think is quite fair, as most mercantile ships, as well as the French and Russian navies, are fitted with direct-acting engines. I am sorry to say our Admiralty have stuck to the more complicated form, I believe to save weight. The disadvantage of the roundabout engine is that it is slow, and if water gets into the cylinders some time elapses before the cylinders can be cleared and the cranks get freely round the centres. Mr. Joy's shifting eccentric is the hydraulic equivalent of the Dodd's wedge motion, invented after Stephenson's link in 1845. I would suggest to Mr. Joy that he might take the old wedge motion, which is a good one, and put a clutch on it, and haul it backwards and forwards with a hydraulic cylinder outside the main engines, and he would dispense with all leathers and stuffing boxes. I have no doubt that in a locomotive this gear would work well for a time, and as such engines work very much like horses going to their stables at night, no great inconvenience might arise from the failure of leathers. The case is entirely different with a steamer making long voyages and dependent on frequent and certain handling of the engines. Mr. Joy has talked about metallic packings. I was so much taken with some experiments made by Professor Tait at Edinburgh University that I adopted them, and I made them of copper, just like the leather, only thinner, and we got very good results so long as the water was clean, but if you get a little bit of grit or dirt in the copper cup it gets cut up and leakage takes place. Mr. Joy says if there is leakage the eccentric runs to full gear. That is well enough, but if you want instant reversal in case of collision and cannot get it by reason of leakage, it is a very serious matter. I wish Mr. Joy success in his idea. He is, however, a pretty bold man to put leathers inside an eccentric that may, and often does, get very hot, and so will lead to the destruction of the leather packings, which are by no means easily replaced. Single eccentric reversing gears, with or without a link, I am afraid have had their day, most having been discarded in new designs of engines at the present day in favour of the old Stephenson link, and that is very bad to beat.

Mr. David Joy (Member): Mr. President and Gentlemen, I came here prepared to face a very full and free discussion, as I fancied that the wide departure from the usual method of treating valve gears which I have brought before you this evening would be likely to provoke many questions, and probably excite much criticism. But I regret that time did not permit this, or adding the further information which the shortness of the paper perhaps required, and I find myself really in the position of having literally nothing to answer, Mr. Brown's remarks being too obviously unnecessary to require answer; as, had he either read or listened to my paper with ordinary attention, he might have noticed that all he objected to had been already answered in the paper. I must, however, first thank him for his courteous remarks on the fact that I have done good work with my former valve gear. And that is true; in spite of opposition, and, more than that, in spite of the copyism of others, that plan has succeeded, but of this later on. Mr. Brown commenced his criticisms by informing us that he had applied himself to this question, and had had made over 1,000 reversing engines—we are all familiar with these very simple and efficient machines—but he goes on to say that his engine is very similar to that shown by myself, with some slight variation of action; but the context and the remark on the 1,000 engines seem to infer a priority of idea for them, as against my completed form of reversing by "fluid pressure" throughout, by which the simplicity of my plan is gained. Need I remind him that I, too, have been working in this direction for very many years, and that indeed I was the first to propose using steam or water at a pressure in a cylinder for reversing large engines by direct connection. This was recorded in my patent, No. 929, of 1857, and since that time I have been carrying out developments of the same idea in various forms and for various purposes, resulting in the mechanism which is before you, and which, I think, claims attention from its great simplicity; meanwhile, the first records I can find of Mr. Brown's connection with this question of steam reversing gear is in his patent of 1867, No. 559. I am quite independent of the cup leathers to which Mr. Brown refers, as, even if I needed to employ these, which I have done hitherto, following the lead of the Westinghouse Brake Company, with perfect success, these cups may be utterly burnt up as he has suggested, but there are still the rams, which are practically a fluid-tight fit. And further, as I stated in the paper, if all the fluid pressure arrangements fail, the eccentrics, if working expansively, simply slip forward into full gear, and the engine goes on as before. But further, the means we have for reversing are at hand to be employed in another form, as an additional resource to prevent heating, as the pumping gear to be used to reverse by hand, when steam is not up, is arranged to be coupled up to the engine when running, at a moment's notice, and by simply turning a cock the shaft may be flooded from within with cold water continuously, so assisting the usual water service acting from without. And again I have stated in the paper that, to be independent of organic material, I have been for long making experiments with metallic rings of various metals and in various forms, to replace the cup leathers, and a number of these are on the table for inspection. And these have already given such good results, and promise so much further advances in the direction of simplicity, and ease, and rapidity of attachment, and cheapness, that Mr. Brown's criticisms of my system, which were directed so almost entirely to this detail, may be taken as answered. But the design of this gear needs no refinements depending on perfect steam or fluid tightness. Has a piston or a valve failed finally if it begins to leak? It is still efficient for most of its work, though not perfect, and must be "set up." But this system includes the recuperation of any leaks, should they occur at any point in the machinery, by the employment of a comparatively small hand pump attached to the fluid-pressure cylinder, which can be put in action in a moment, or may be coupled up to the engine itself. So in the gear are contained the elements of self-supply. Mr. Brown followed by saying that I had drawn a comparison between the complication of the "roundabout" double-cylinder (reversing) engine and my gear, which he did not think fair. Again, he here shows how he has failed to grasp the special points in my new gear. Between the mere reversing element, be it the all-round double-cylinder engine and any direct-acting single-cylinder gear, I question if there is any difference in cost, or much in simplicity, worth discussing. My comparison was of the whole valve gear of the Stephenson link type, as against my single movable eccentric, with all the saving of parts resulting; thus, one eccentric to each valve, all the motion links, drag links, reversing shaft, four reversing levers, bearings, &c., including fully five times the number of joints and moving parts that I have. In all these parts, too, there is a vast saving of weight in my gear, if the Admiralty want to save weight, as Mr. Brown suggests. Besides, there is a tangible saving in all the complicated and multifold greasing apparatus required to serve all the points in a Stephenson link gear. And the two drawings I showed made all this very clear, by the colouring of the similar parts in each case alike. The engines I chose for the comparison were not of an old-fashioned style, but some of the most modern and successful, and have been fitted on the second-class cruisers of *Apollo* type. And on these engines the new gear will fit without the smallest alteration, but simply replacing the link gear, the shafts being already hollow. Referring to the suggestion that I should take the old wedge motion, and haul it backward and forward by a hydraulic cylinder, it was just because I was so familiar with the complication of parts, and the impossibility of getting sufficient area of wearing surfaces (all these also being at excessive angles, resulting in the abandonment of the system as soon as it was tried), that I did not look the way of it, but struck out for myself on this new plan—new in this application to effect the transmission of power to my working machinery by fluid pressure, which is so perfectly controllable for the purpose, and which is coming so much into use now. As instances, I need hardly name the hauling and lifting machinery in the dockyards, the City lift or elevator, the loading and training of big guns on shipboard, &c. Then for the further suggestion that this gear might work well for a time on a locomotive, it *has* done so for now over a year without the smallest sign of giving out, and during that time it has been subjected to as many reversals, and to as much "linking up," as well as to as frequent and continued runs at very high speeds of revolution, as a cross-Channel steamer would get in six or seven years. This, surely, is a fair test. But I agree with Mr. Brown that "the case is entirely different with a steamer making long voyages," &c., but this, instead of being worse for the new gear, is vastly in its favour, as, if the eccentrics are to be set, and kept for days together at the same point, it is one of the features of the system, and the easiest and simplest possible to do, to fix them by a locking gear, or, rather, a propping gear, dependent on the fluid pressure, which automatically drops away the *instant* any alteration of the reversing gear is attempted either way. So in long-voyage ships, all through the voyage, the fluid pressure bears no strain, and there is no tendency at all towards the leakage it is feared will take place. Finally, I thank Mr. Brown for the expression of his wish for my success in this idea, and I am amused at his suggestion that I am "a pretty bold man." I will not dispute this. I dared, and have before dared, to try to advance on practical mechanical science, and surely the experience of the past may stand for something to indicate the future. In three definite cases of this class of work, in a new direction of the application of mechanical science, I have practically and definitely succeeded in what I sought, and this against the reiterated warnings of the pessimists of the day. The last only I will name, and in this I hope I may be acquitted of intending to boast. My radial valve gear, for which the Lords of Her Majesty's Privy Council recently extended my patent another seven years, may be accepted as a success, as having been applied to nearly 500,000 I.H.P., and to nearly 3,000 locomotives, and I anticipate a better future for this, with good grounds for its realisation.

The CHAIRMAN (Admiral the Right Hon. Sir J. Dalrymple Hay, Bart., K.C.B., D.C.L., F.R.S., Vice-President): Gentlemen, I am sure you will readily accord to Mr. Joy a vote of thanks for the paper he has kindly read to us.

CONCLUDING PROCEEDINGS.

Mr. C. E. **Stromeyer** (Member): Sir John Hay and Gentlemen, I feel very pleased at having been called upon to propose the vote of thanks to the Council, for in doing so I am discharging a personal obligation which I owe to them for having on several occasions selected my papers to be read here. I know their work must be arduous, not only in persuading members to experiment, to investigate, and to read papers, but also in selecting those which they consider the best to lay before this Society. As I have sometimes come before you as a reader of papers, and have also been present on a large number of other occasions, and have always listened with great interest to those which have been read here, I may say that I am representing the average member, in whose name I am proposing this vote of thanks to the Council. I wish to couple with it the name of Mr. Martell, who has been on the Council so long, who has attended its meetings so regularly, and who is one of its most distinguished ornaments.

Mr. Josiah **McGregor** (Member): I beg to second that. I think it requires no further remark from me to emphasise the deservedness of such a vote of thanks. The work which the Council have to do here is very arduous indeed. That alone of having to look through all the papers is considerable, and the amount of other business which they have to do is very great, therefore I think the least we can do is to accord them a hearty vote of thanks.

Carried unanimously.

Mr. B. **Martell** (Vice-President): Gentlemen, I beg, on the part of the Council, to express our very sincere thanks to Mr. Stromeyer for proposing this vote, and to Mr. McGregor for seconding it. I can only say that the Council, as has been said, really exert themselves to the utmost for the interests of this Institution. The only fault perhaps that we have to find is that the outport members of Council do not come and support us a little oftener than they do. We can understand there would be a good deal of difficulty in coming from Scotland, for instance, to join a Council meeting; but I sometimes find that when some of them are in London they rather fail in their duty in turning up at the Council meeting when they know there is one to be held. I hope that will be remedied, and that we shall have more support from them. I know the Council has a good deal more to do than many of the members understand, in looking after the interests of the members in every way, and their comforts as well. They are at the present time very arduously and earnestly exercised in laying out the programme for the Summer Meeting, and I may say to the members here present that we thoroughly believe they will have a most excellent entertainment, as well as a most useful and instructive time, if they attend the meetings at Southampton. I hope the meetings will take place somewhere in the middle of July, and I hope the efforts of the Council will be rewarded by finding that a large number of members will respond to the invitation to be present on that occasion. I return my sincere thanks, on the part of the Council, to Mr. Stromeyer and Mr. McGregor for proposing and seconding this vote of thanks.

Mr. W. H. **White**, C.B., LL.D., F.R.S. (Vice-President): Sir John Hay and Gentlemen, I have to propose a vote which we pass annually, which, in a certain sense, is formal, but which, I am sure, we shall all heartily support. It is that of thanks to the Society of Arts for allowing us the continued use of this hall. I believe it is just twenty-nine years ago since I first attended a meeting of the Institution of Naval Architects in this hall. I was then a young student at the School of Naval Architecture, and I sat very far back in the corner, and looked on all the proceedings with great awe. Since that time I have become more familiar with our proceedings. I am sure I express the feelings of all the members when I say that we have grown to be much at home here; that we realise fully the advantage it is to meet in such a hall as this, so conveniently situated; and that we are all most grateful to the Society of Arts for their continued kindness in placing it at our disposal. I beg to move that a vote of thanks be accorded to the Society of Arts.

Mr. J. Inglis (Member of Council): Sir John Hay and Gentlemen, as Mr. White says, this is almost a statutory motion, and it is scarcely necessary for me to say anything more in favour of the resolution, especially as upon a former occasion I had the honour to move the resolution myself; and I think I said upon that occasion everything that I could say in favour of it. We find ourselves so very well situated in these commodious rooms that I am sure we should feel far from at home anywhere else. I hope the Society of Arts will extend this privilege to us for many years to come.

Carried unanimously.

Mr. Henry Morgan (Treasurer, Vice-President): Now that these subjects, more or less formal, have been disposed of, it becomes my very agreeable duty to bring before you the last point to consider this evening—I say to consider, but it is a matter which will not require much consideration, and on which I am sure we shall all be agreed. I refer to the great obligation we are under to our worthy Chairman for the kind and efficient manner in which he has presided over this series of meetings, including, of course, our dinner. You are aware that when Lord Ravensworth last year vacated the office of President of this Institution, Lord Brassey entered upon that duty, but Lord Brassey for many months past has been absent in India in connection with the Opium Commission, and, as he could not be here to preside over these meetings, the Council had to look round for a substitute. They had not to look very far or very long, because they immediately saw that Sir John Hay, who has assisted us on many previous occasions during the temporary absence of the President, was at hand, and we saw that he was for many reasons the most efficient Vice-President we could invite, and he was then, as always, perfectly willing to accord us his valuable services. I may be pardoned, perhaps, as I am getting a somewhat old officer of the Institution, and one who has known Sir John Hay for many years, if I remind you of some of the points in connection with the special fitness of Sir John Hay having been asked to preside as chairman. I do not refer, of course, to the result of these meetings, but rather to prior considerations. Sir John Hay has been connected with this Institution, if not from the first year, very nearly so. I tried to look over my first volume to-day, but, unfortunately, I could not find it, but he has been with us, at any rate, for many years, probably from the first. He is also, as you know, an Admiral in Her Majesty's Service, and he has been employed in the most important duties in the service of the Navy, and has been, probably, familiar with every ship designed and built for Her Majesty's Service certainly during over forty years. There was a paper read here at one of the meetings of this Session on armour. Sir John Hay was the very first officer who was entrusted with the consideration of the best means of producing armour, and he was commanding a line-of-battle ship in the Black Sea during the Russian War at the time of the bombardment of Sebastopol, as we have had the pleasure of hearing here, and was himself on board one of the French floating batteries—the first that ever went into action. That was during their attack on Kinburn, in the Black Sea. Those are bygone considerations, of course. I need not remind you how very successful these meetings have been, and how much we owe to the tact and efficiency of our Chairman, in securing such successful and agreeable meetings as we have had. These meetings are probably the largest we have ever had—certainly the attendance at the dinner was the largest we have ever had. Not only the meetings here, but the dinner went off in every way to our great satisfaction; and I trust it will be a pleasure to remember that this Session has been not only one of the most agreeable and useful to us, but one that will live the longest in the permanent good it has conferred on this Institution. There is one other little circumstance I should like to remind you of. I said just now that Sir John Hay was probably as familiar as anyone with the designs of warships during many years. Our excellent and talented friend, Mr. White, who stands at the head of the shipbuilding at the Admiralty—and long may he continue to do so—brought before us during this Session practically the completion of the Naval Programme, which included the building of seventy additional ships—what is commonly called the Hamilton Programme. Down stairs you may see a beautiful painting by Signor Martino, representing that fleet in its completion. Now to-day is issued a new Naval Programme—one of those further efforts by which we show that Britannia intends to continue to rule the waves. It has fallen, therefore, to the lot of our excellent —I might almost say our venerable friend, looking at the number of years Sir John Hay has been with us, to preside at these meetings, when one programme goes out and another one comes in, a circumstance which I think conveys a little appropriateness, and which, I trust, is a source of some satisfaction to Sir John. I need not detain you longer. I am sure you all feel we are indebted to Sir John Hay for his able Chairmanship of this Institution, and for that reason I move that we give him a hearty vote of thanks.

Mr. W. H. M. **Ellis** (Associate): I have great pleasure in seconding the vote of thanks to Sir John Hay. Mr. Morgan has so completely sketched his career that I am sure I can add nothing. In the absence of our President, and the retirement of our Past President, Lord Ravensworth—one of the best we ever had—I am sure we could not have had a more efficient Chairman. There is only one point which Mr. Morgan forgot to mention, which is this—that actually Sir John Hay was able to give his experience of the ramming of ships fifty years ago, in, I think, the Gulf of Guinea, *à propos* of Mr. White's paper. I am sure you will all join in a hearty vote of thanks to Sir John Hay, whom we hope we shall see here for many years to come.

Carried unanimously.

Admiral the Right Hon. Sir J. **Dalrymple Hay**, Bart., K.C.B., D.C.L., F.R.S. (Vice-President): Gentlemen, I am very grateful to you for your kindness in receiving Mr. Morgan's far too flattering character of me in the manner in which you have received it. Mr. Ellis has also stretched a point in my favour which I hardly deserve. The fact is that when the chair was pronounced to be vacant, and I was applied to to come and fill Lord Brassey's place, I am afraid I did not come as readily as my friend Mr. Morgan suggested. But it was not because I did not honour the place in which you have been pleased to put me; but because, in the first place, I was not quite sure I was well enough, or had hearing enough, to make a tolerably good Chairman, and, in the second place, because I thought others might have filled it with more advantage. However, the Council were pleased to insist, and I yielded. That is not a great proof of strength of character, I am afraid. I am very grateful to the persons who have assembled in this hall for the order which they themselves have maintained. They have given me no duty whatever to perform in that direction. It has been a most satisfactory meeting; the papers have been of the greatest possible interest, and the association of so many friends together has cemented a union which is always agreeable, and I hope, after Mr. Martell's most splendid exposition of the advantages of it, we shall have an equally successful meeting at Southampton. It is a very easy thing to preside here. It is not the Chairman, it is the Secretary. The unfailing courtesy, the great assiduity, the wonderful tact of Mr. Holmes is that which has made us a successful Institution, and I do not believe—I pay all respect to Presidents past and present, and to all the Councils of which I have been a member—that without our Secretary we should have attained the position we have. I was one of the first five members of the Institution, if I remember rightly, when Scott Russell enlisted me. Mr. Holmes, since he has been our Secretary, has carried on the work of the previous Secretary with the greatest possible advantage, and I do not believe any learned Institution in London, or any other place, has a Secretary who, all round, is as good a one as Mr. Holmes. I therefore take the liberty of adding to the list of votes which were on the paper that of a cordial vote of thanks to Mr. Holmes for what he has done for us, and I should ask Mr. White to second that.

Mr. W. H. **White**, C.B., LL.D., F.R.S. (Vice-President): If seconding is necessary, and I am sure it scarcely can be, I do so most heartily. You, Sir, have expressed our feelings in what you have said in relation to our Secretary. We are all glad he has been with us so long, and we hope he will always feel it worth his while to remain with us and give us the benefit of his services.

The **Secretary**: Sir John Hay, Mr. White, and Gentlemen, I do not exactly know how to thank you after this most flattering speech, which, I am sure, is far more flattering than any services which I have ever rendered to the Institution deserve. But, at any rate, I say that the services which it is in my power to render are rendered not as a matter of duty merely, but they have been, and are, and always will be, a source of the greatest possible pleasure to me. I thank you, one and all, most heartily for your kindness.

NOMINAL INDEX.

Being an Alphabetical List of the Names of the Authors of Papers read before the Institution, and of the Speakers who took part in the Discussions which followed the Reading of the Papers.

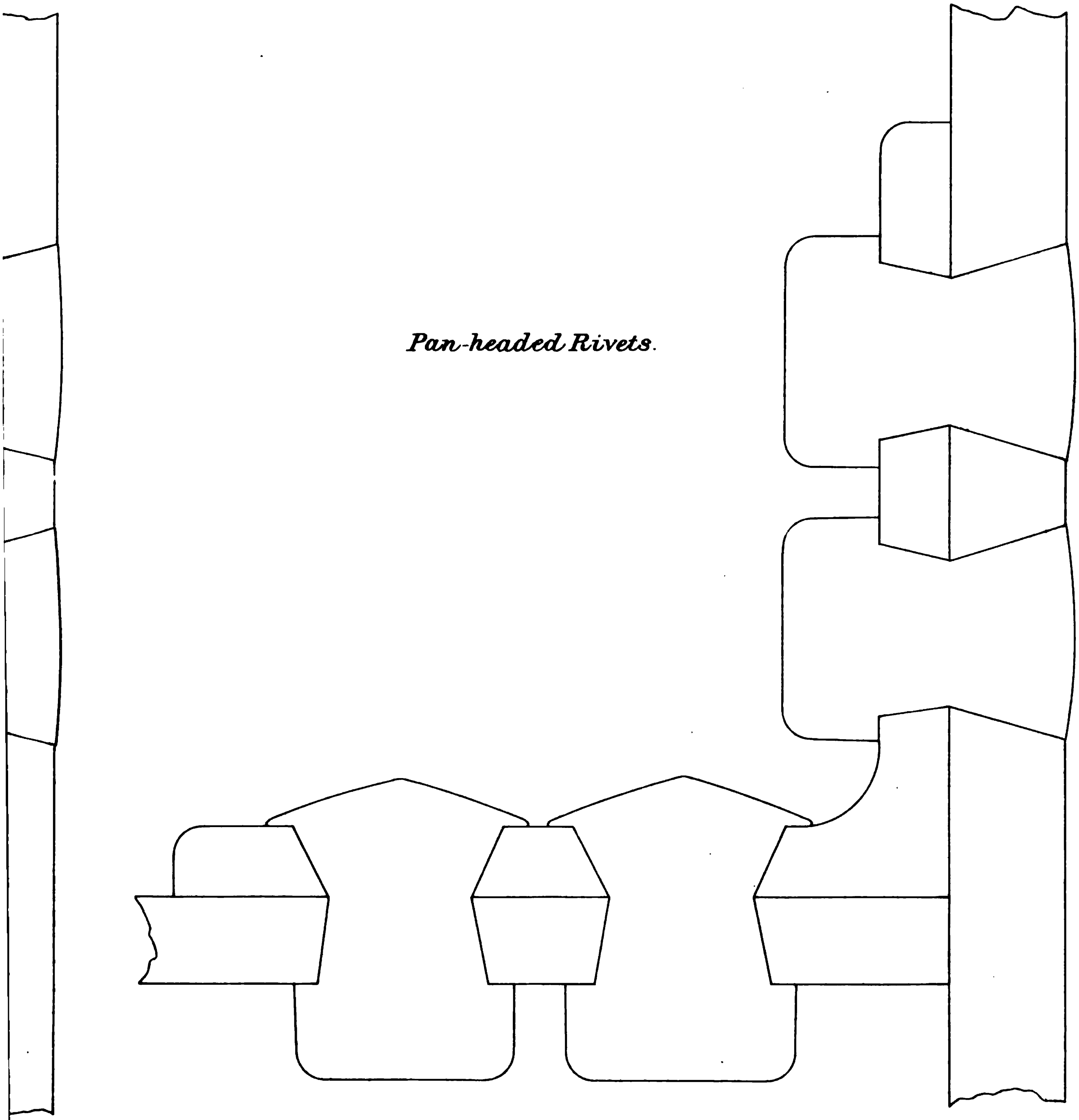
UNWIN BROTHERS, PRINTERS, THE GRESHAM PRESS, 27, PILGRIM STREET, LUDGATE HILL, E.C.

Plate I.

lk.

FIG. 4.

ver Plates to shell plating at top of Oil compartments.



Scale Full size.

ng Oil in Bulk.

FIG. 5

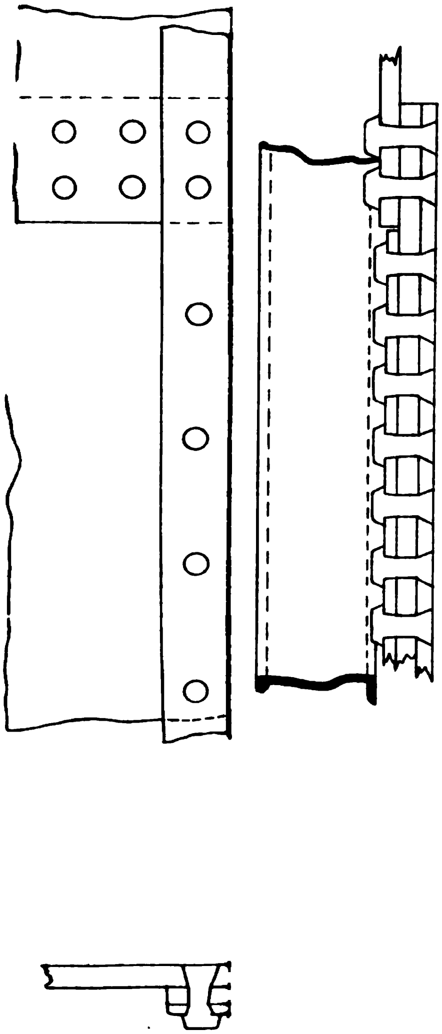
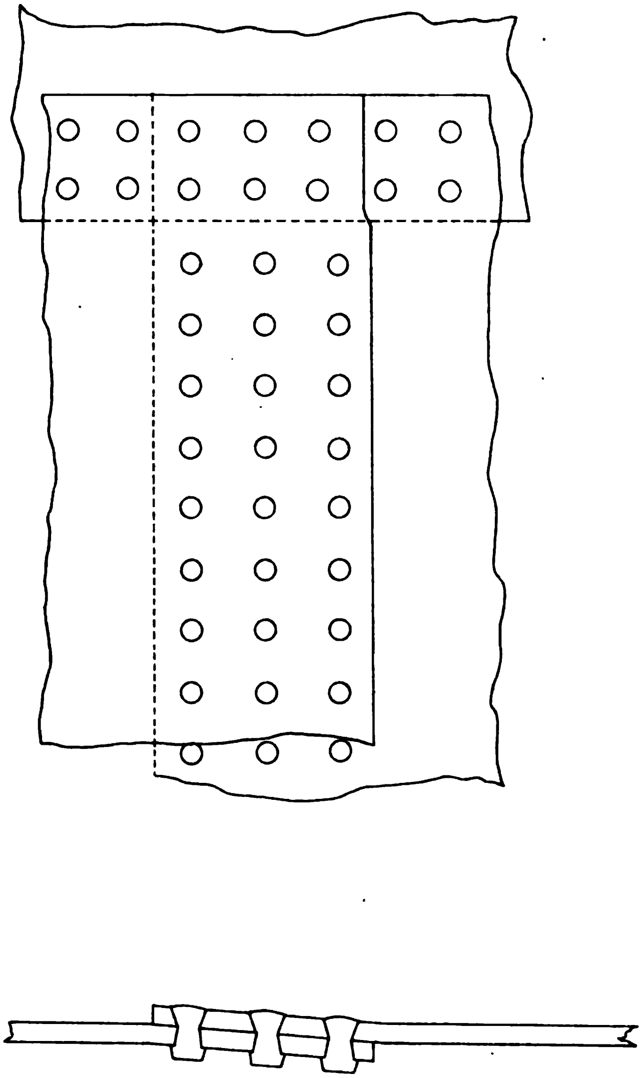


FIG. 7. *Overlapped Butt.*

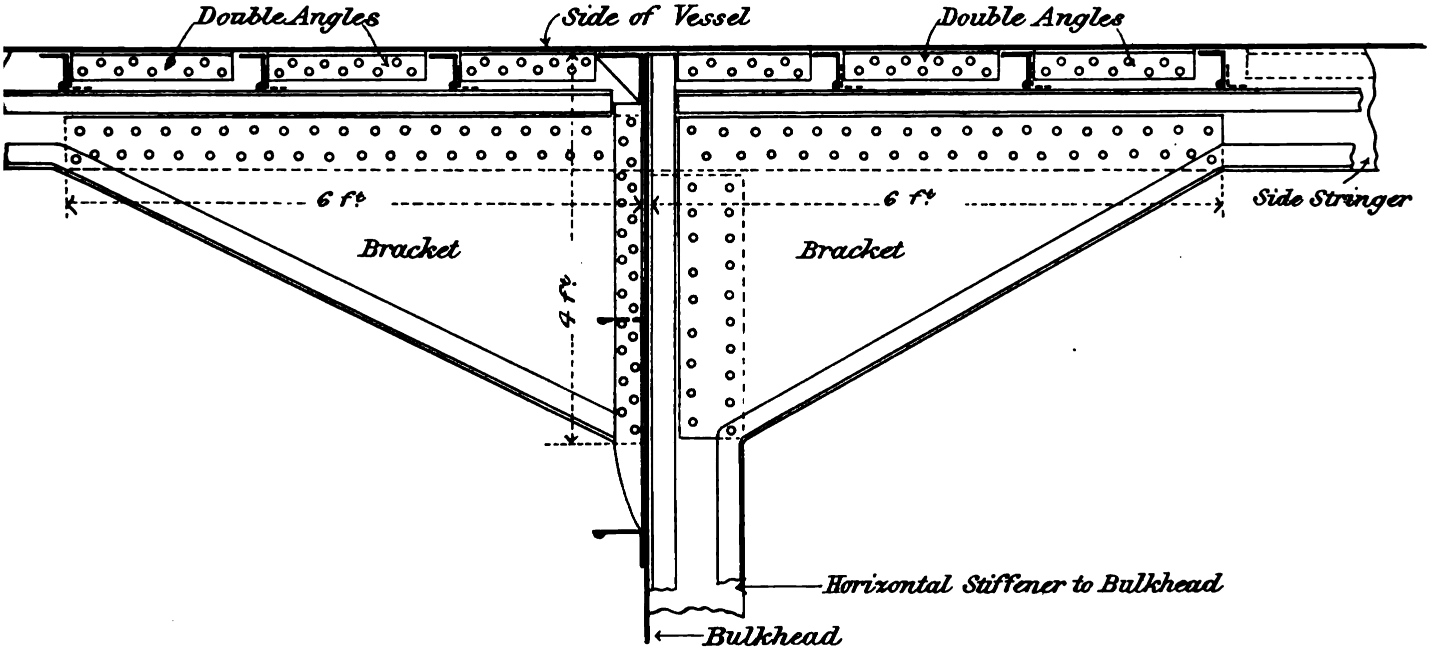


Scale 1 inch - 1 foot.

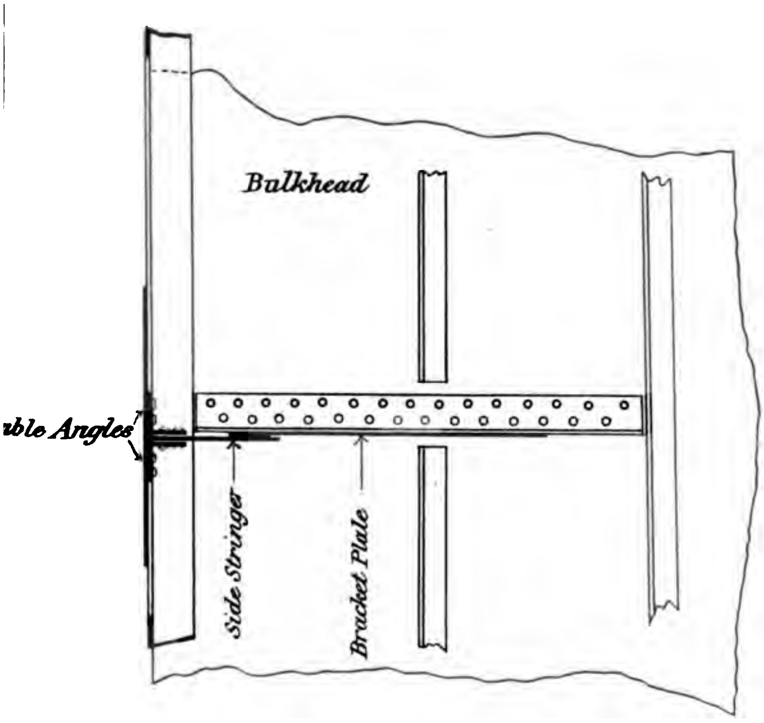
To Illustrate Mr. B. Martell's Paper on Points of Interest in the Construction and Repair of Vessels carrying Oil in Bulk.

FIG. 8 & 9.

CONNECTION OF SIDE STRINGERS TO SHELL PLATING & BULKHEAD.



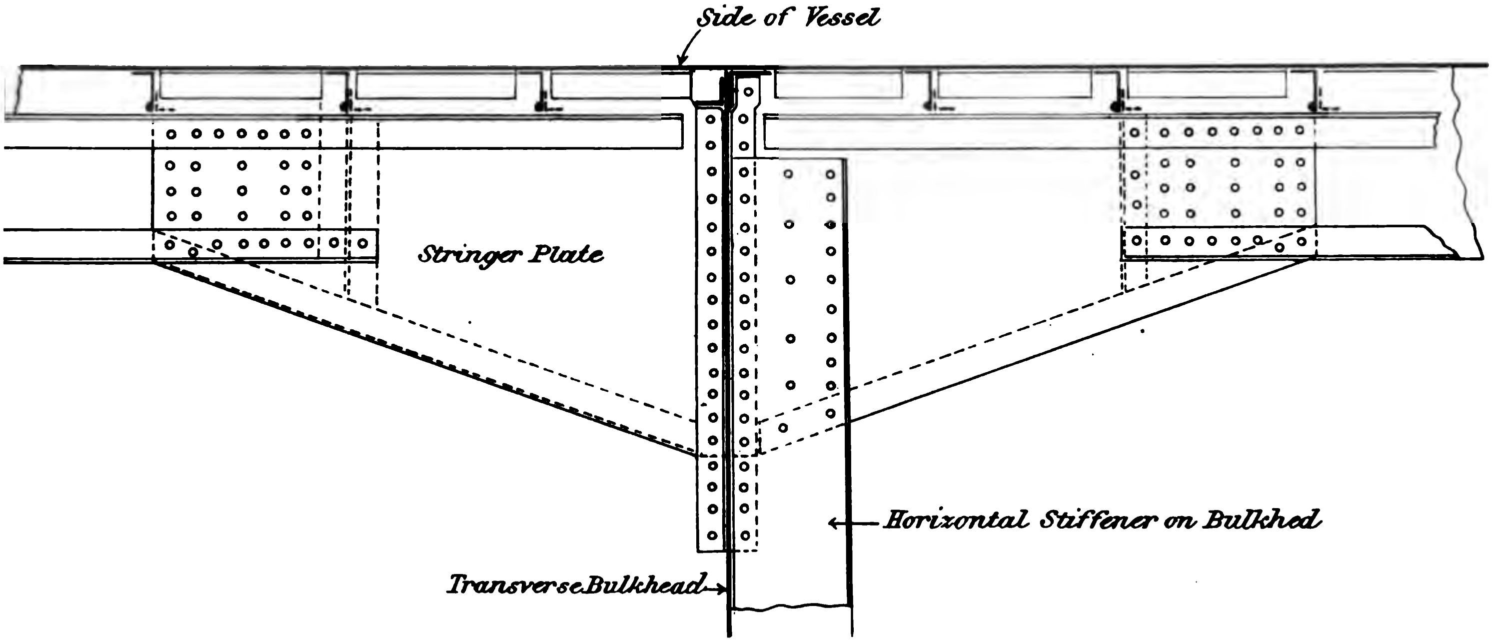
ELEVATION OF FIG. 9.



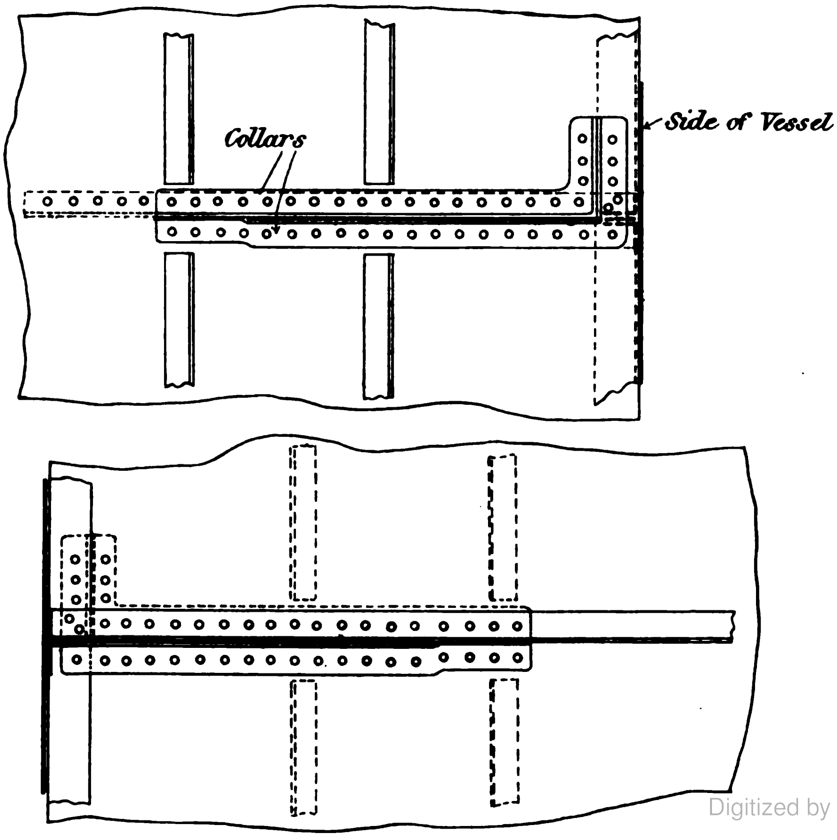
To Illustrate Mr. B. Martell's Paper on Points of Interest in the Construction and Repair of Vessels carrying Oil in Bulk.

FIG. 10.

STRINGER PLATE MADE CONTINUOUS THROUGH THE BULKHEAD & FITTED WITH COLLARS.



ELEVATIONS OF FIG. 10.

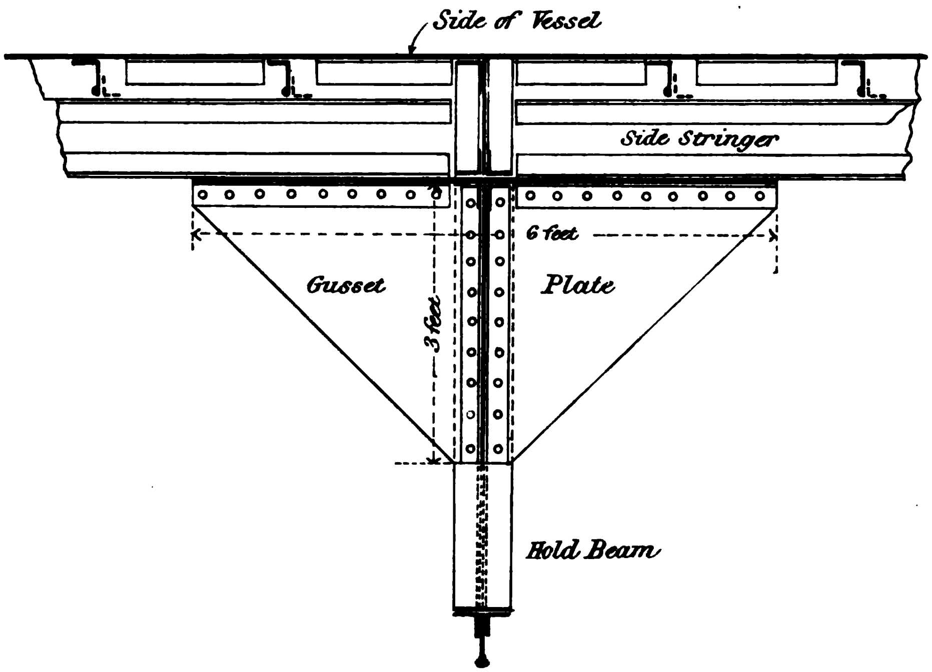


Scale ½-1 foot

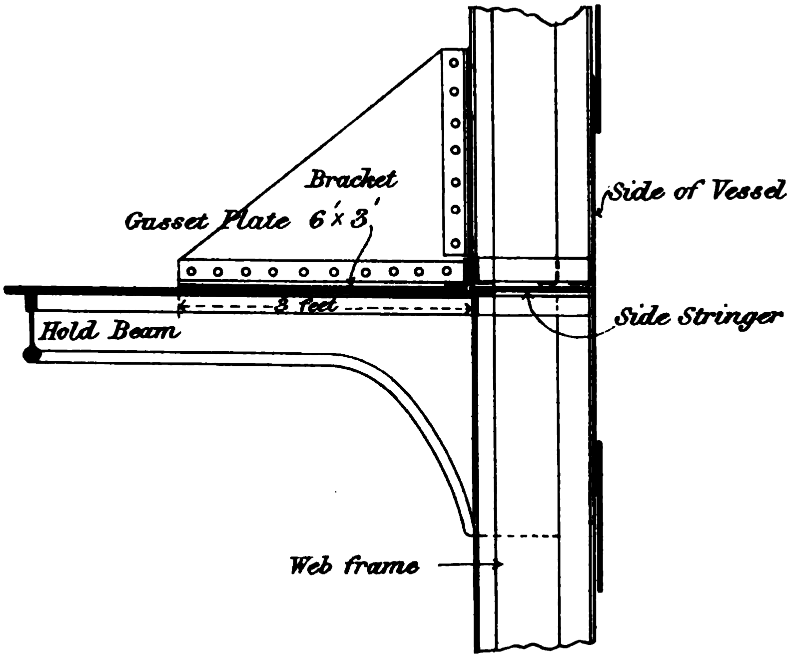
To Illustrate Mr. B. Martell's Paper on Points of Interest in the Construction and Repair of Vessels carrying Oil in Bulk.

FIG. 11.

CONNECTION OF A WIDE SPACED HOLD BEAM IN TANKS



ELEVATION OF FIG. 11.



Scale ½ 1-foot

To Illustrate Mr. B. Martell's Paper on Points of Interest in the Construction and Repair of Vessels carrying Oil in Bulk.

CONNECTION OF A SIDE KEELSON TO THE BULKHEADS

FIG. 12.

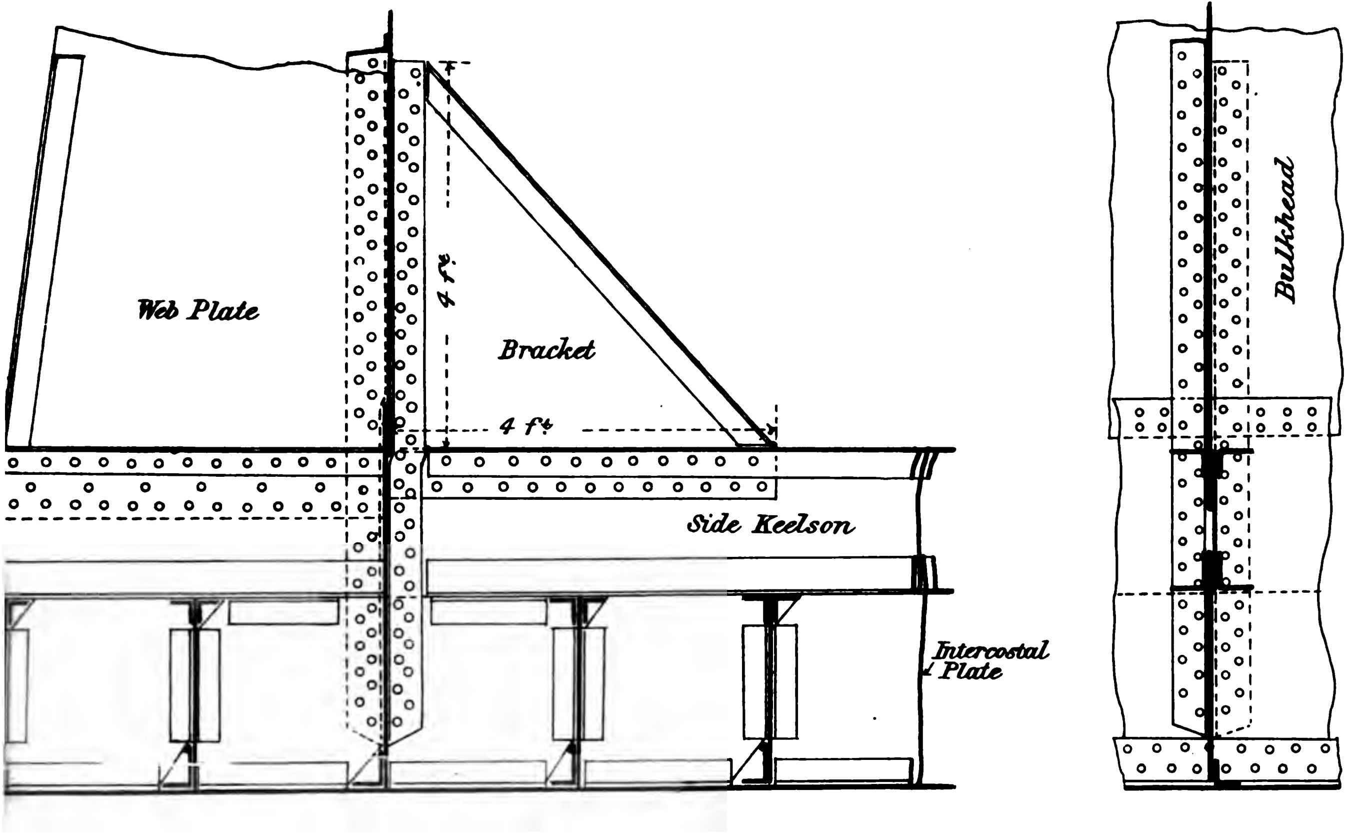
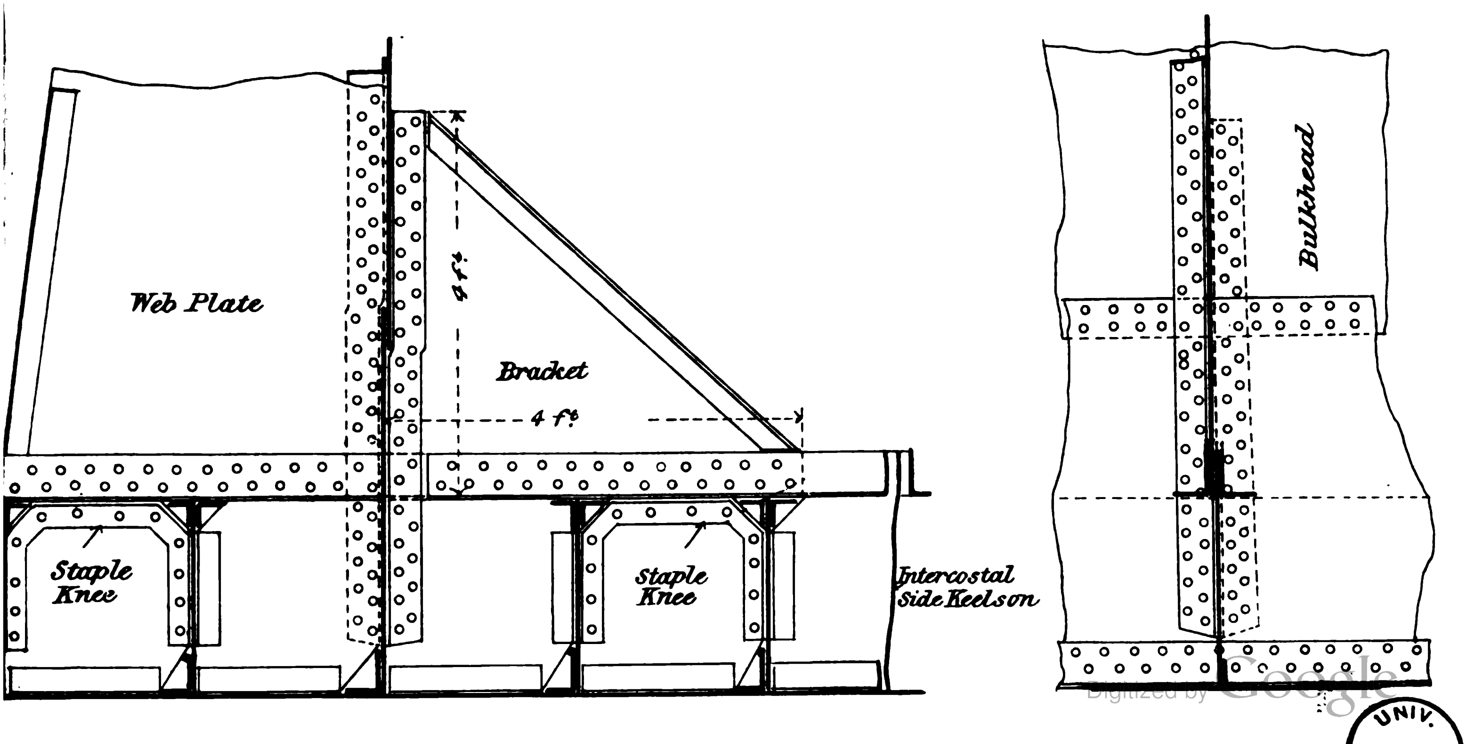


FIG. 13.

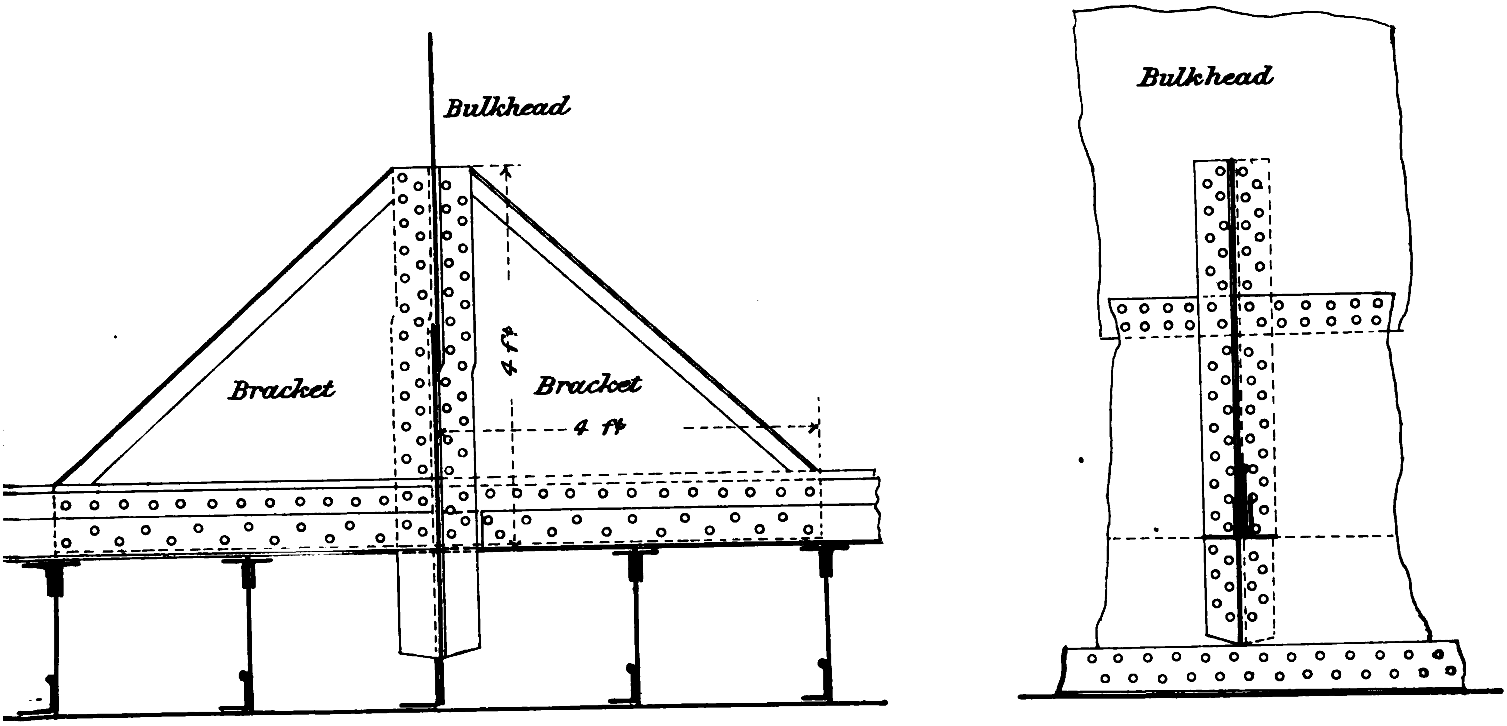
CONNECTION OF AN INTERCOSTAL SIDE KEELSON TO BULKHEADS.



To Illustrate Mr. B. Martell's Paper on Points of Interest in the Construction and Repair of Vessels carrying Oil in Bulk.

FIG. 14.

CONNECTION OF A BULB PLATE BILGE KEELSON TO BULKHEADS

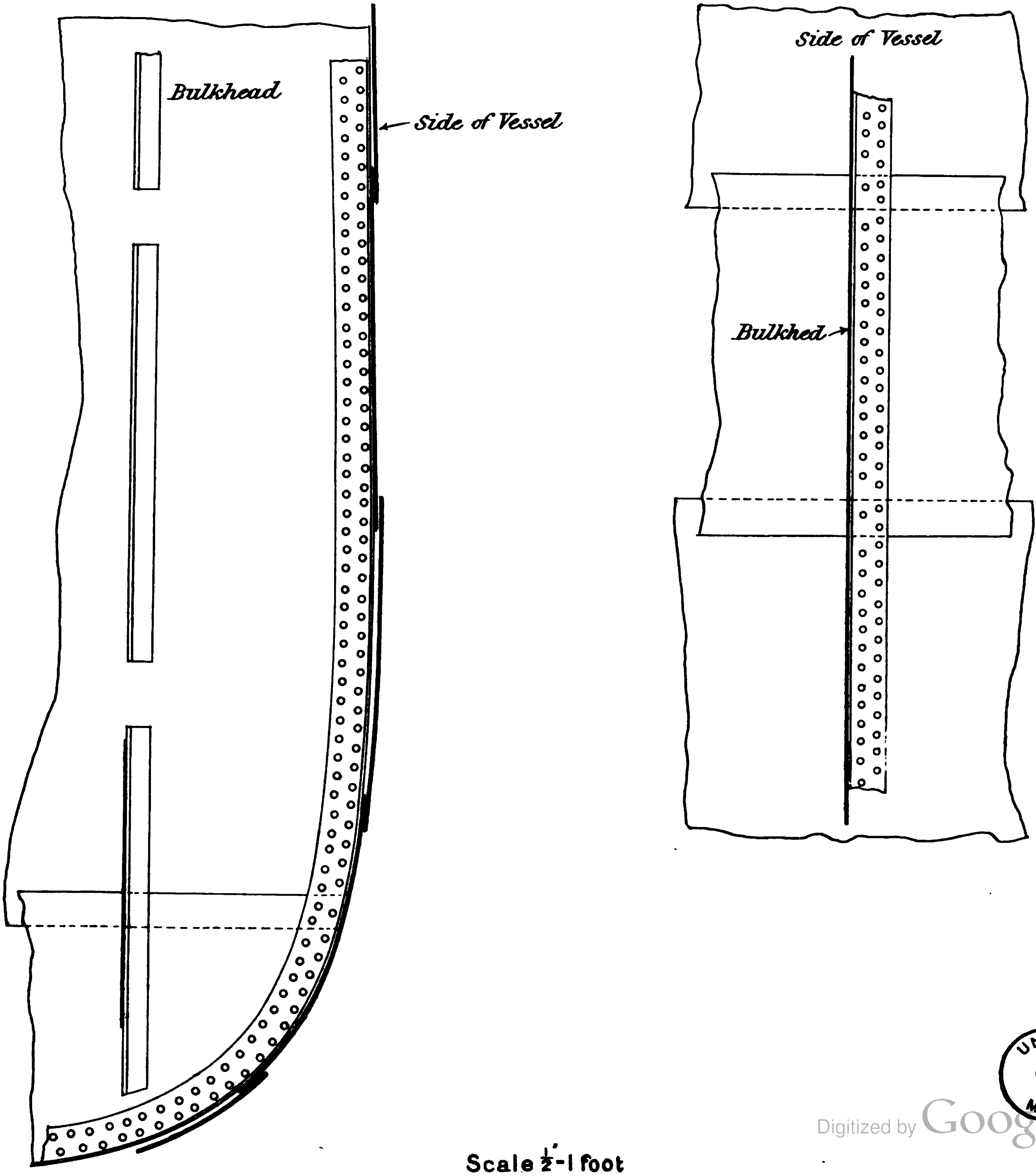


Scale $\frac{1}{2}$" = 1 foot

To Illustrate Mr. B. Martell's Paper on Points of Interest in the Construction and Repair of Vessels carrying Oil in Bulk.

FIG. 15.

CONNECTION OF BULKHEADS TO THE VESSELS SIDES BY A LARGE SINGLE ANGLE BAR WITH DOUBLE RIVETING



Scale ½"-1 foot

Trans. Inst. Naval Architects, Vol. XXXV., 1894.

To Illustrate Mr. B. Martell's Paper on Points of Interest
of Vessels carrying Oil in Bui

Plate X.

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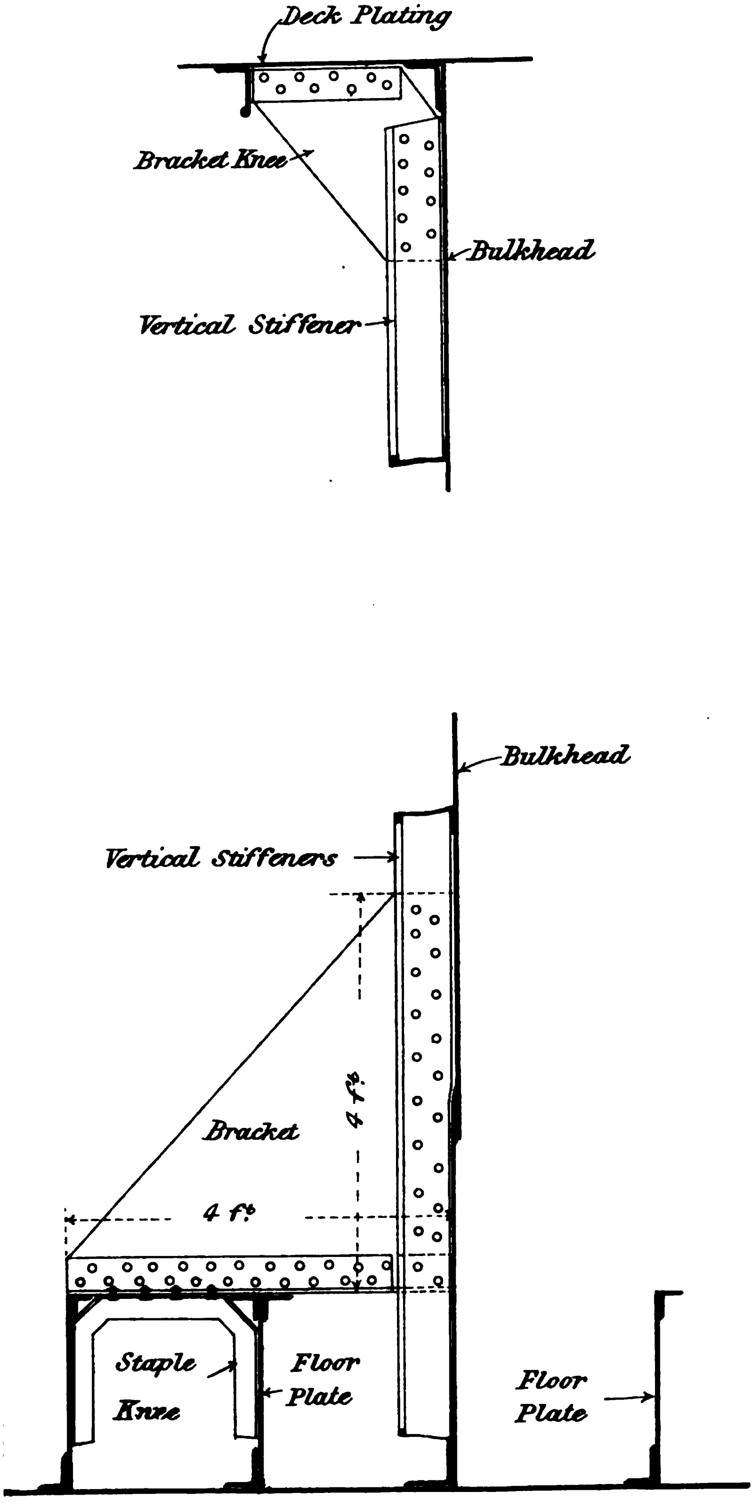
Fig. 16.

Connection of the Vertical Stiffeners to Bulkheads at Heel
Floor Plates and the upper ends of the Stiffeners to th

AND



Scale ½′-1 foot

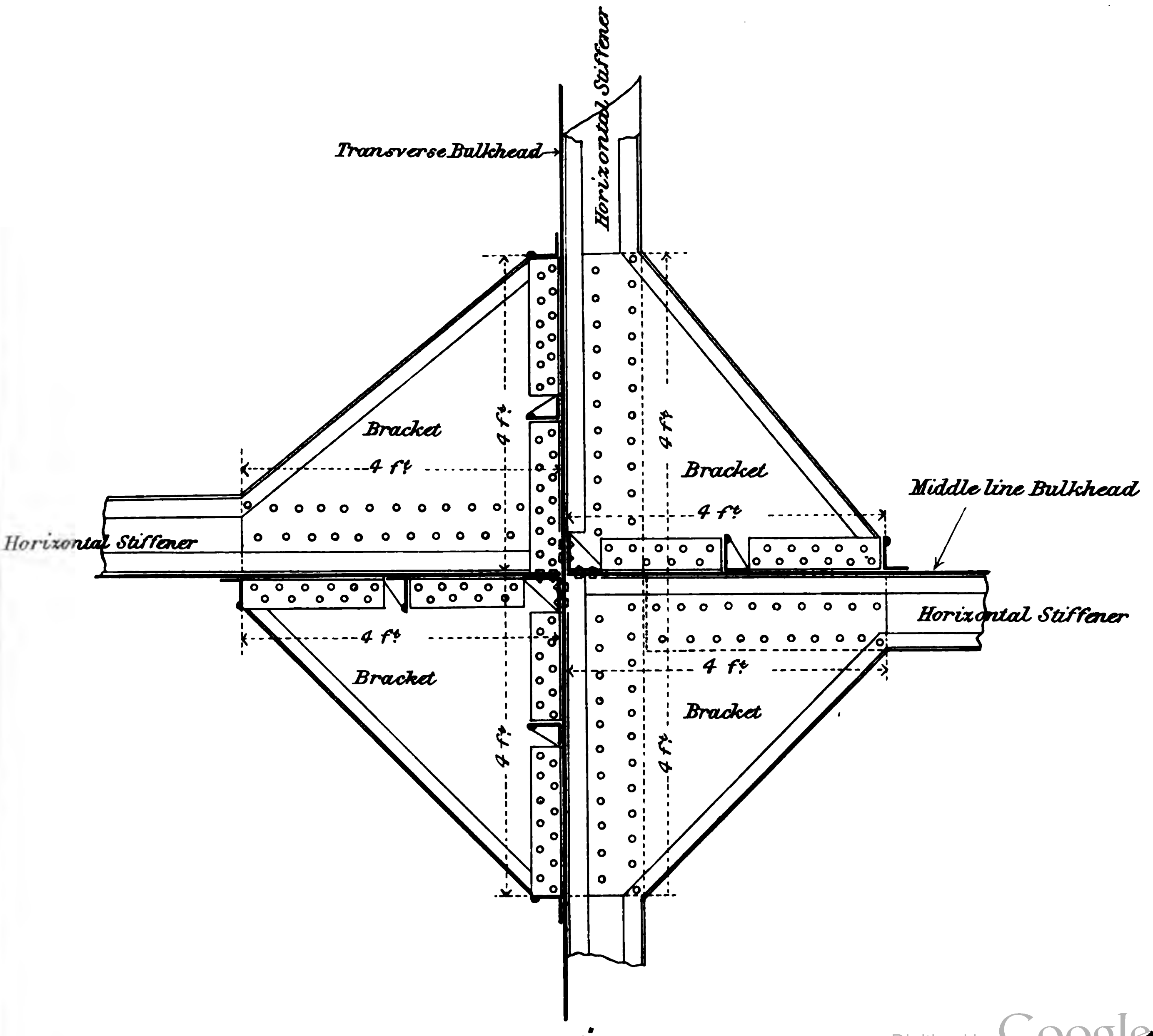
ulkhead

tiffener

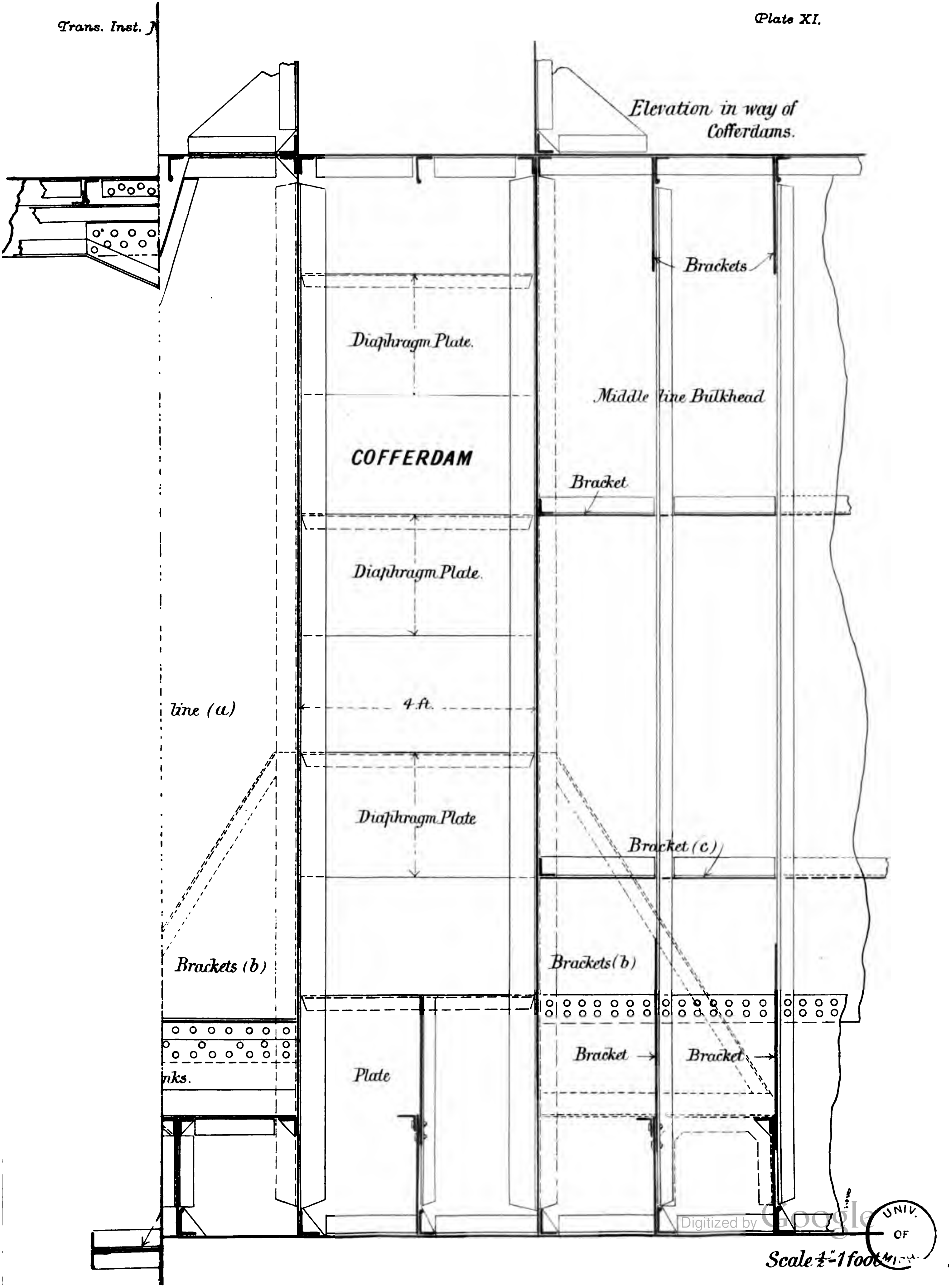
To Illustrate Mr. B. Martell's Paper on Points of Interest in the Construction and Repair of Vessels carrying Oil in Bulk.

FIG. 17.

CONNECTION OF THE HORIZONTAL STIFFENERS ON THE TRANSVERSE AND MIDDLE LINE BULKHEADS AT THE CORNERS OF THE TANKS.



Scale ½"=1 foot


Elevation in way of Cofferdams.
Brackets
Diaphragm Plate.
Middle line Bulkhead
COFFERDAM
Bracket
Diaphragm Plate.
line (a)
4 ft.
Diaphragm Plate
Bracket (c)
Brackets (b)
Brackets (b)
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Bracket
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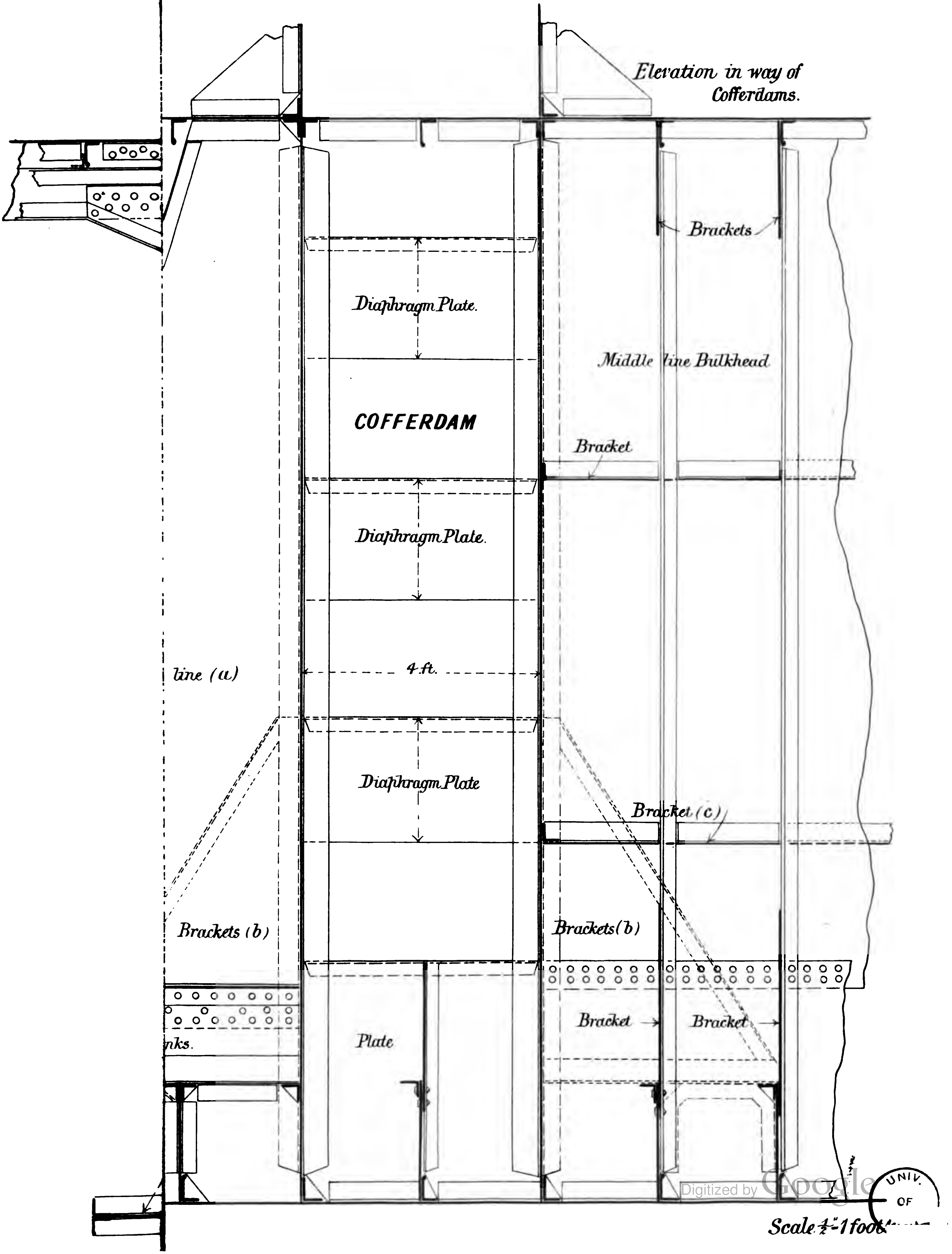
Plate
Scale ½" = 1 foot


Elevation in way of Cofferdams.

Scale ½"-1 foot.

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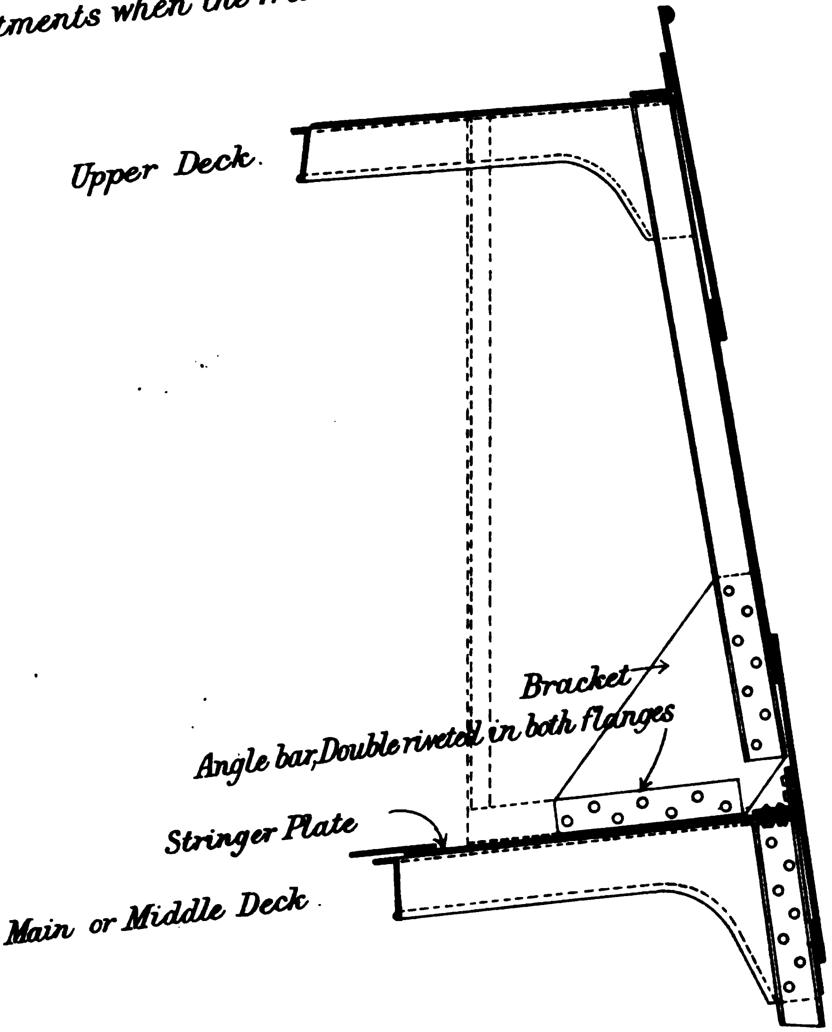
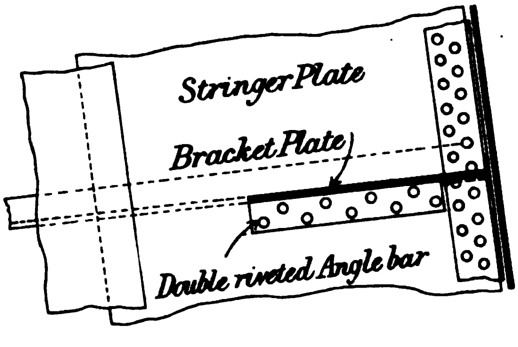
Naval Architects, Vol. XXXV., 1894.

llustrate Mr. B. Martell's Paper on Points of Interest in the Construction and Repair of Vessels carrying Oil in Bulk.

FIG. 22.

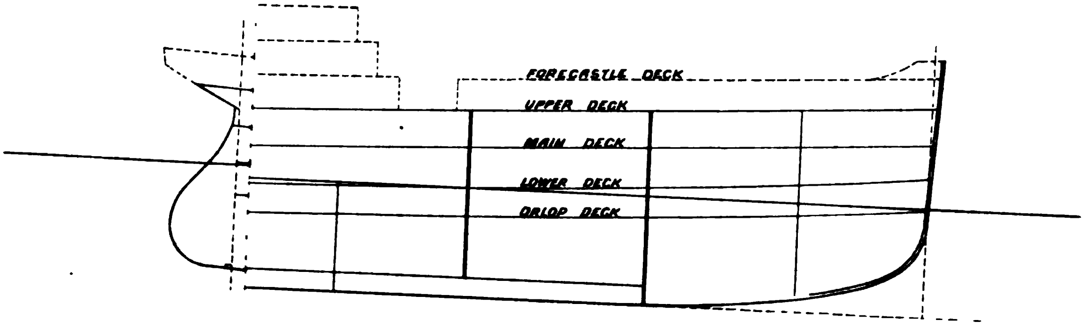
Bracket connecting Stringer Plate and Frames at side on top of the Oil Compartments when the frames are cut at the Main or Middle Deck.

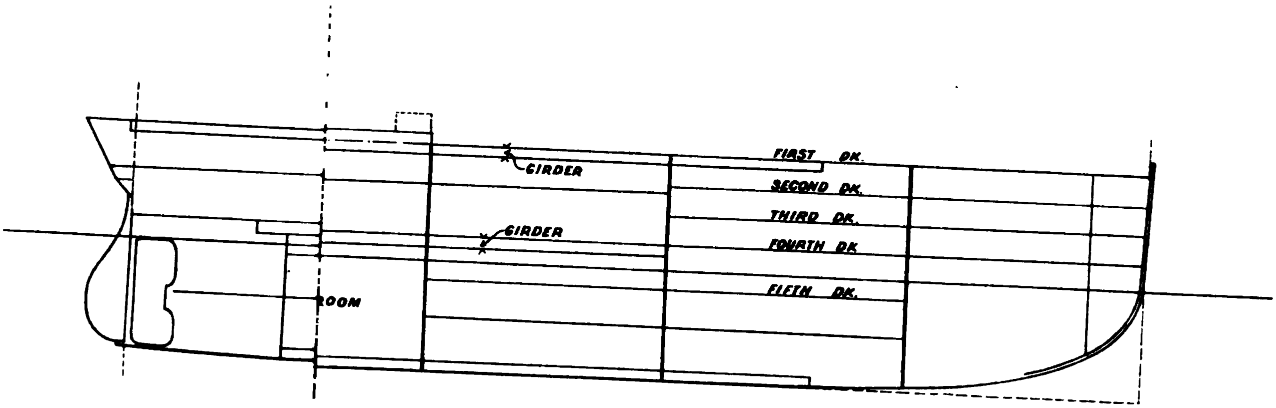




Scale ¾"-1 foot.

Plate XVI.


FORECASTLE DECK
UPPER DECK
MAIN DECK
LOWER DECK
ORLOP DECK


GIRDER
GIRDER
FIRST DK.
SECOND DK.
THIRD DK.
FOURTH DK.
FIFTH DK.
ROOM

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GURE 1.

XIII.

To Illustrate Mr. J. D. Ellis' Paper on Some Experi
Draught and hot Air, applied to Mari
" Serve " Tubes and Ret

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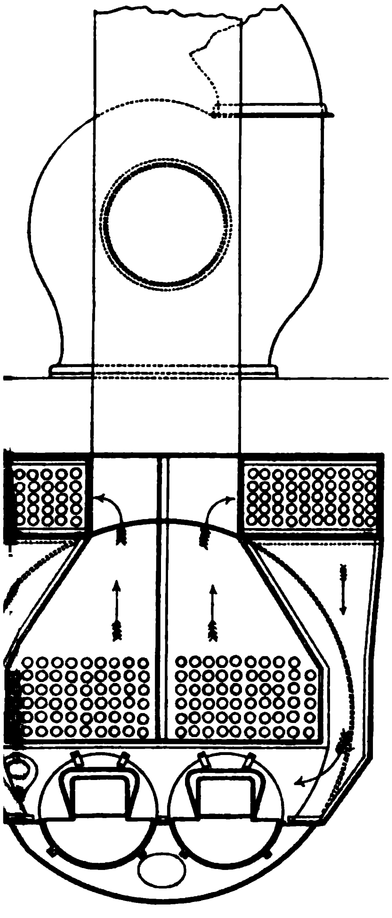
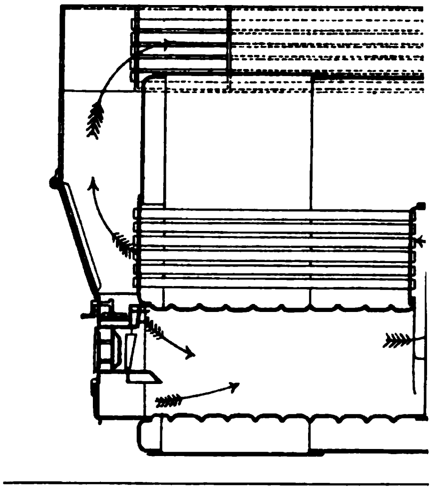
GURE 1.





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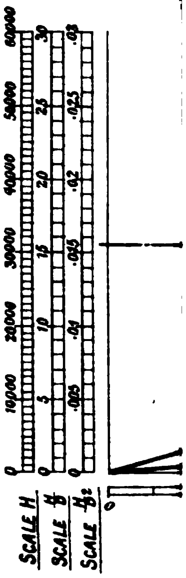
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SCALE H
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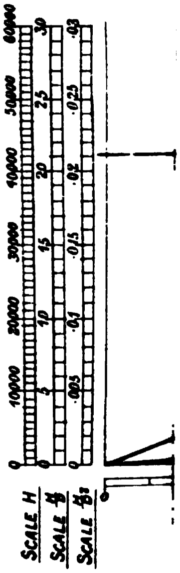
SCALE H/D²

GURE I.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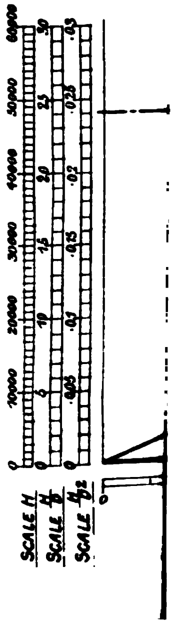
SCALE H/D
SCALE H/D²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SCALE H
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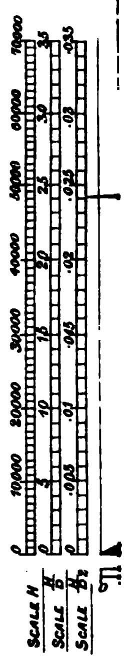

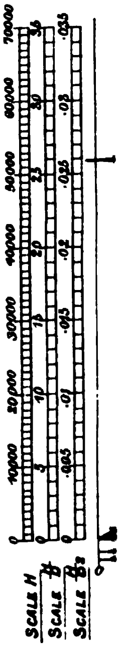

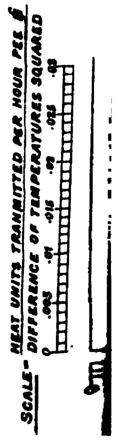

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IGURE I.

To Illustrate Mr. A. Blechynden's Paper on an Account of some Experiments on the Transmission of Heat through Steel Plates from heated Gas on the one Side to Water at the other.

4 a.

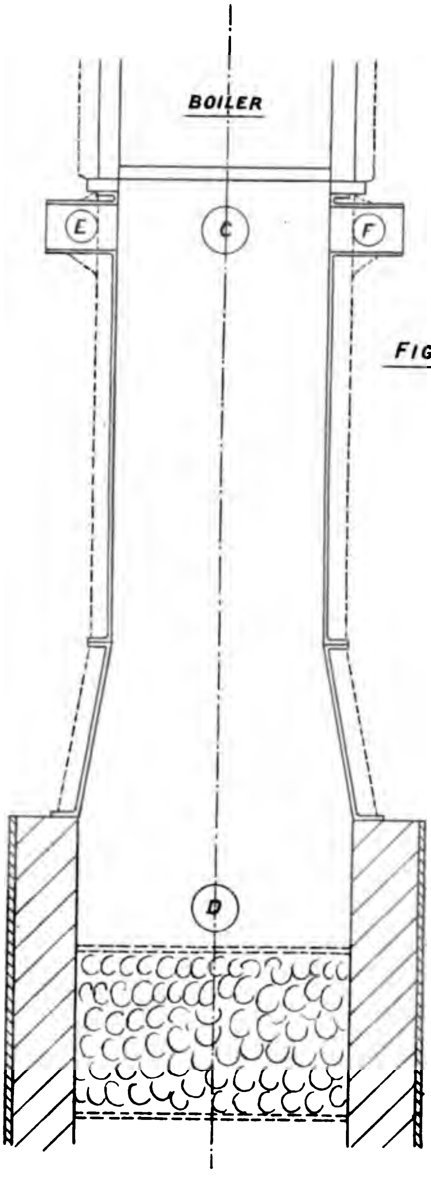

FIGURE 2.

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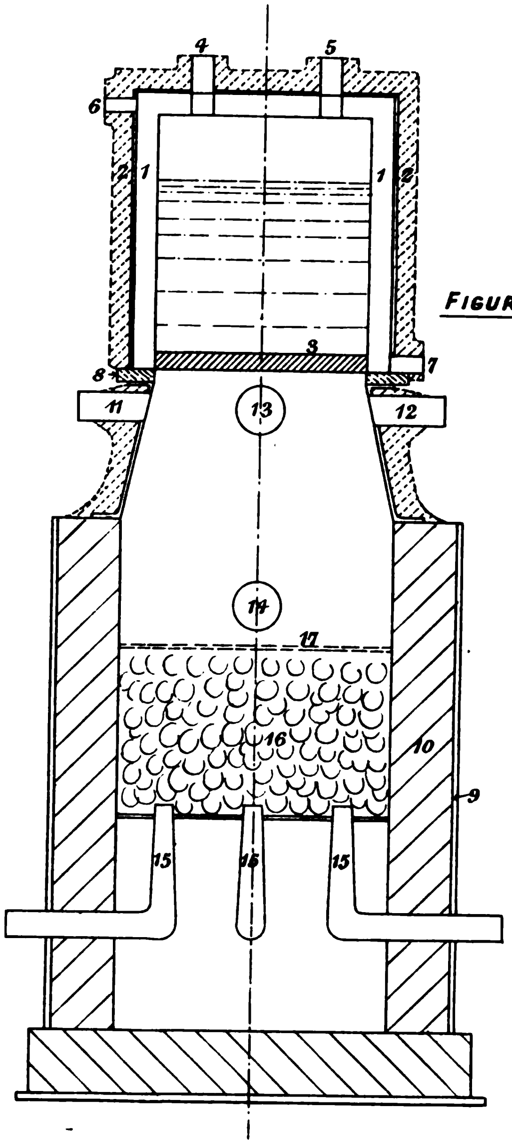

FIGURE 1.

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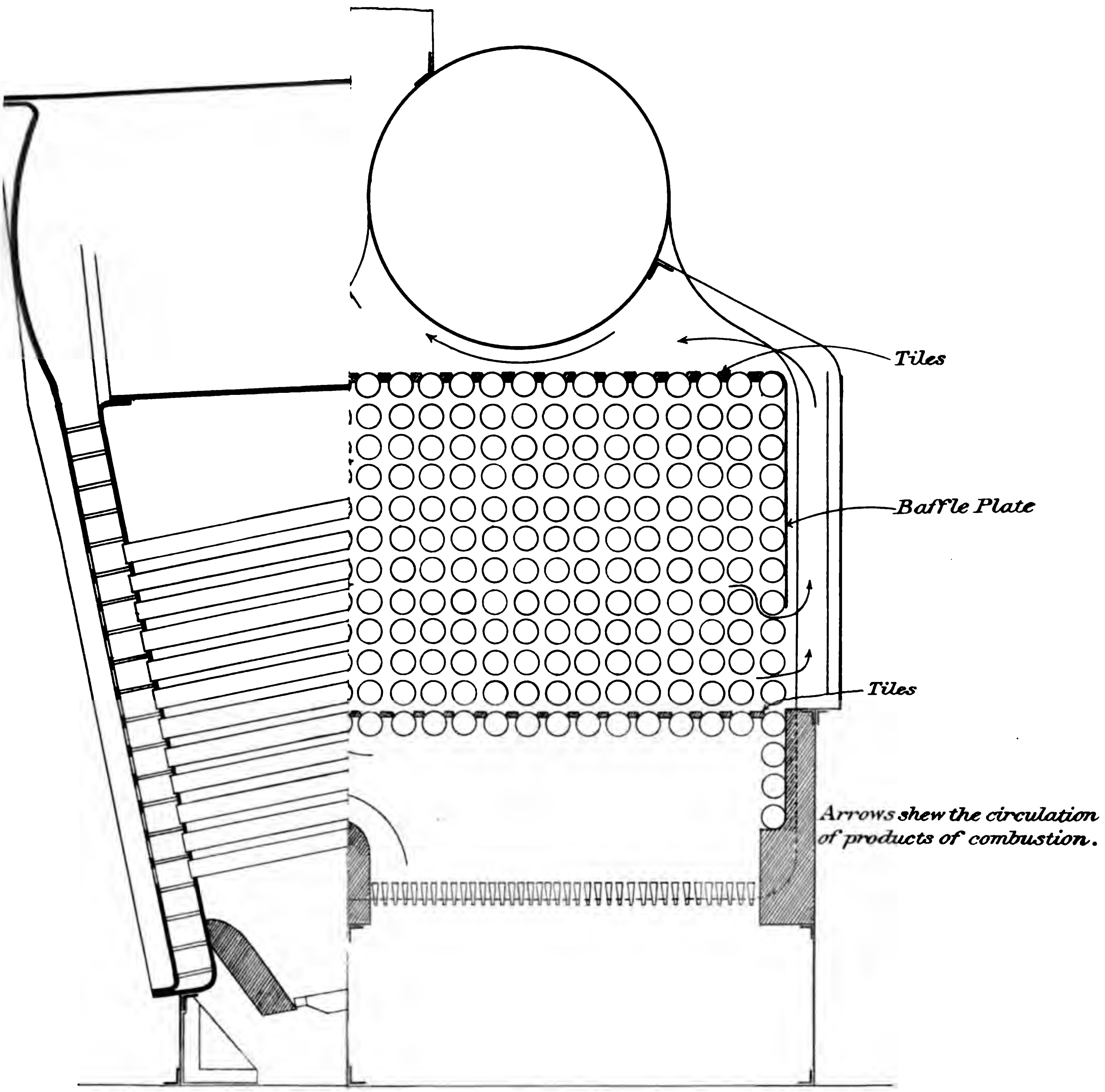


BOILER

To Illustrate Mr. J. T. Milton's Paper on the present Position of Water-Tube Boilers as applied for Marine Purposes.

BELLEVILLE BOILER.

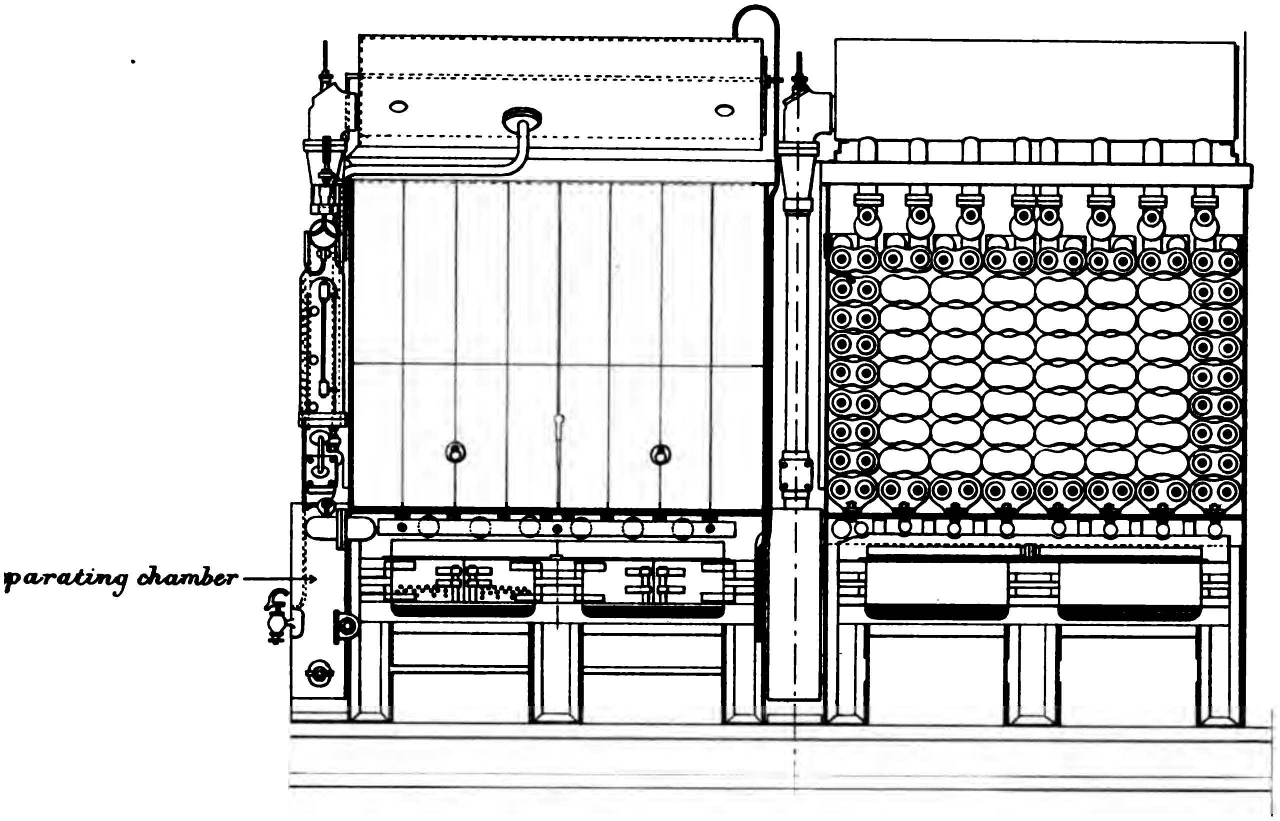
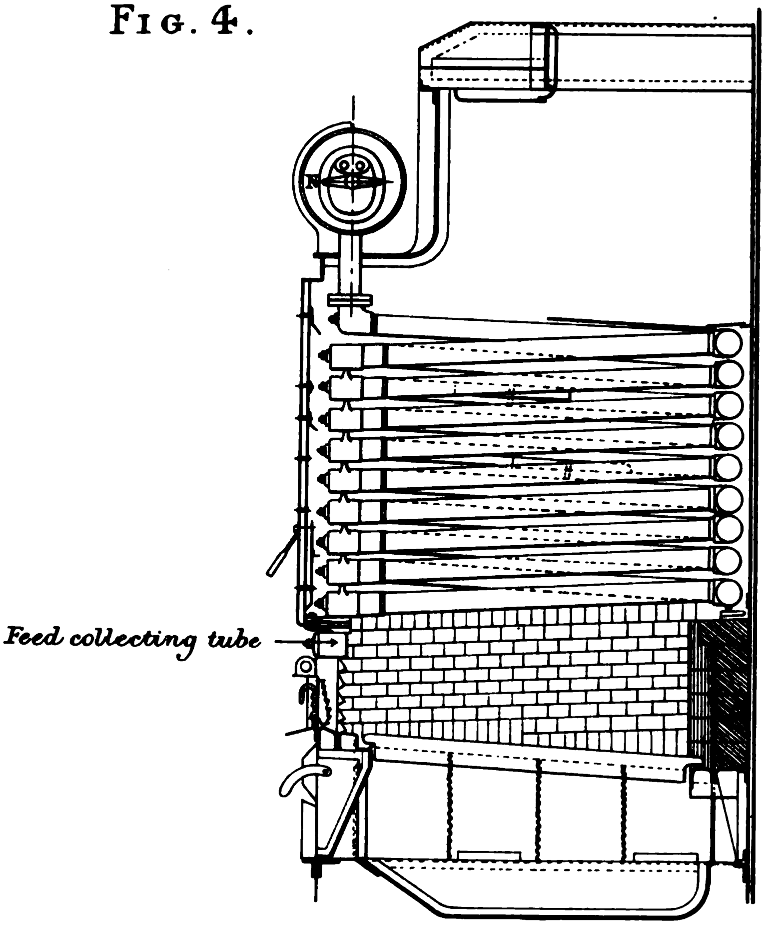
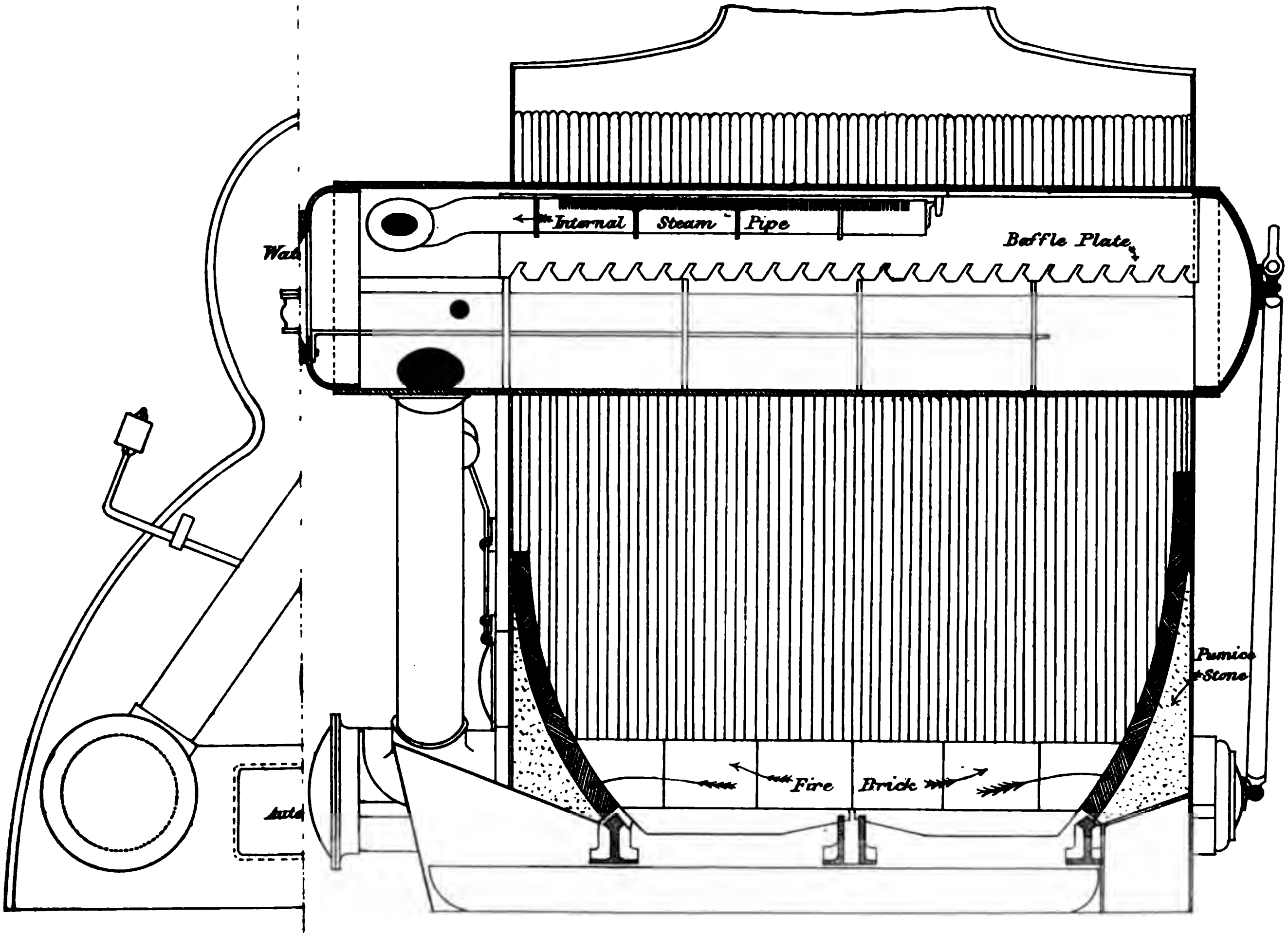
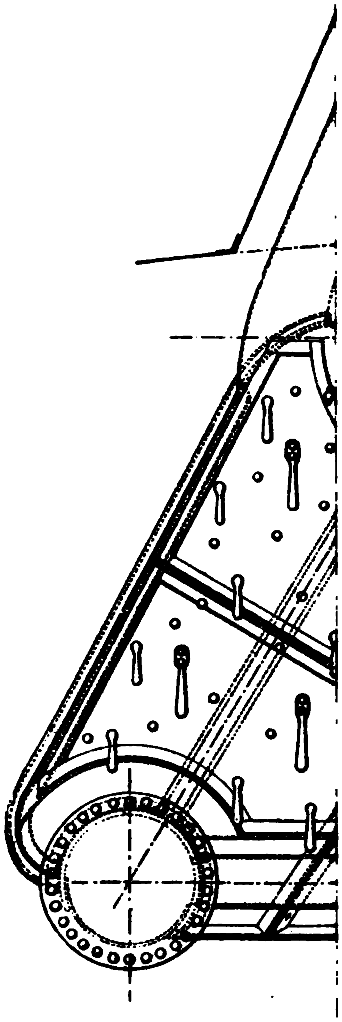


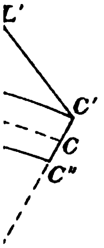
FIG. 4.



pplied for Marine Purposes.



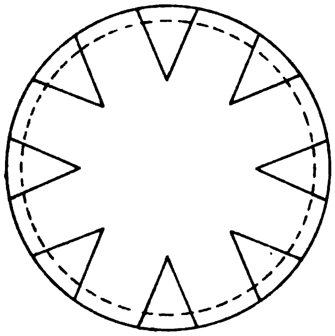



L'
C'
C
C"

Trans. Inst. Naval Architects, Vol. XXXV., 1894.   Plate XXX.

To Illustrate Mr. G. H. Bryan's Paper on the Theory of thin Plating and its Applicability to Calculations of the Strength of Bulk-Head Plating and similar Structures.

Fig. 1.



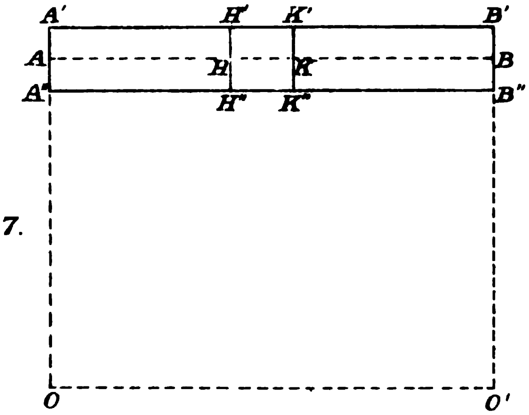


Fig. 7.

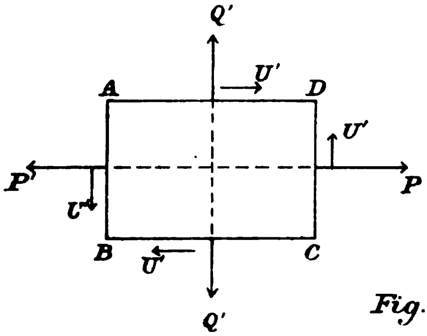
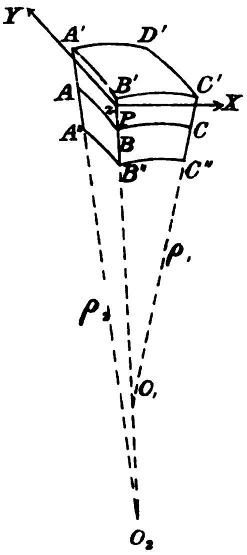


Fig. 2.

Fig. 9.



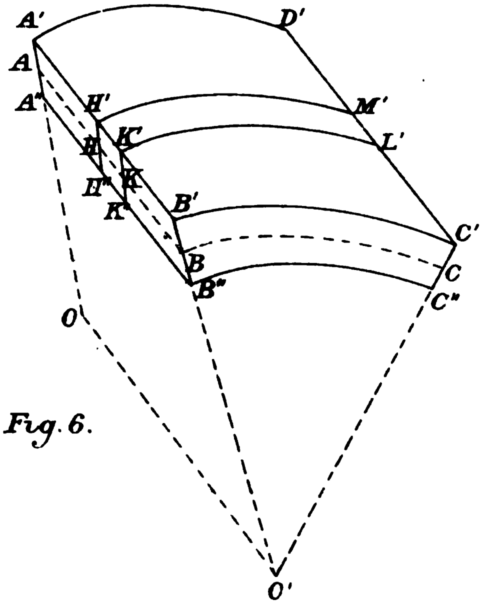


Fig. 6.

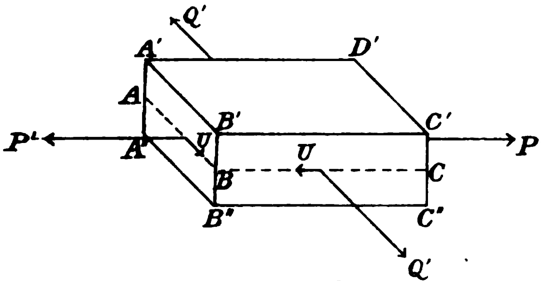


Fig. 3.

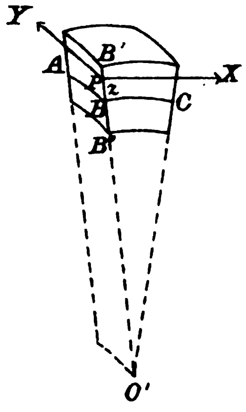
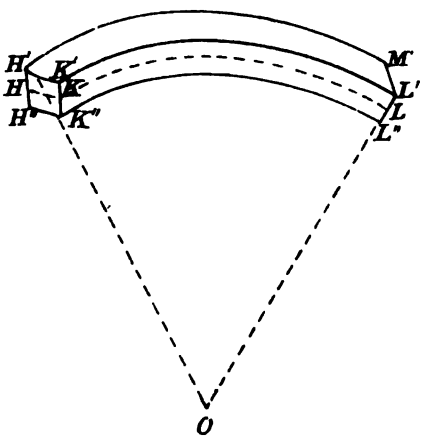


Fig. 8.

Fig. 4.



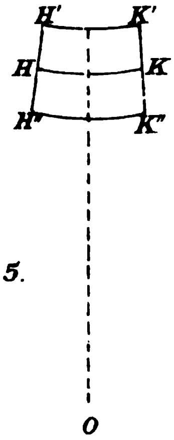
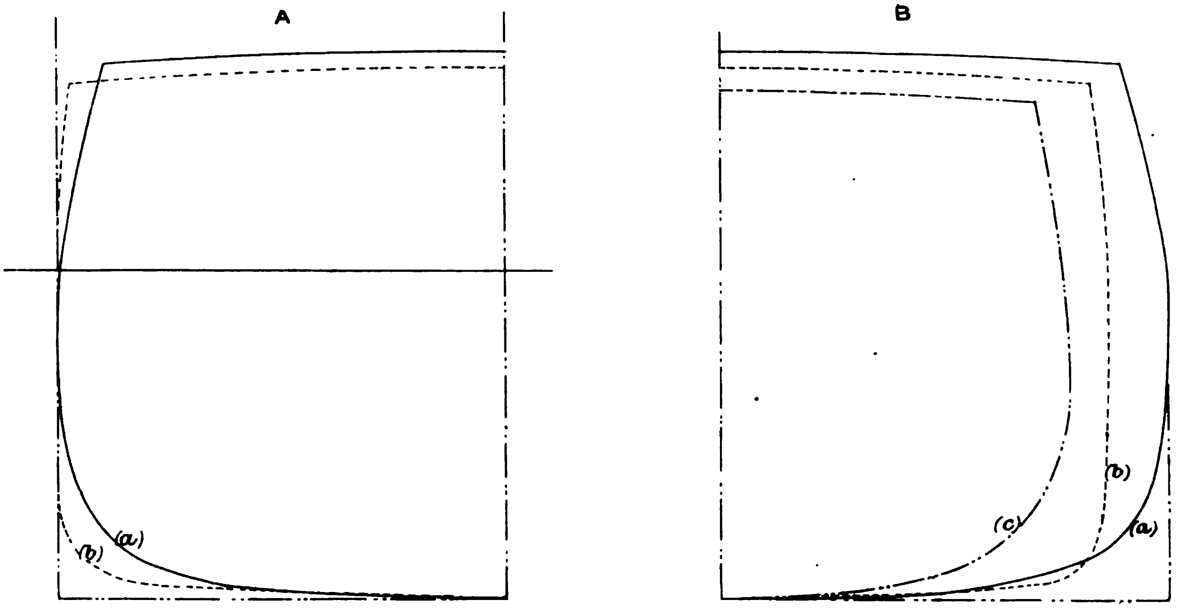


Fig. 5.

To Illustrate Mr. W. H. White's Paper on The Qualities and Performances of recent first-class Battleships.

FIG. 1.

MIDSHIP SECTIONS



(a) Midship Section of "Royal Sovereign"
(b) " " Atlantic Liner (Broadened)

(a) Midship Section of "Royal Sovereign"
(b) " " Atlantic Liner
(c) " " "Sultan"

To Illustrate Mr. W. H. White's Paper on The Qualities and Performances of recent first-class Battleships.

FIG. 2.

CURVES OF STABILITY FOR H.M.S. "ROYAL SOVEREIGN"

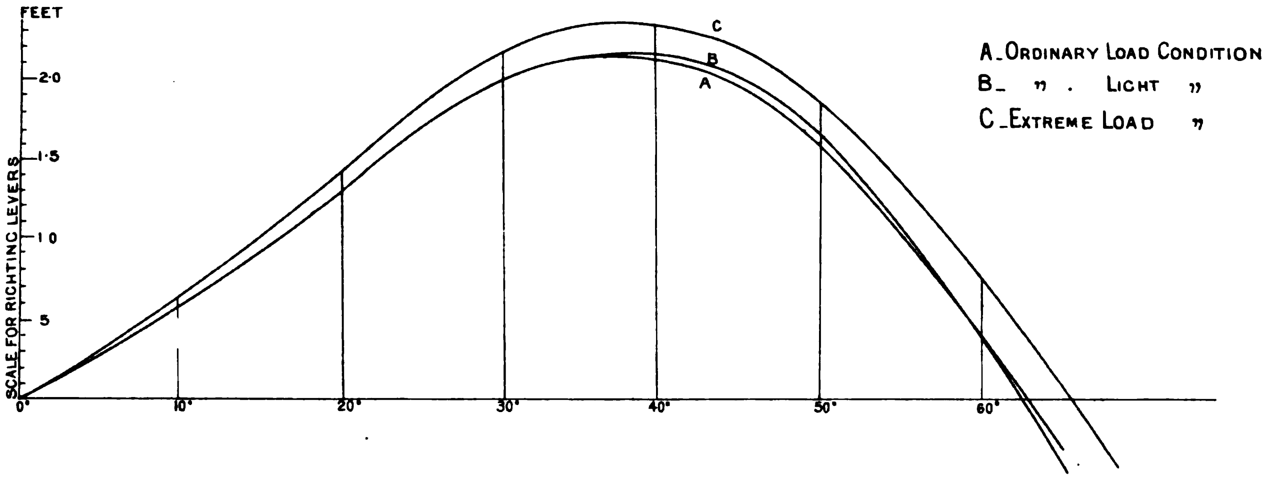


FIG. 3.

CURVES OF STABILITY FOR H.M.S. "MONARCH"

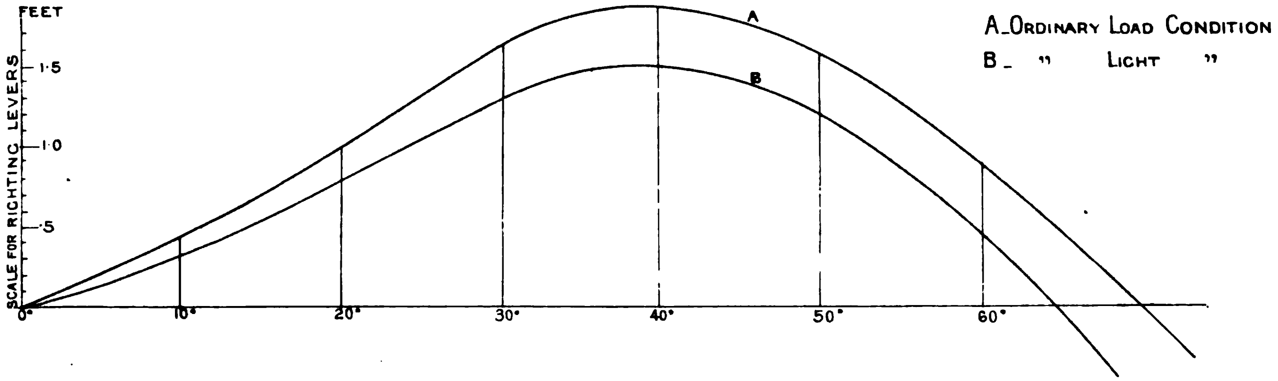
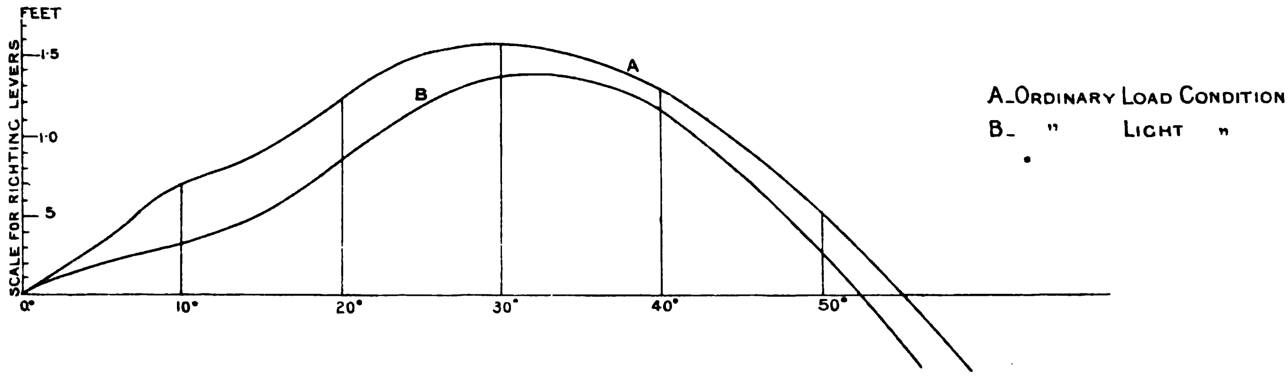


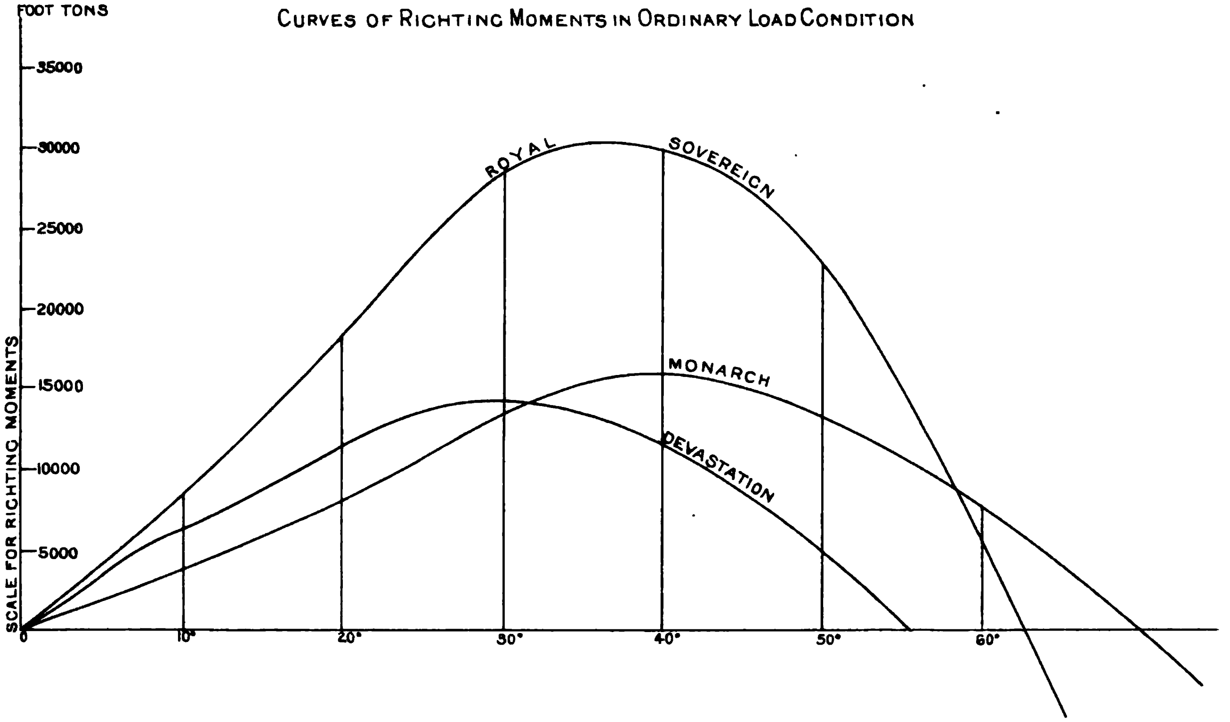
FIG. 4.

CURVES OF STABILITY FOR H.M.S. "DEVASTATION"



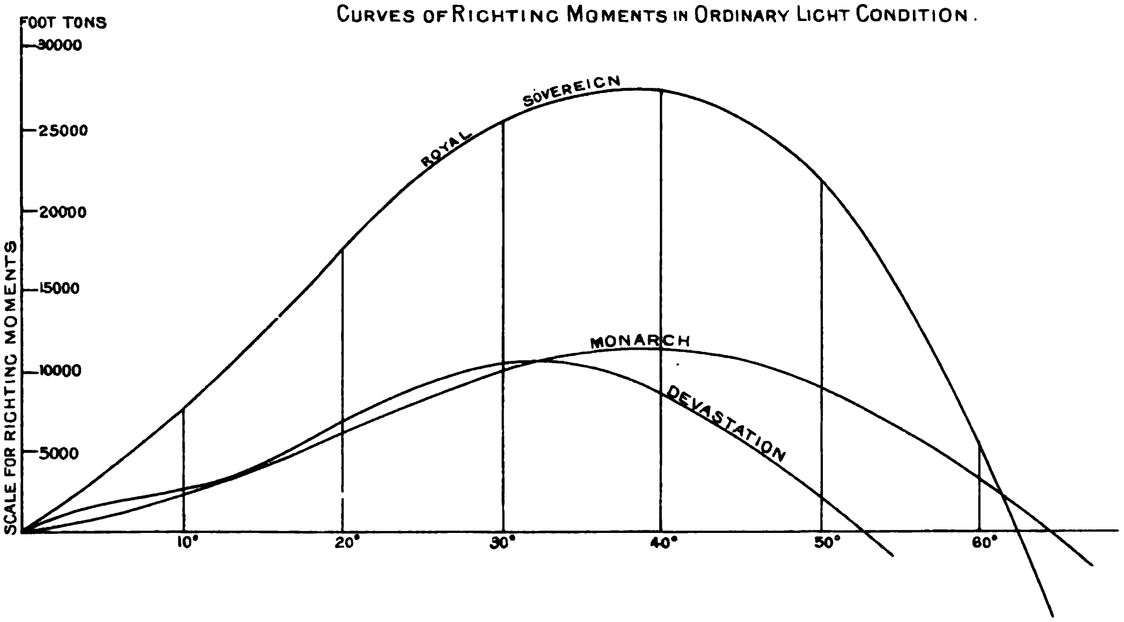
To Illustrate Mr. W. H. White's Paper on The Qualities and Performances of recent first-class Battleships.

Fig. 5.



Curves of Righting Moments in Ordinary Load Condition

Fig. 6.



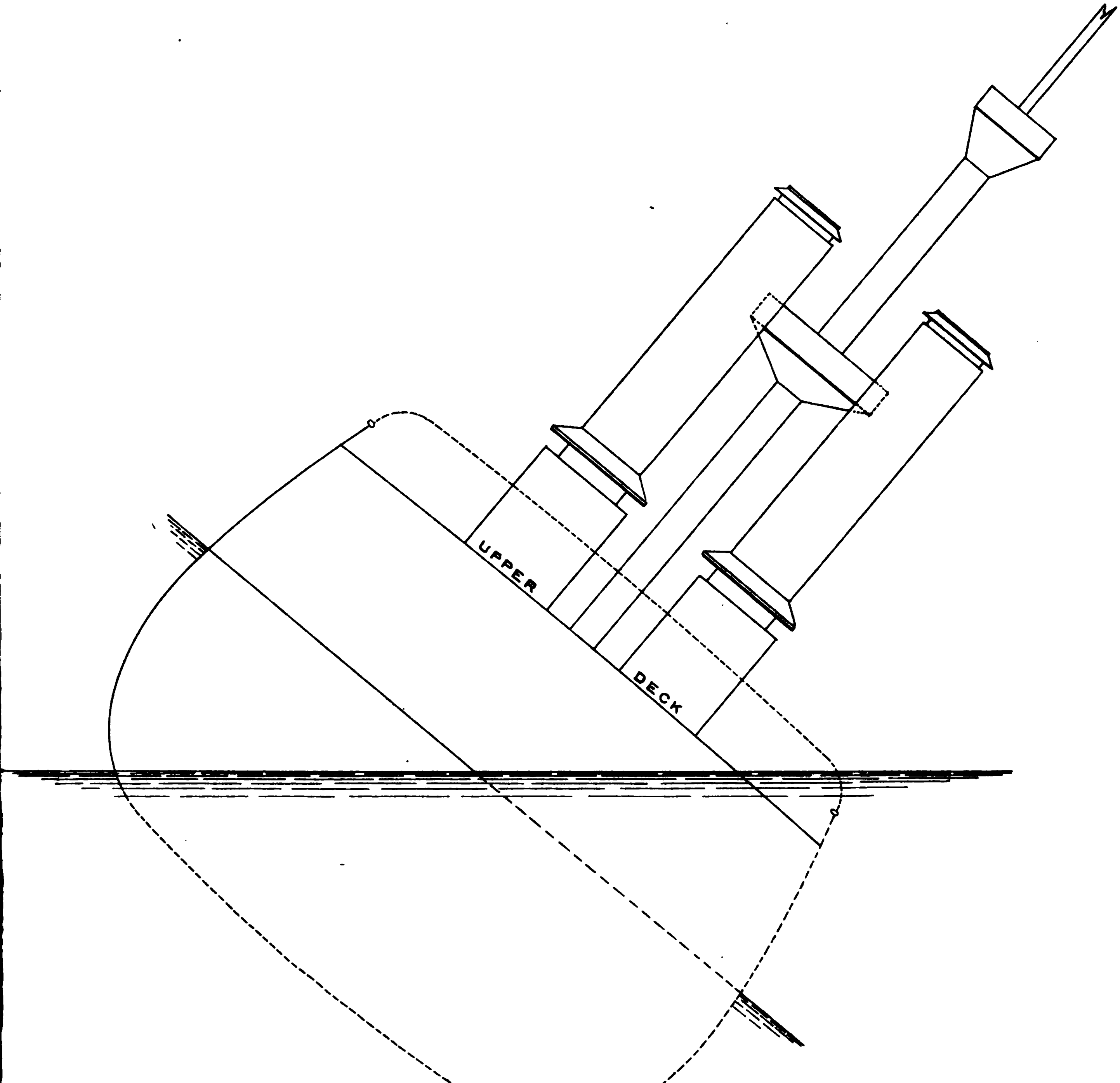
Curves of Righting Moments in Ordinary Light Condition.

To Illustrate Mr. W. H. White's Paper on The Qualities and Performances of recent first-class Battleships.

FIG. 7.

H. M. S. "RESOLUTION"

If inclined at 40° in Smooth Water.

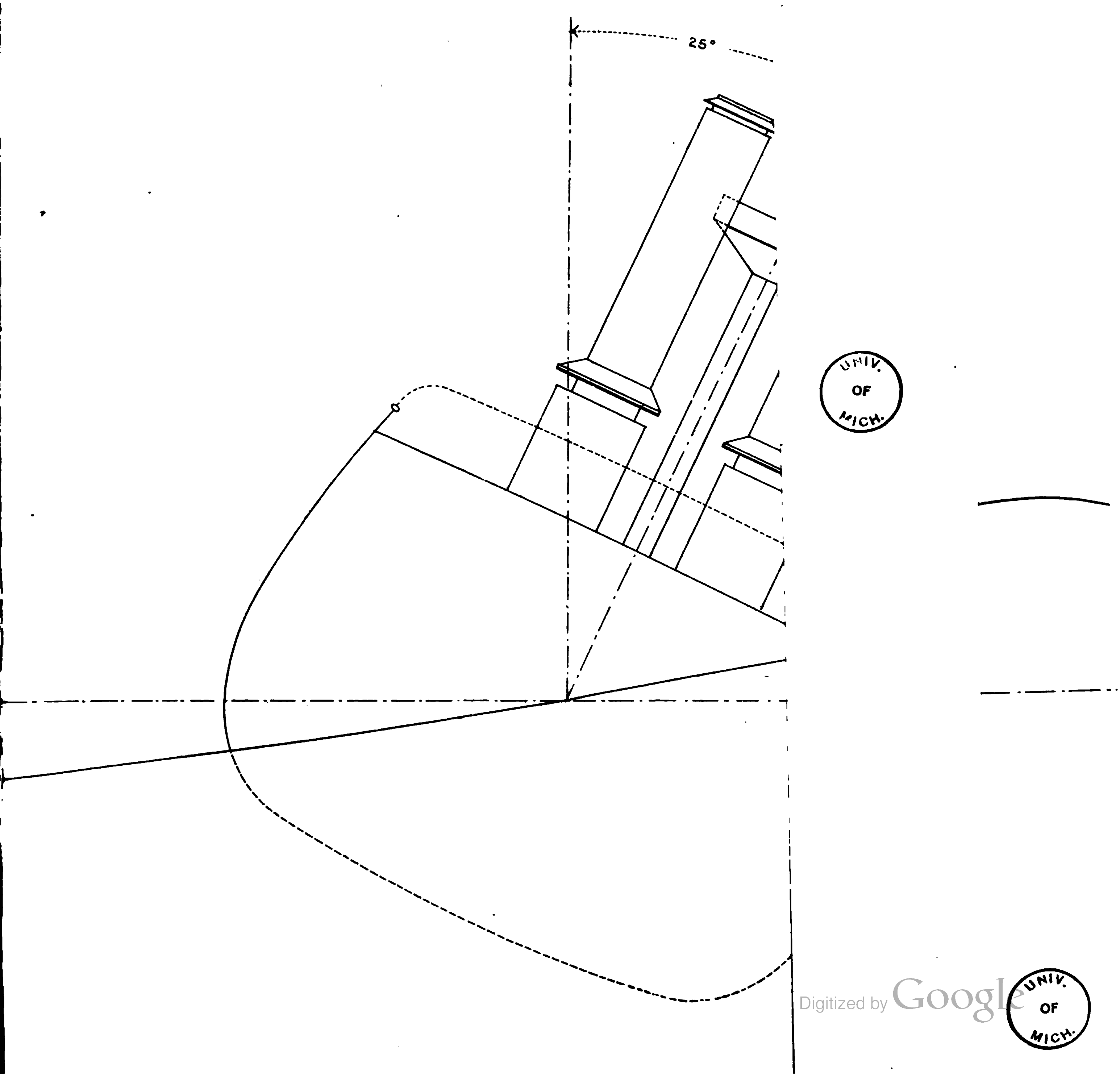


To Illustrate Mr. W. H. White's Paper on T
and Performances of recent first-class Ba

FIG. 8.

H. M. S. "RESOLUTION"

Broadside on to a Wave 600 Ft long, 30 Ft high showin
necessary to put her Bulwarks under Water.

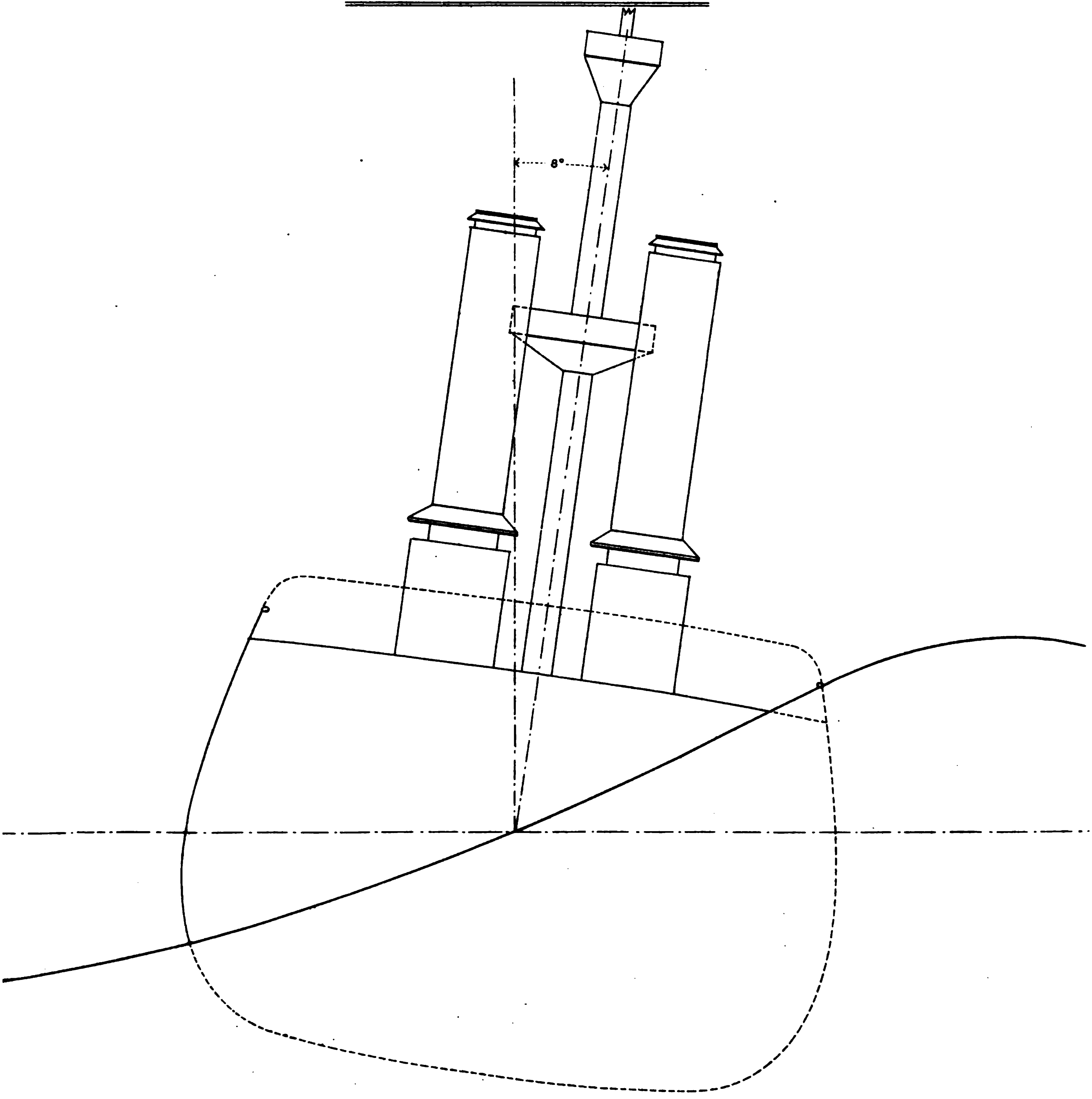


To Illustrate Mr. W. H. White's Paper on The Qualities and Performances of recent first-class Battleships.

FIG. 9.

H. M. S. "RESOLUTION"

Broadside on to a Wave 300 Ft long, 42 Ft high showing Inclination necessary to put her Bulwarks under Water

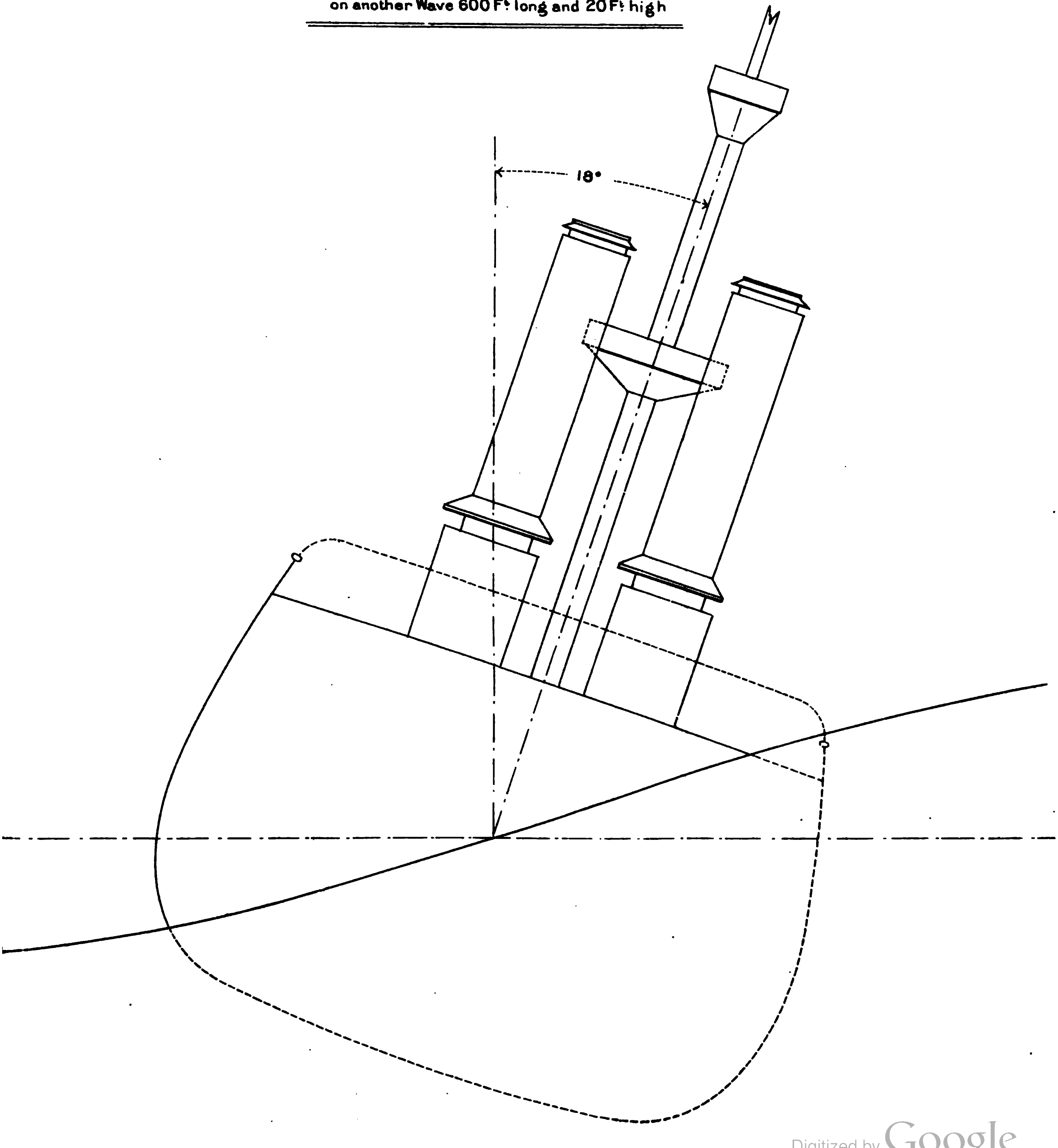


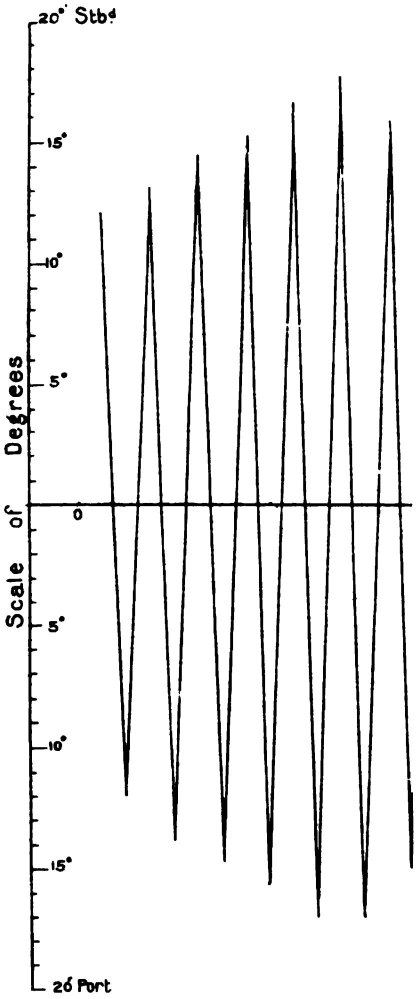
To Illustrate Mr. W. H. White's Paper on The Qualities and Performances of recent first-class Battleships.

FIG. 10.

H. M. S. "RESOLUTION"

Broadside on a Wave 300 Ft long, 20 Ft high supurposed on another Wave 600 Ft long and 20 Ft high

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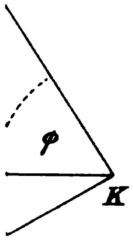
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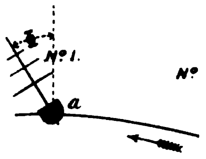
To Illustrate Mons. E. Bertin's Paper ng.



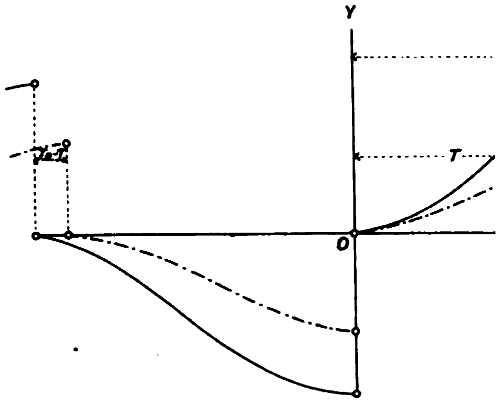
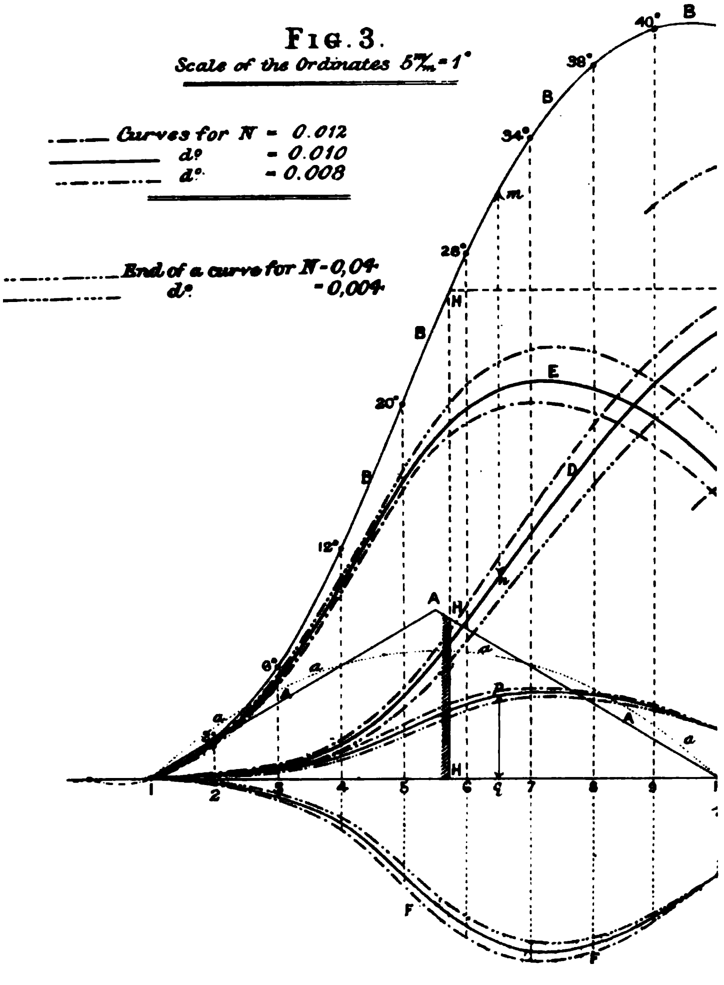
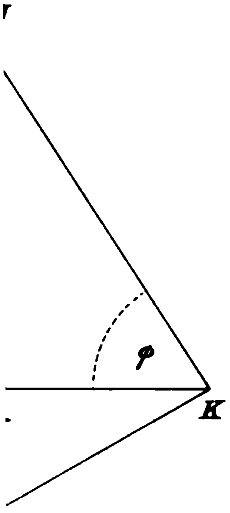


FIG. 3.

Scale of the Ordinates 5 m/m = 1°





To Illustrate Prof. A. G. Greenhill's Paper on The Stresses on a Ship due to Rolling.

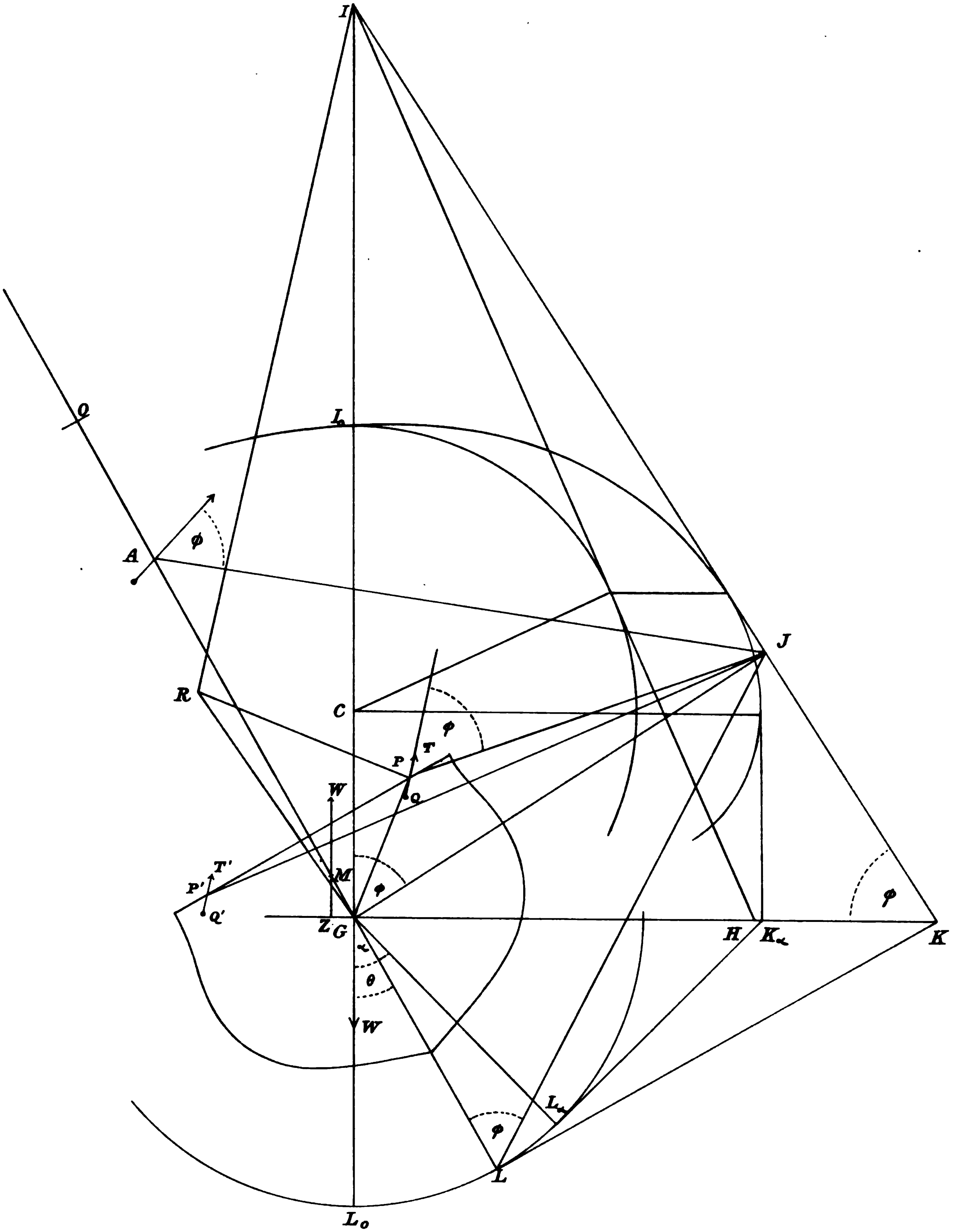


FIG. 1.

To Illustrate Prof. A. G. Greenhill's Paper on The Stresses on a Ship due to Rolling.

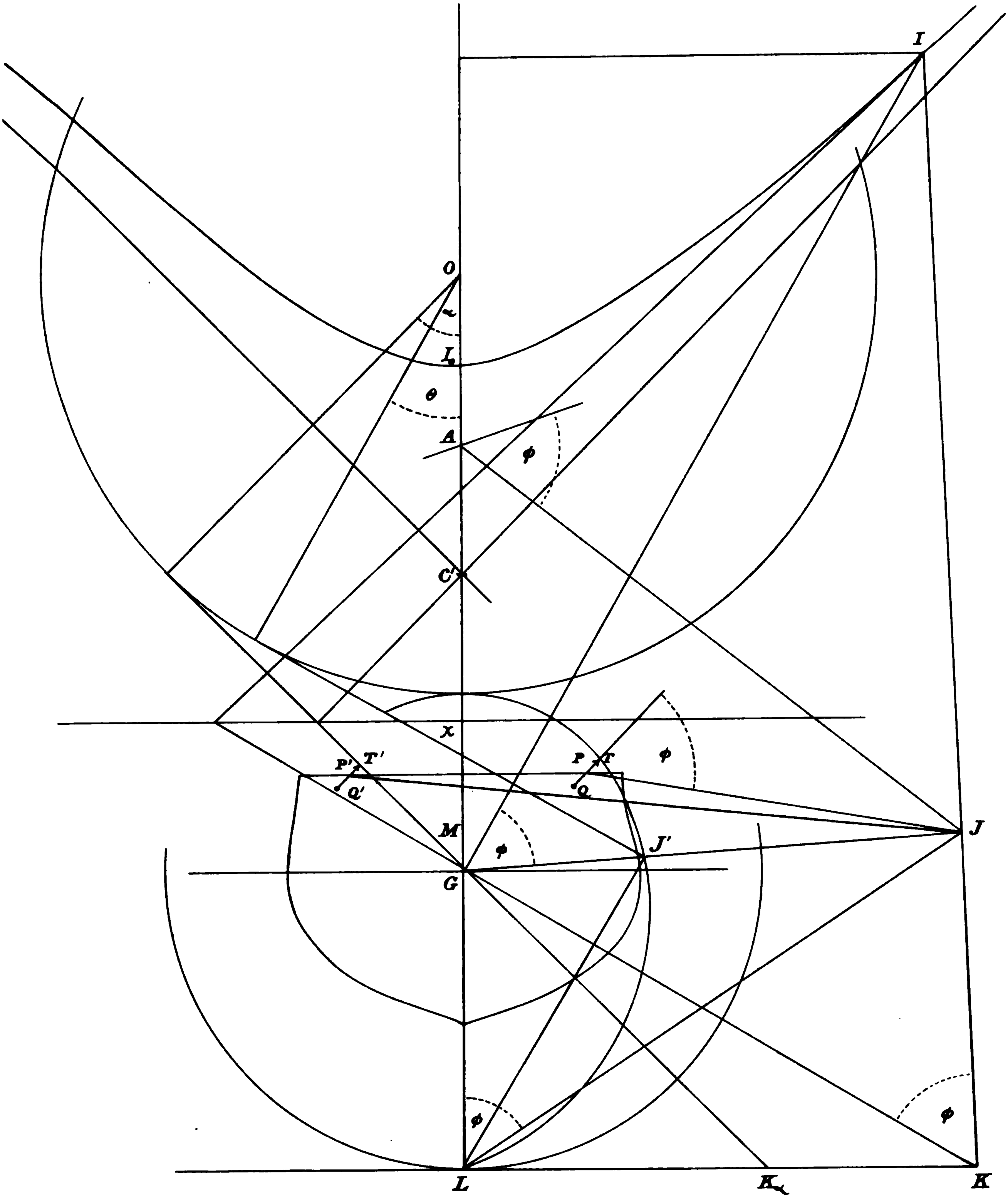


FIG. 2.

To Illustrate Prof. A. G. Greenhill's Paper on Leclert's Theorem.

FIG. 1.

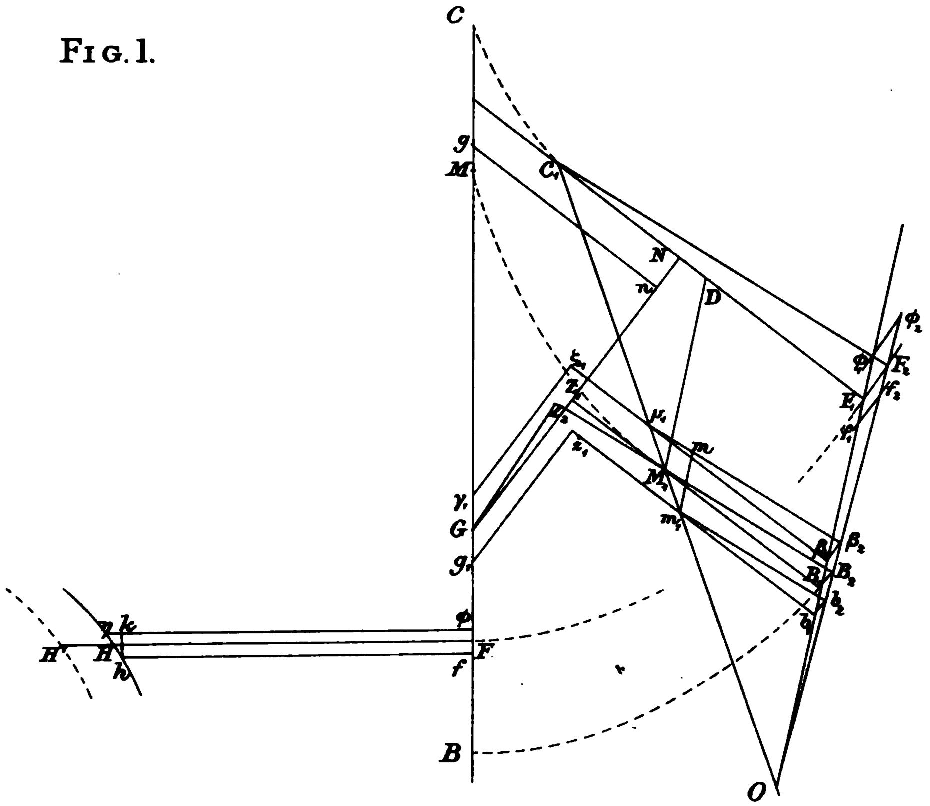
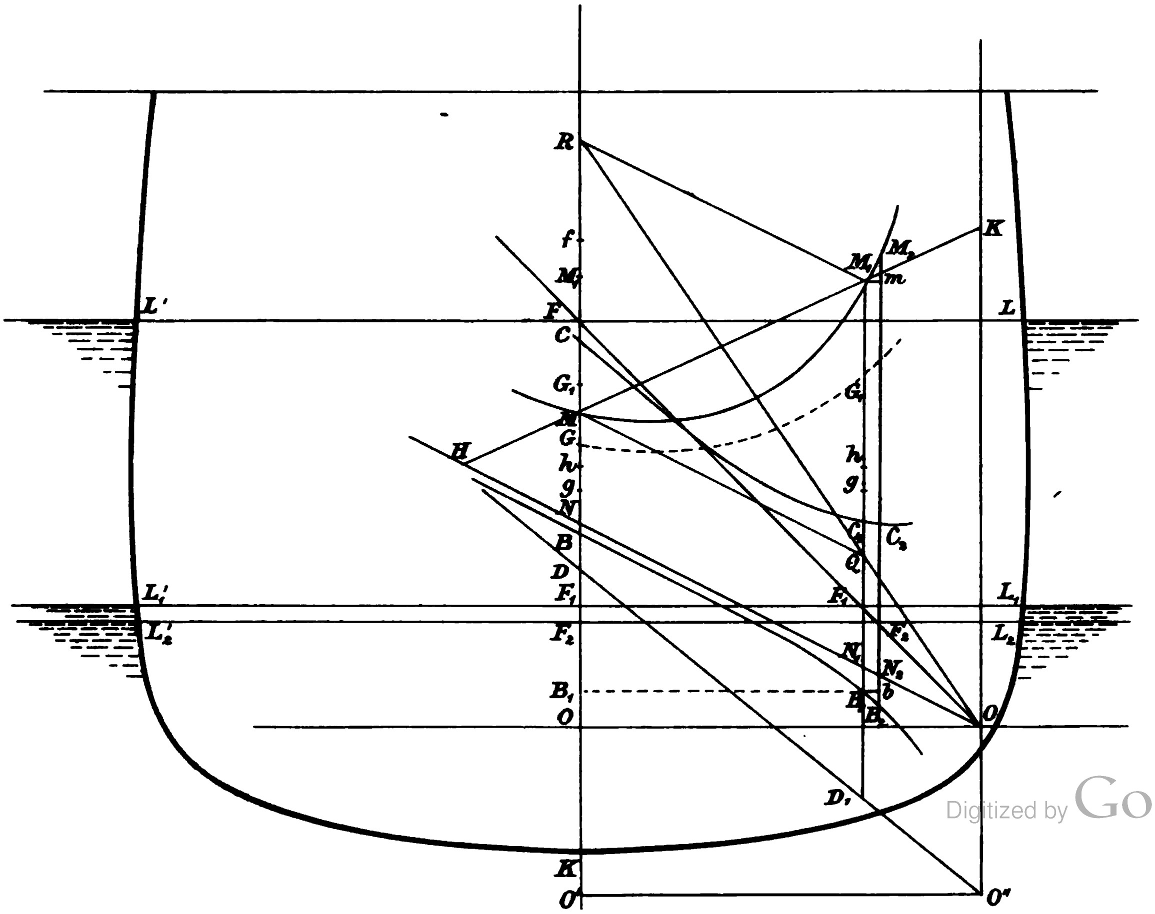


FIG. 2.



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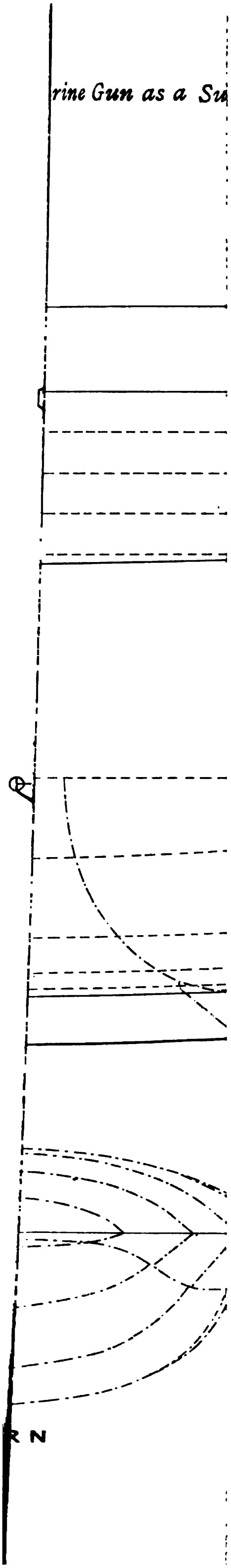
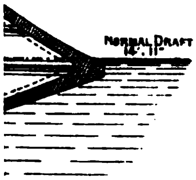
V.





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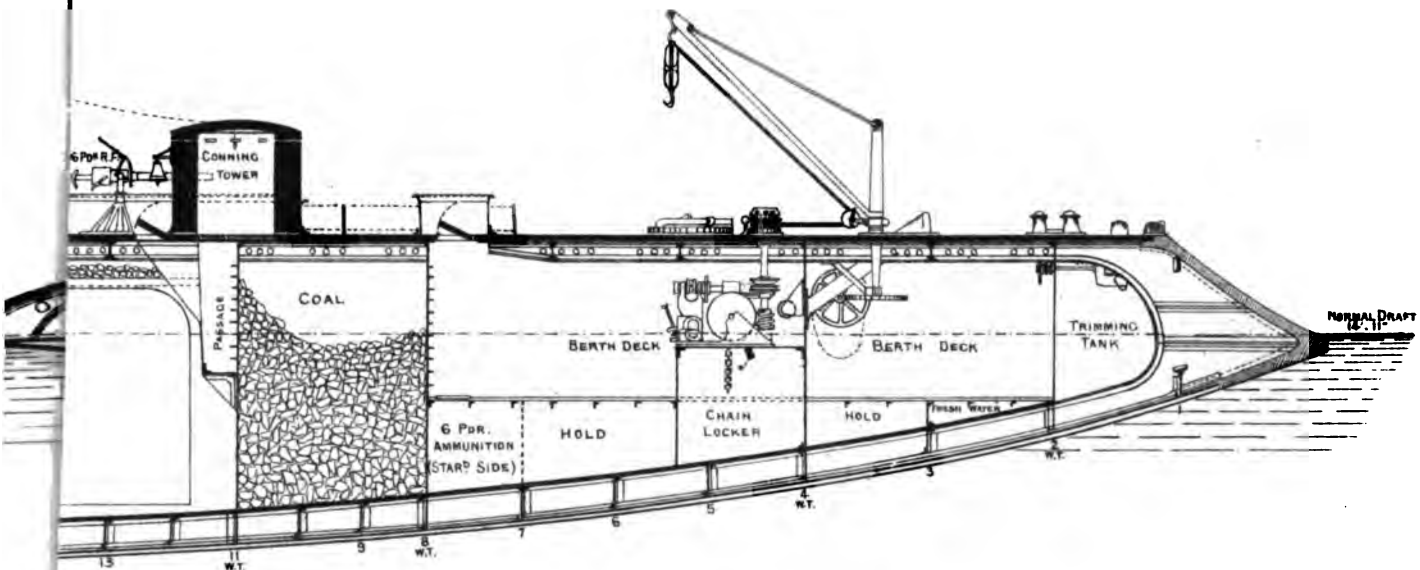
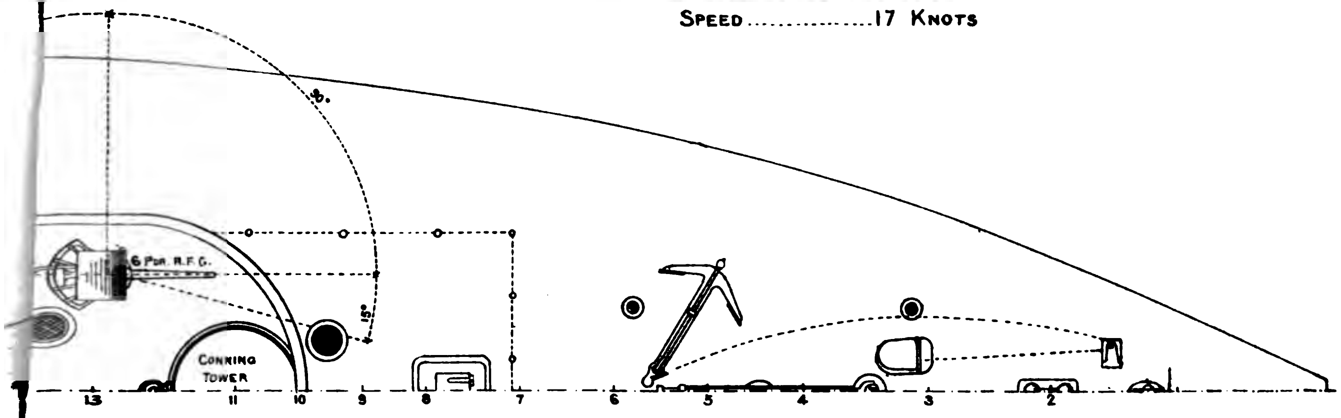


MACHINERY.

Twin Screw	Two Engines
Dia. of Cylinder	25"-36"-56"
Stroke	36"
I.H.P.	4800
Speed	17 Knots



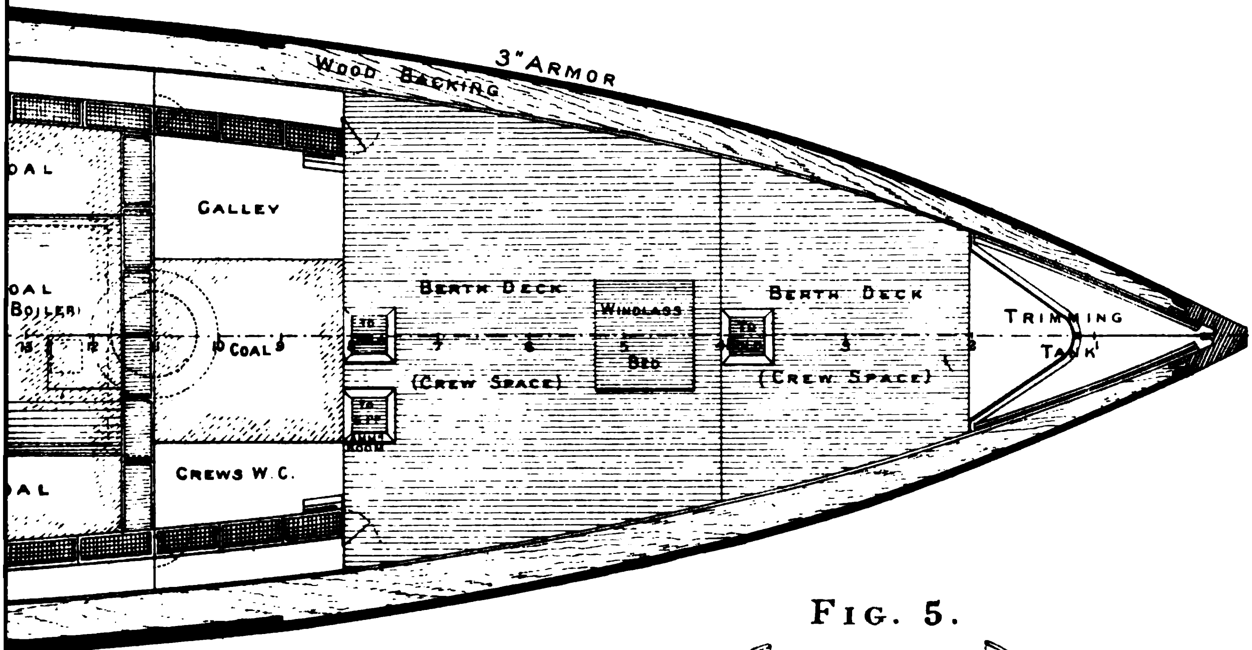
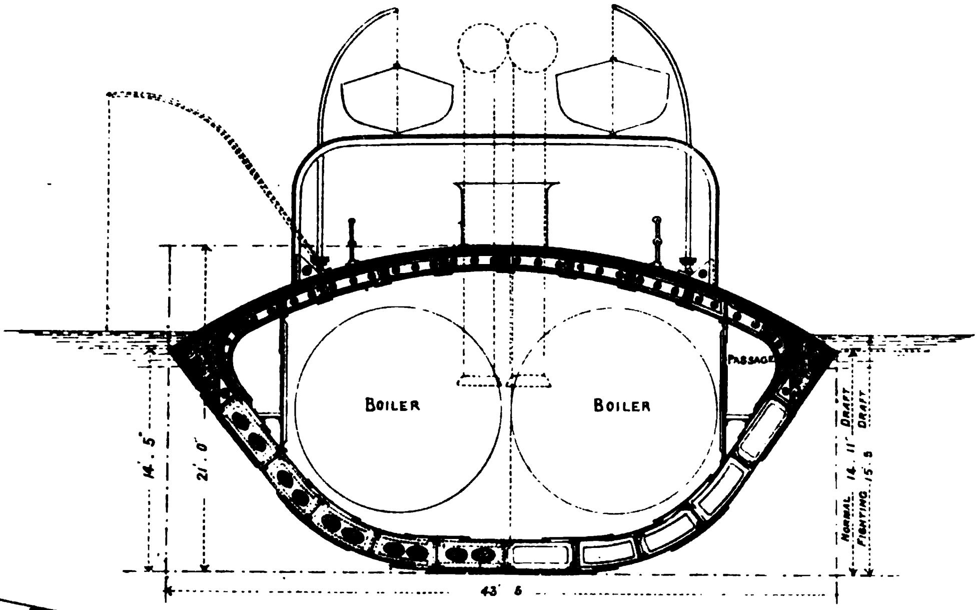


FIG. 5.



Harbour Defence Ram.
Section at ⊗

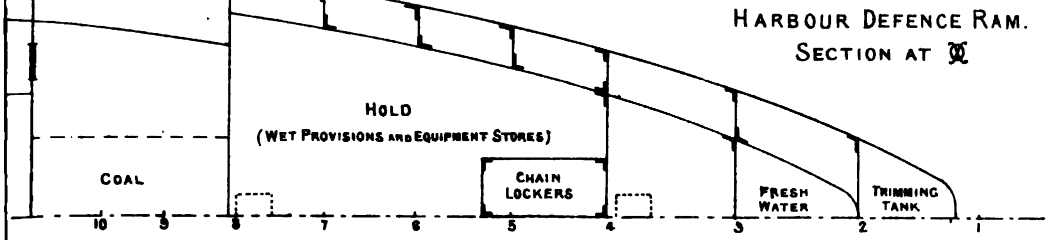
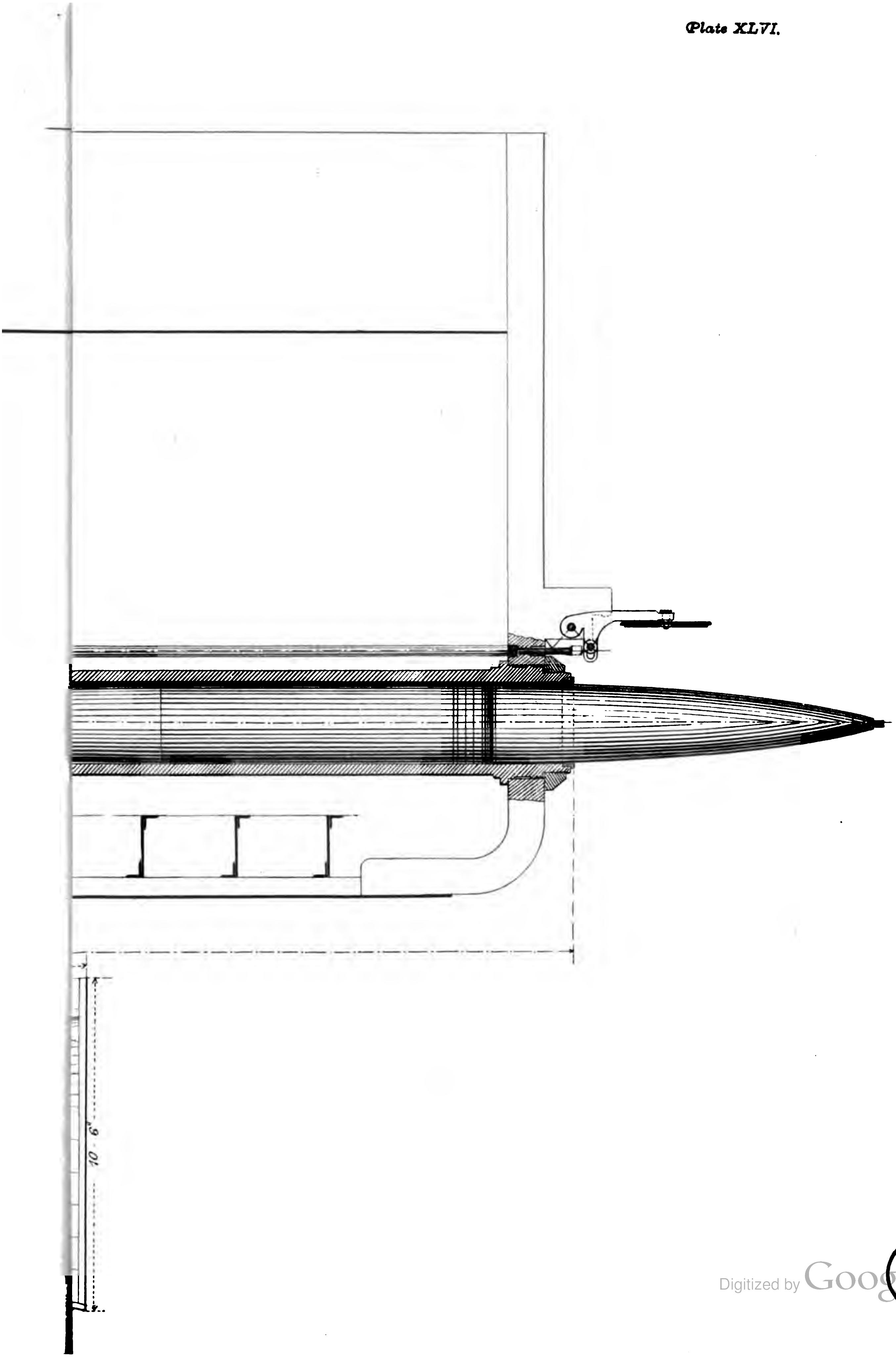
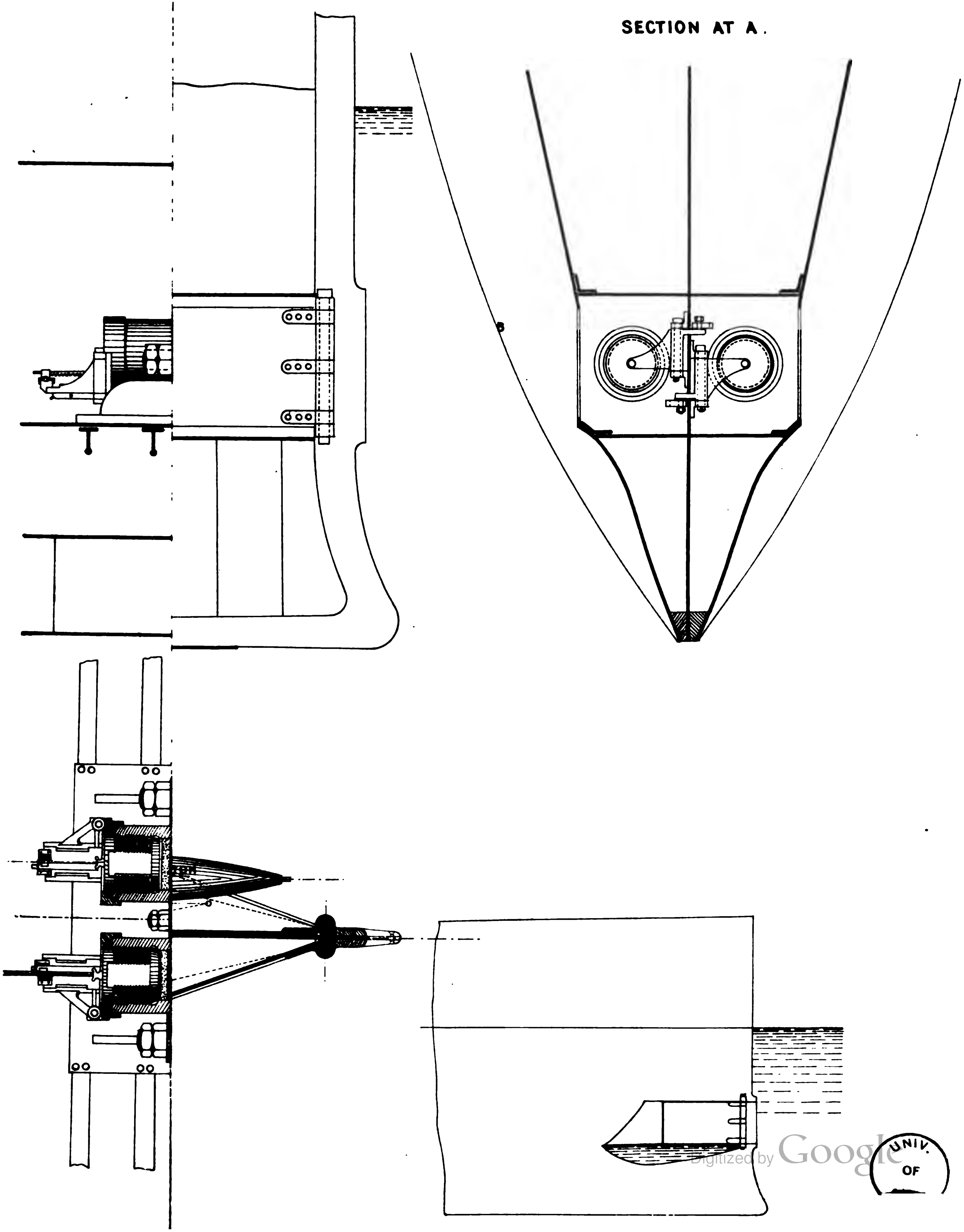


Plate XLVI.



Trans. Inst. N *Plate XLVII.*

titute for the Ram.



ns. Inst. Naval Architects, Vol. XXXV., 1894.

To Illustrate Mr. J. I. Thornycroft's Paper on The Circulation in the Thornycroft Water-Tube Boiler.

DIAGRAM SHEWING SPACE OCCUPIED BY LOCOMOTIVE & THORNYCROFT WATER-TUBE BOILERS IN VESSELS OF THE 'SPEEDY' TYPE.

FIG 1.

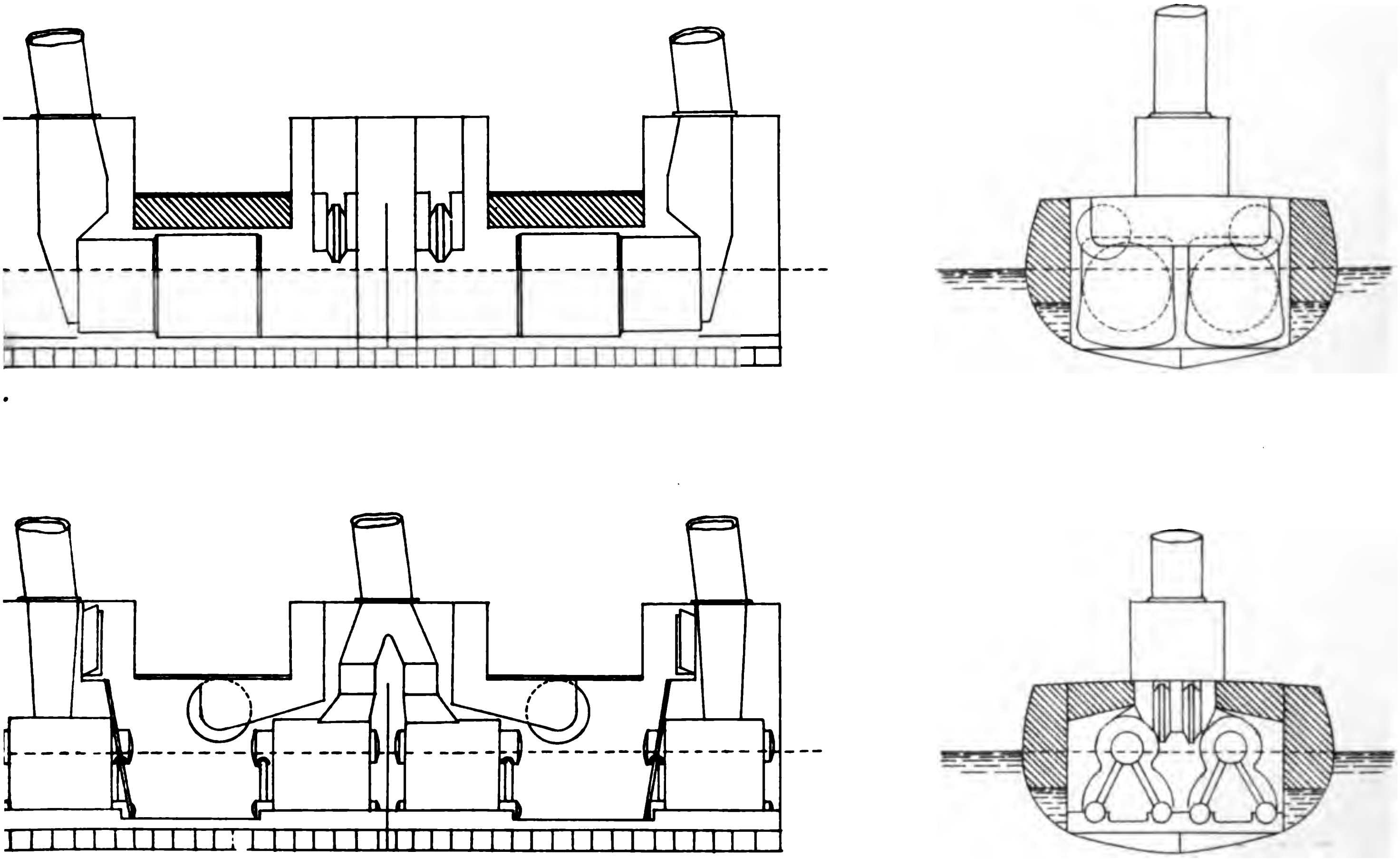


TABLE 1.

PARTICULARS OF BOILERS.		LOCOMOTIVE BOILERS	THORNYCROFT WATER-TUBE BOILERS
Total Indicated Horse Power		3500	4500
Number of Boilers per Ship		4	8
Area of Grate per Boiler	*Sq. Ft.*	45½	25½
Total area of Grate per Ship	" "	182	204
Heating Surface (per Boiler) of Firebox	" "	272¾	64·6
Total Heating Surface per boiler	" "	1597	1840
Total Heating Surface per Ship	" "	6388	14720
Total Weight of Boilers and mountings, dry	*Tons.*	82	79·74
Total Weight of Water in Boilers	" "	30	12·78
Total Weight of Boilers & Water per Ship	" "	112	92·52

To Illustrate Mr. J. I. Thornycroft's Paper on The Circulation in the Thornycroft Water-Tube Boiler.

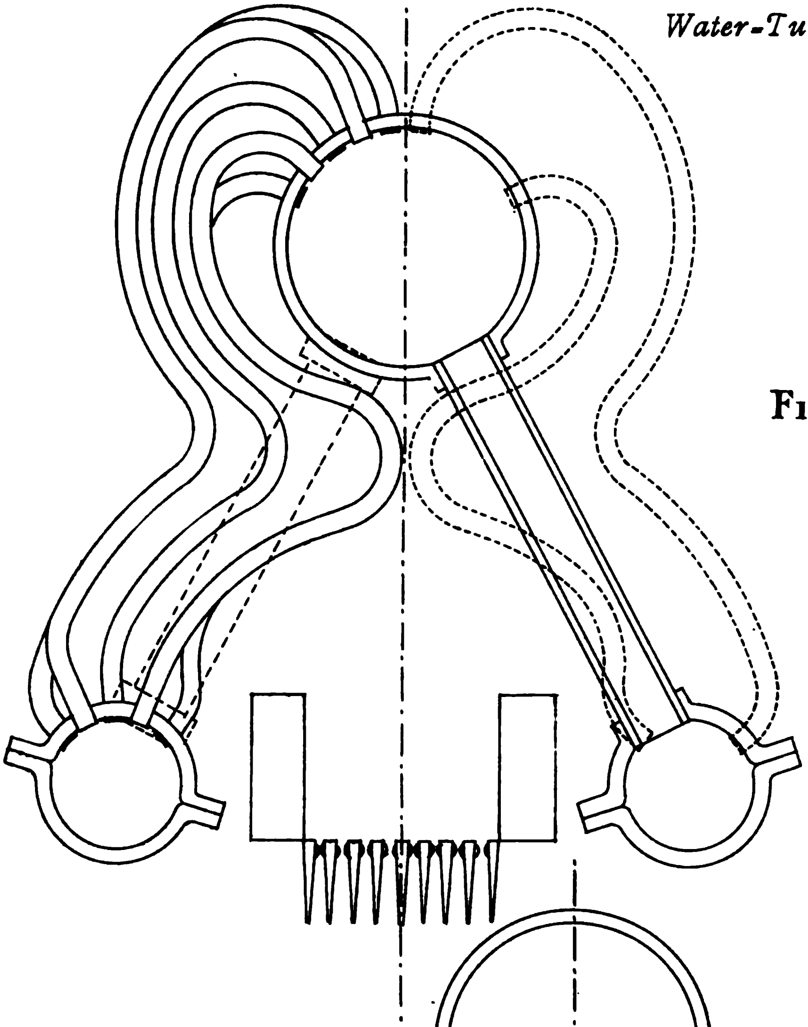


Fig 3.

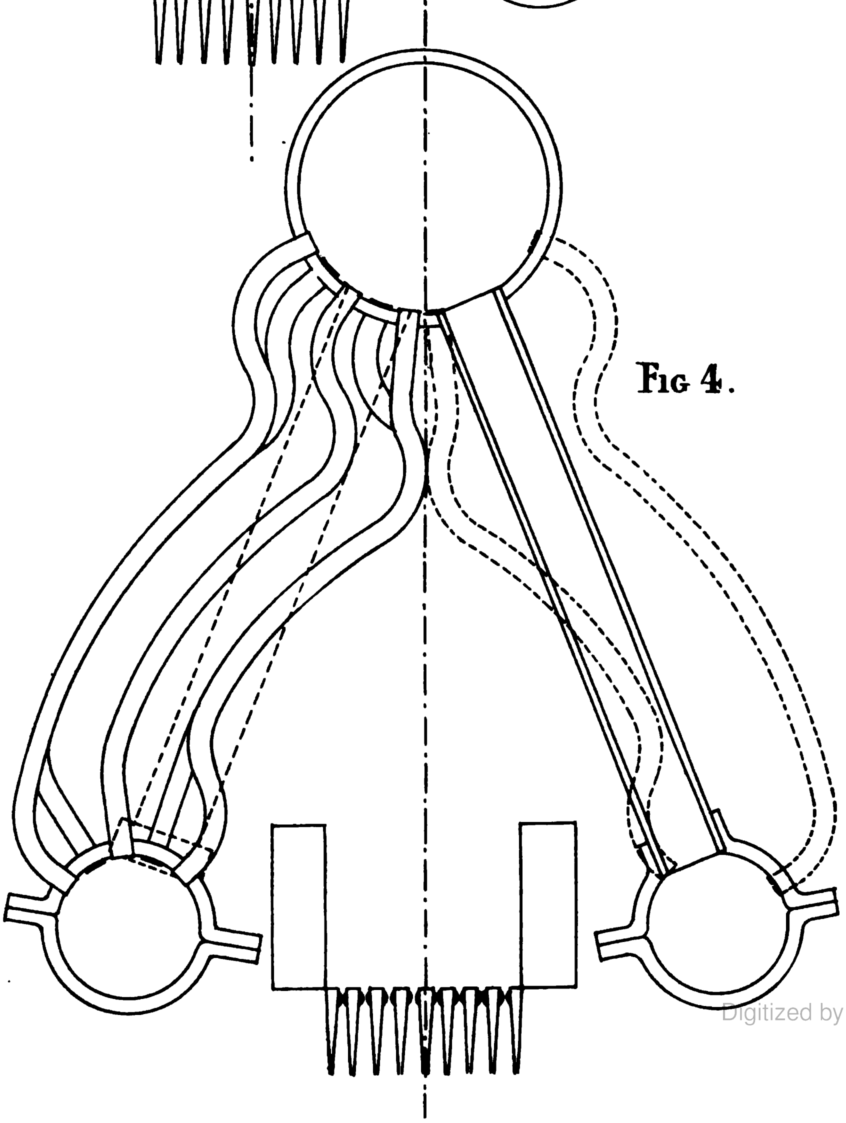
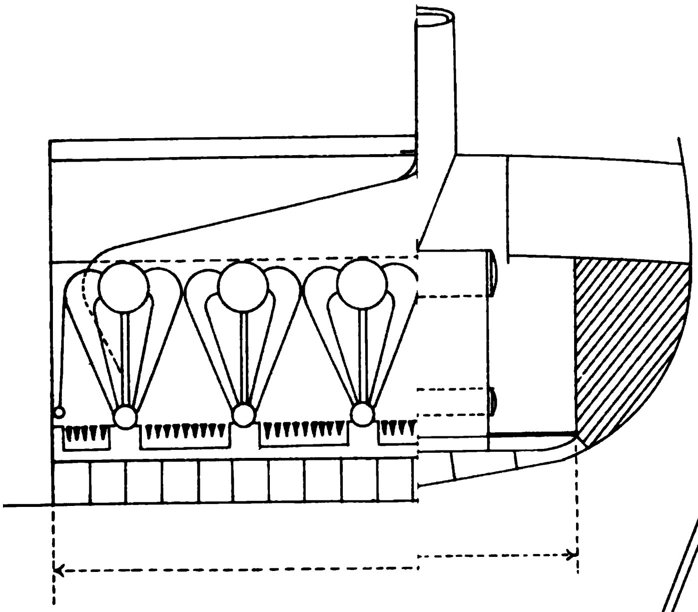


Fig 4.

Trans. Inst. Naval Archit

Plate L.

ube Boiler.



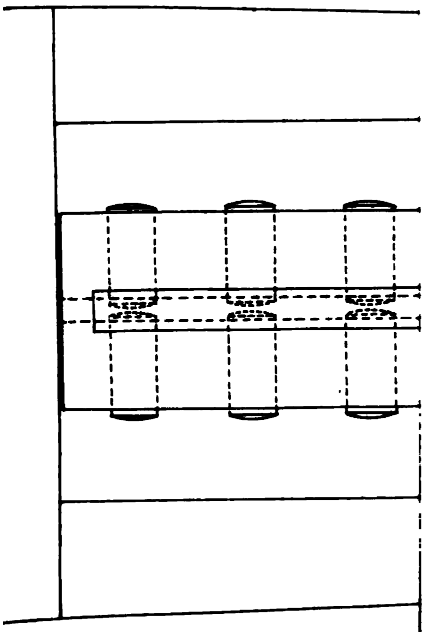
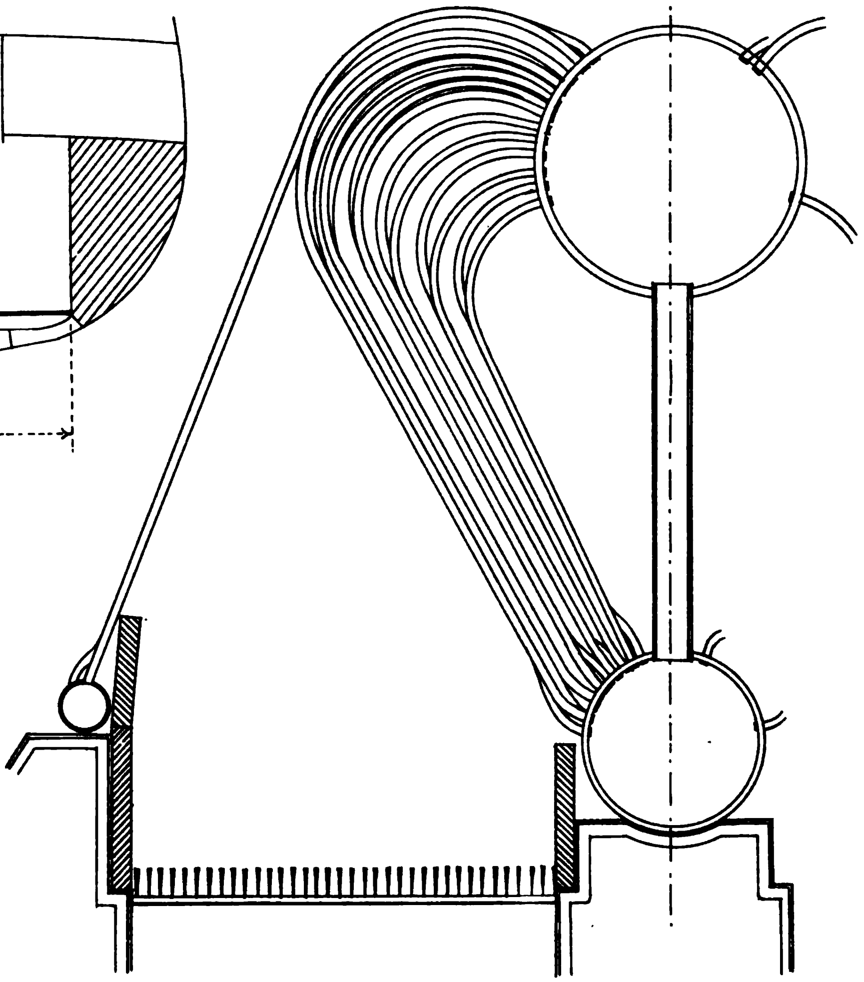
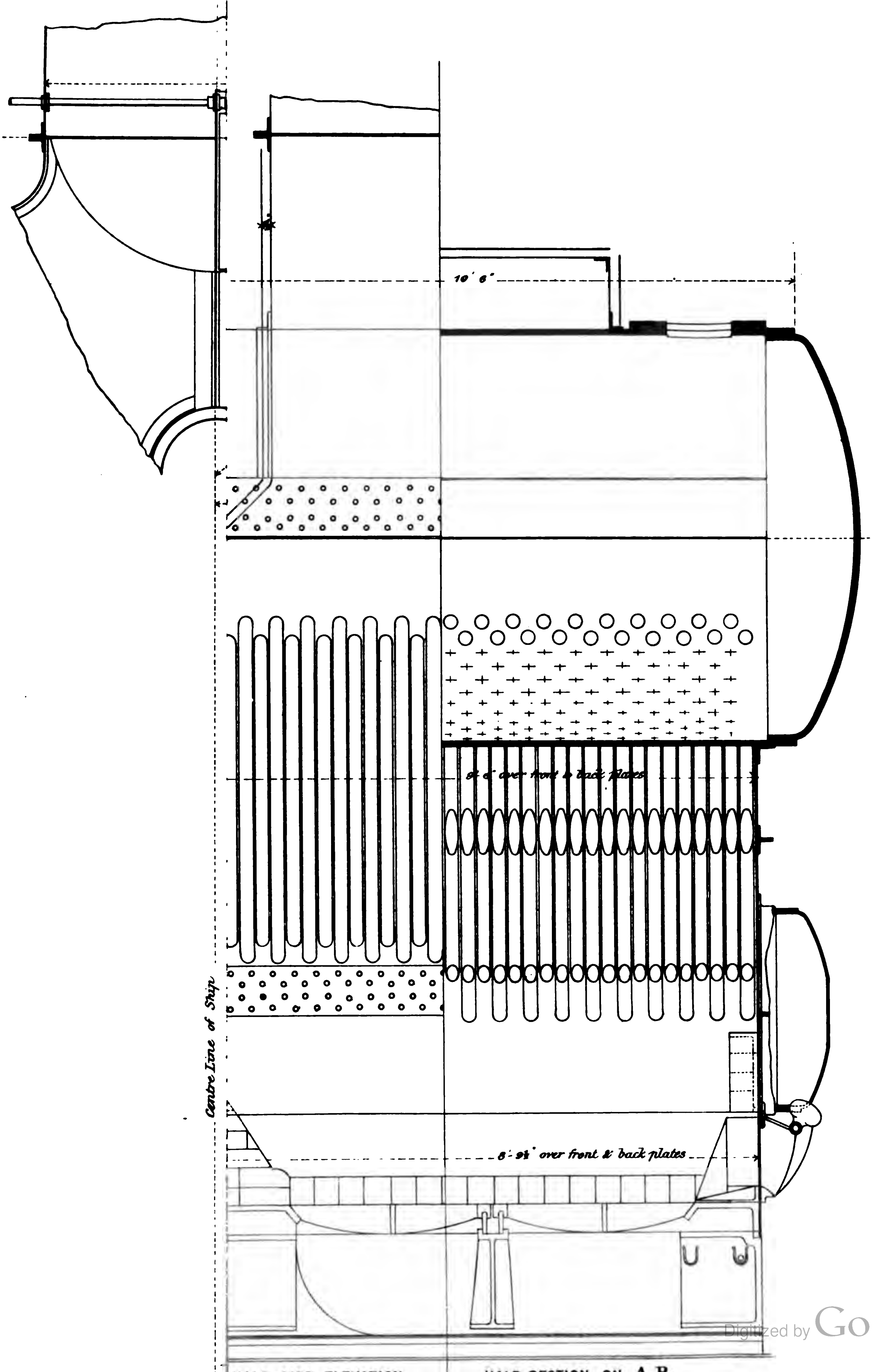


FIG 5.

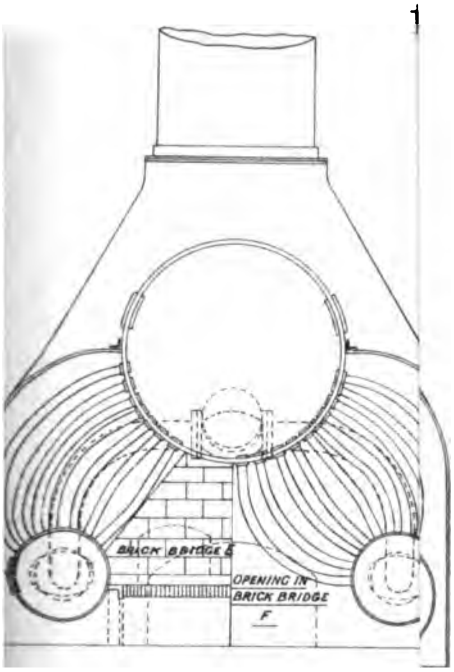
DARING TYPE.





HALF SIDE ELEVATION

HALF SECTION ON A.B.



SECTION AT A.B. – SECTION AT (
THROUGH FURNACE

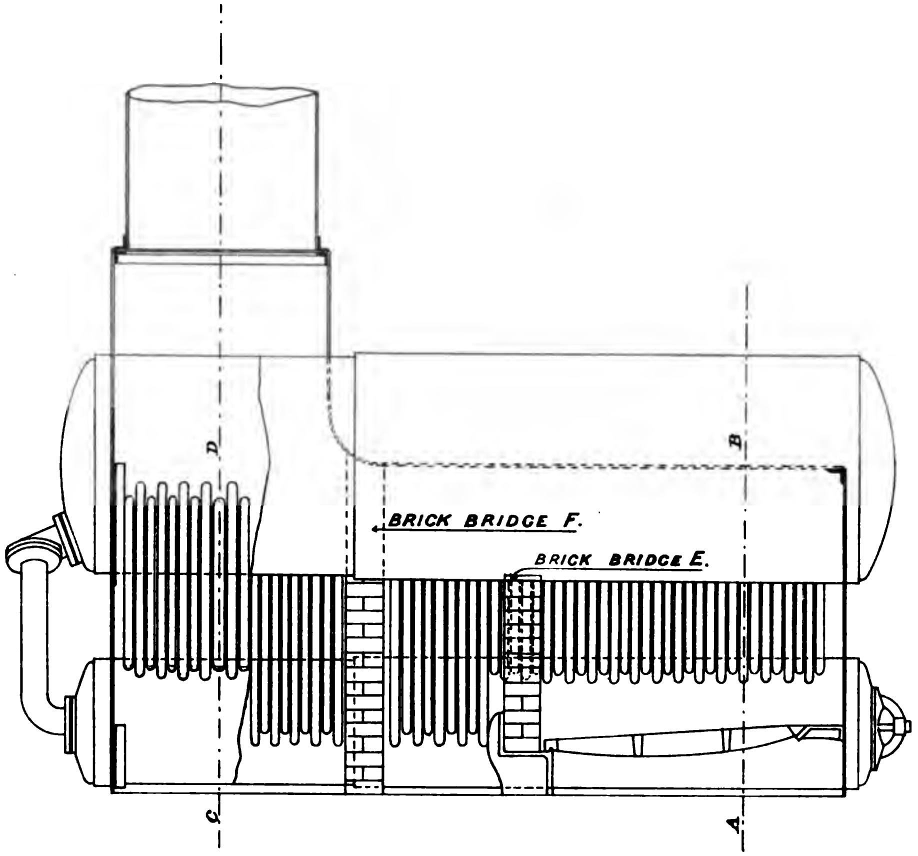
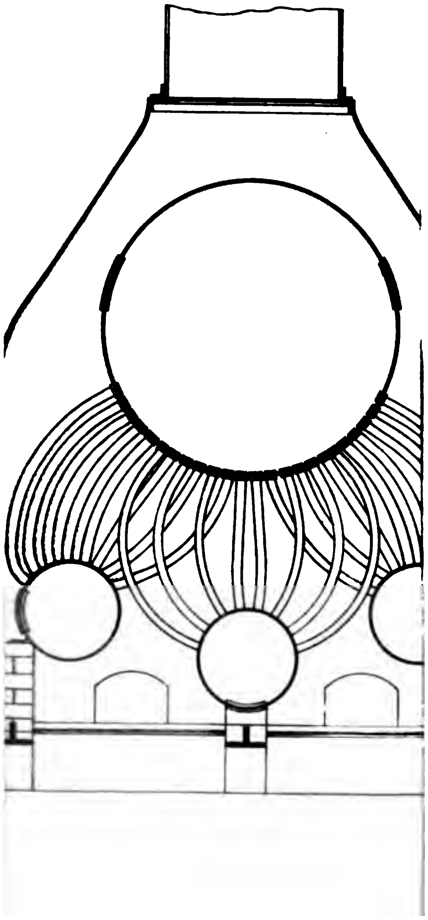
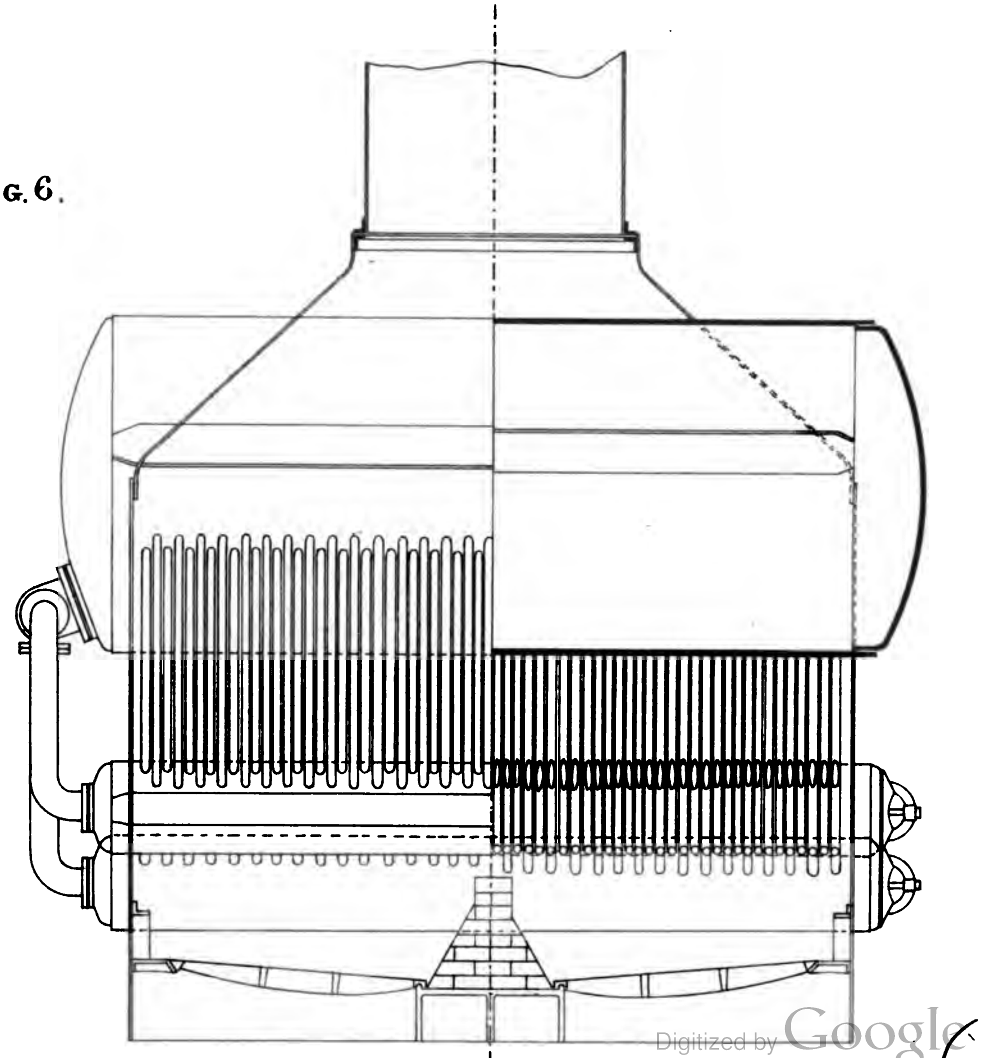


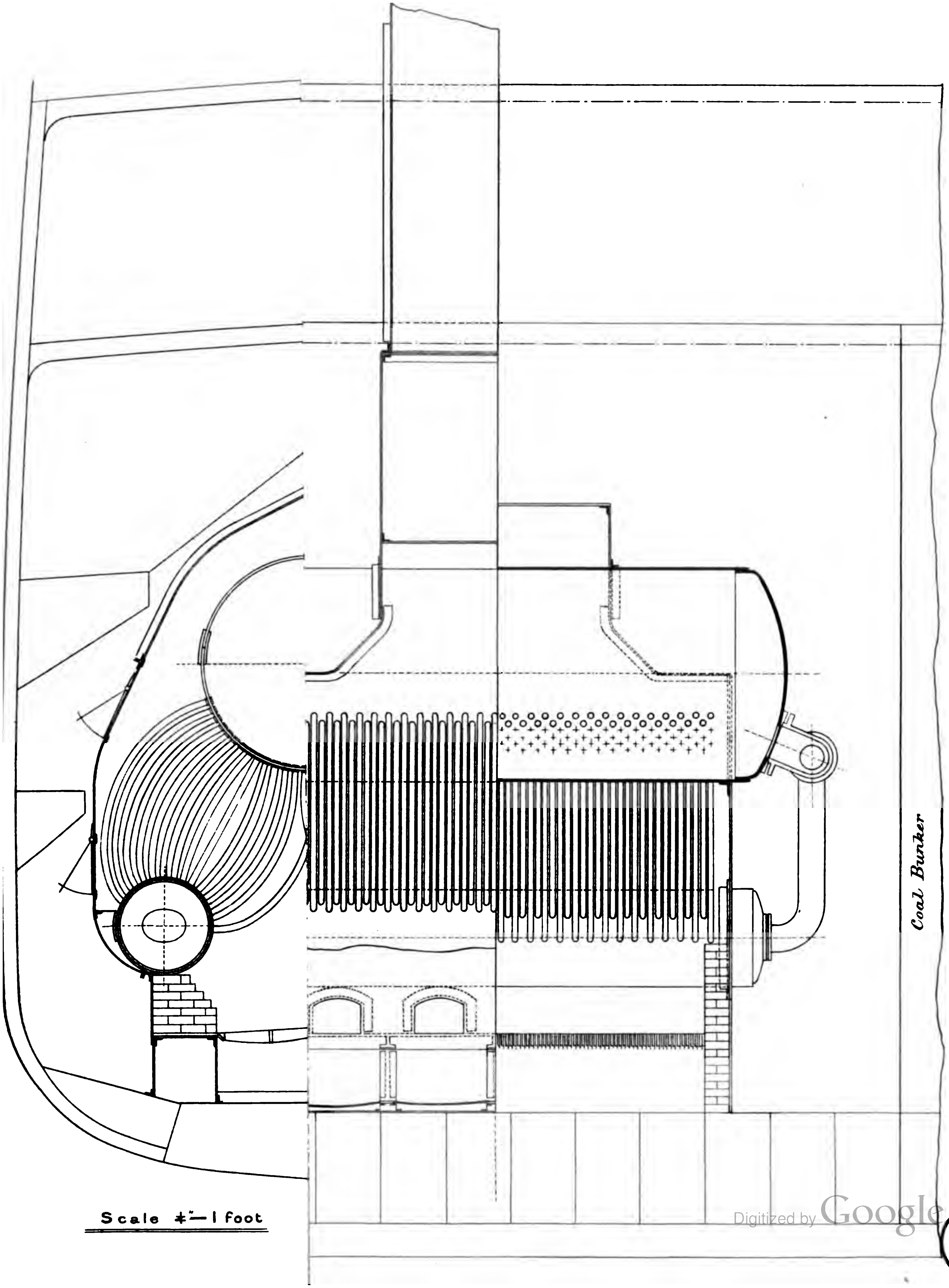
FIG. 6.



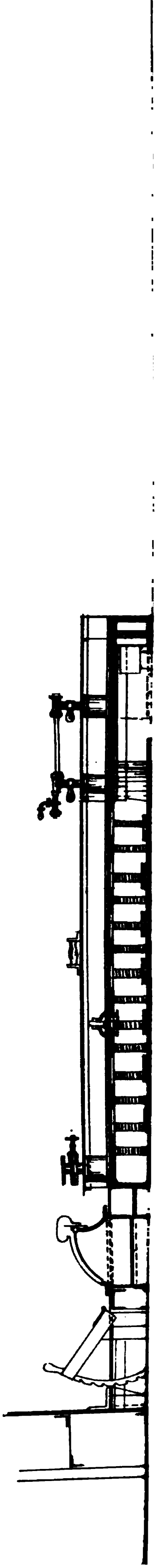


SCALE ¼ INCH - ONE FOOT.

oilers.



Scale ¾" – 1 foot



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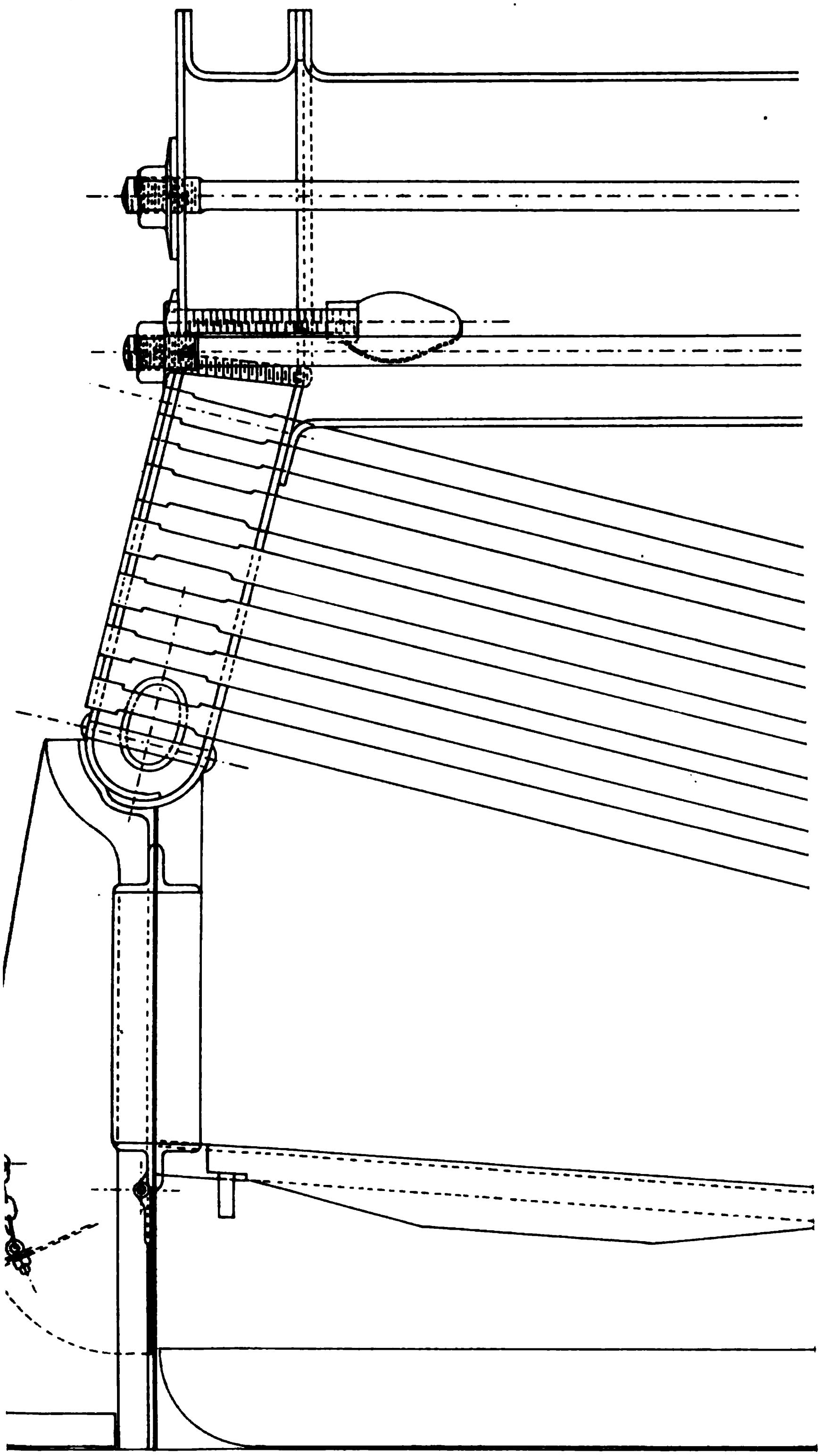
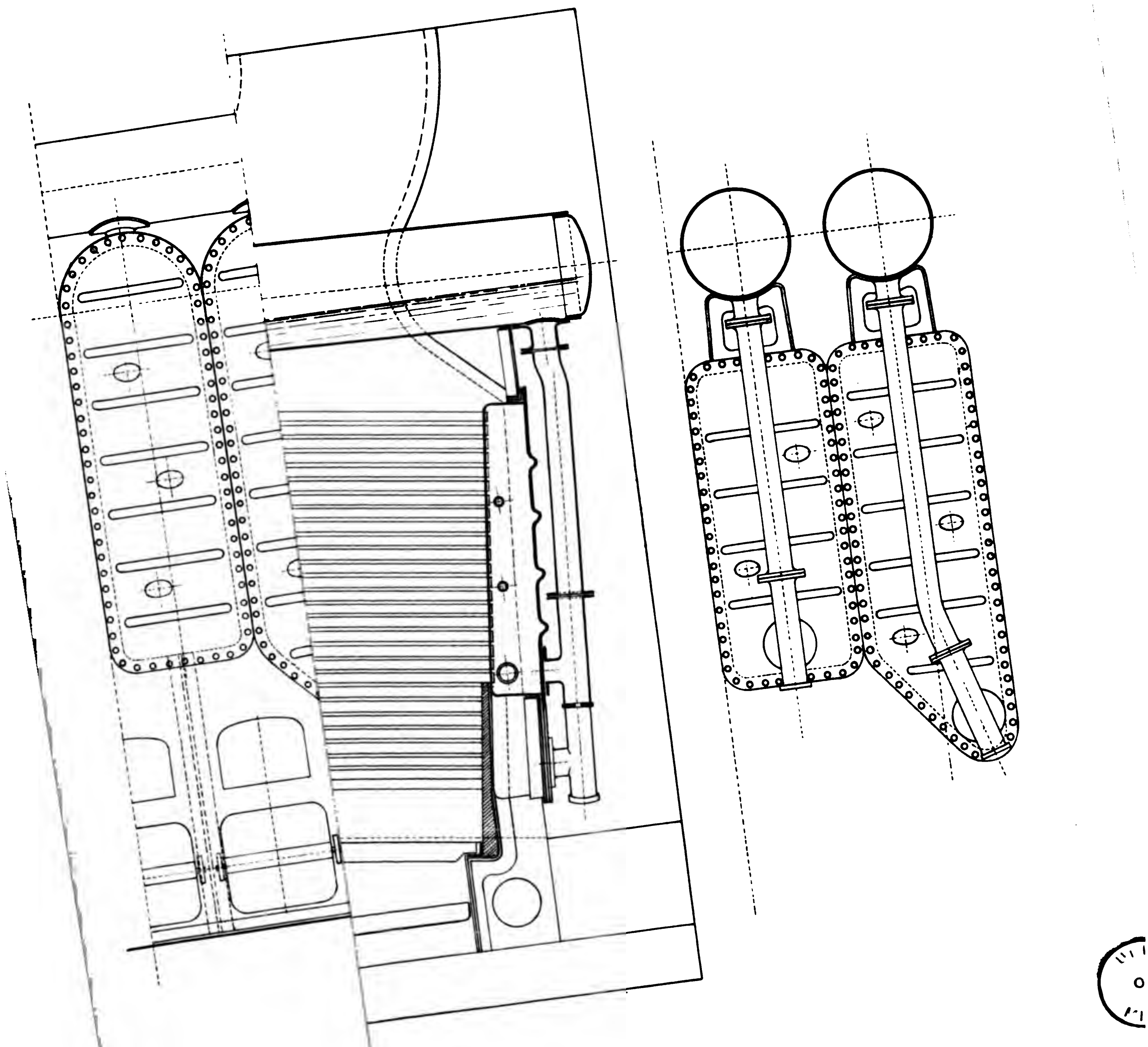
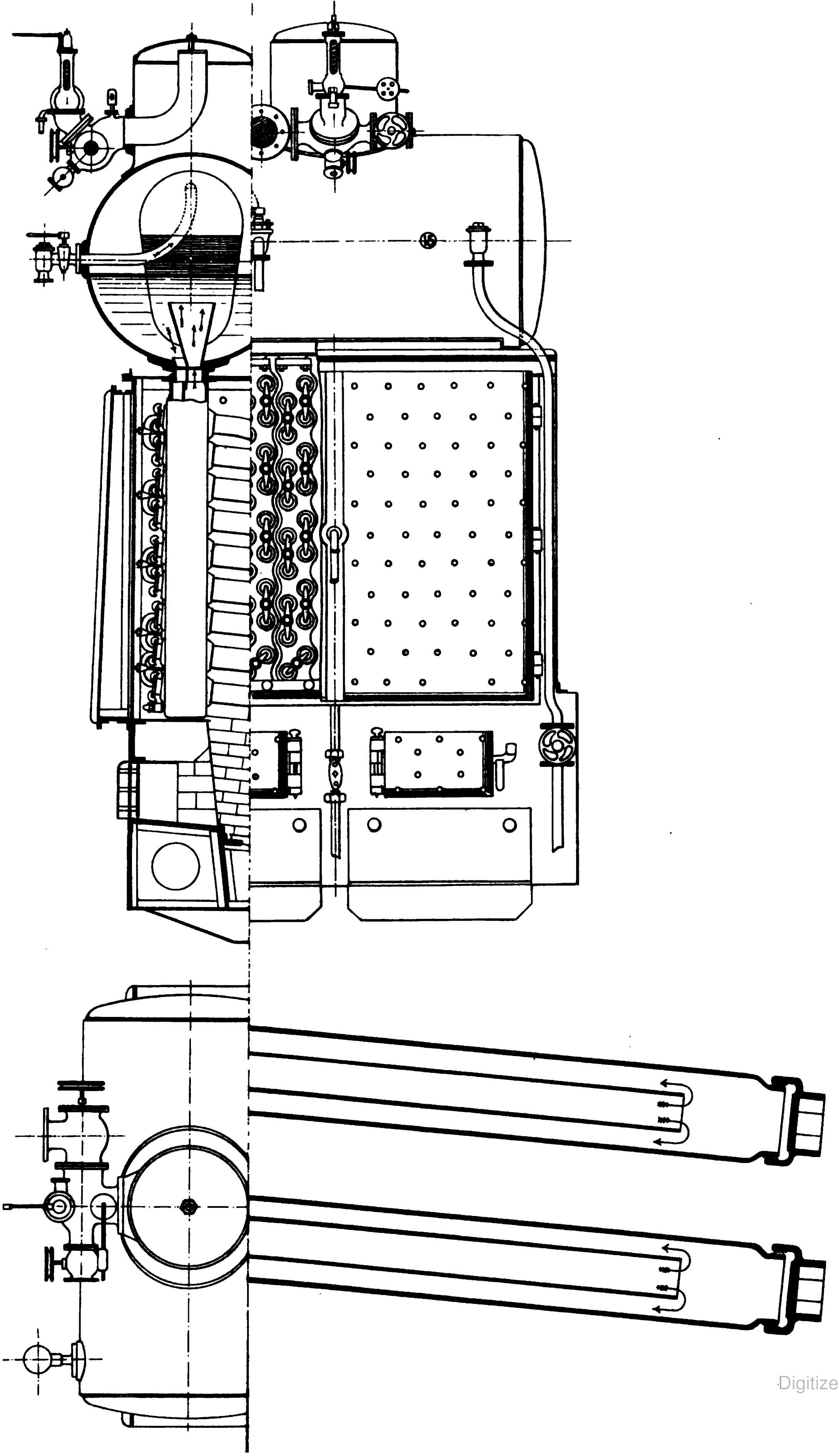
s. Inst. Naval Architects, Vol. XXXV., 1894.

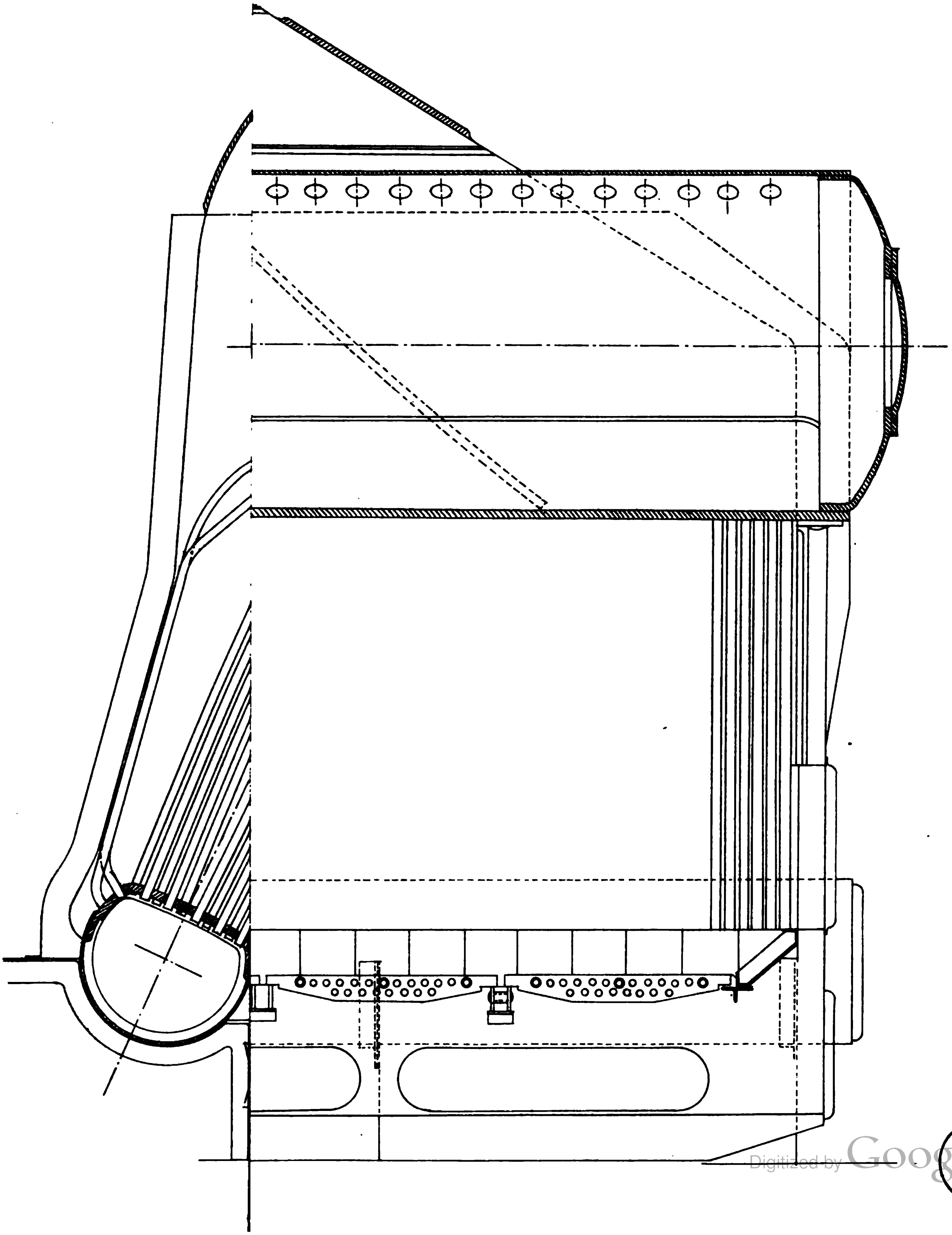
To Illustrate Mr. J. T. Milton's Pap

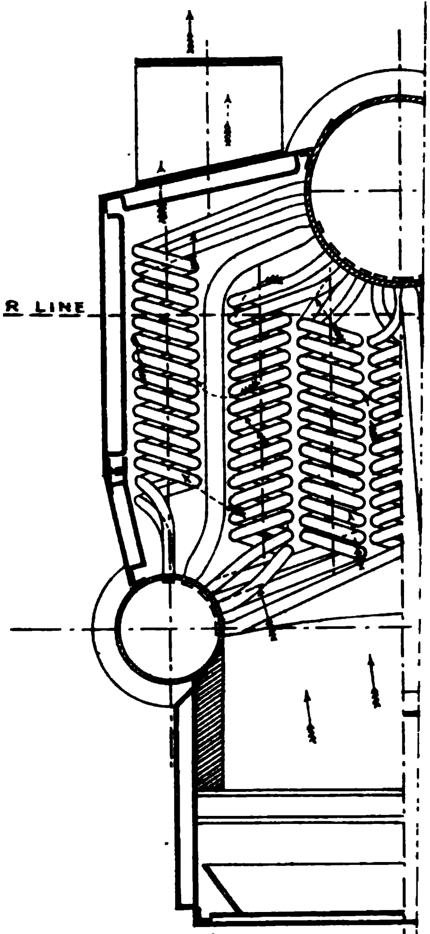


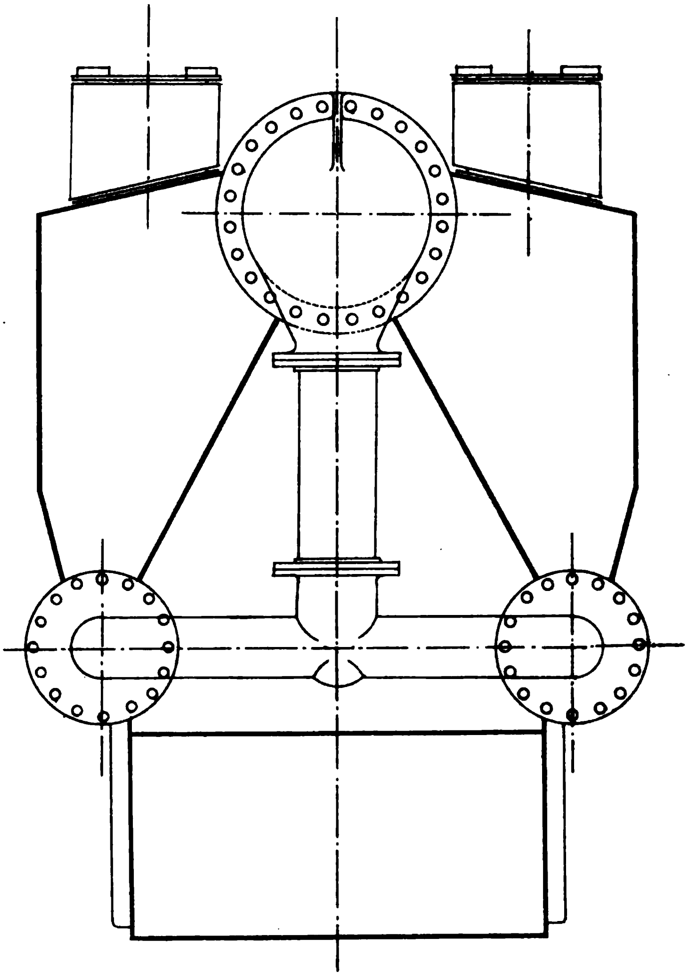
YARROW'S PATENT WATERTUBE BO

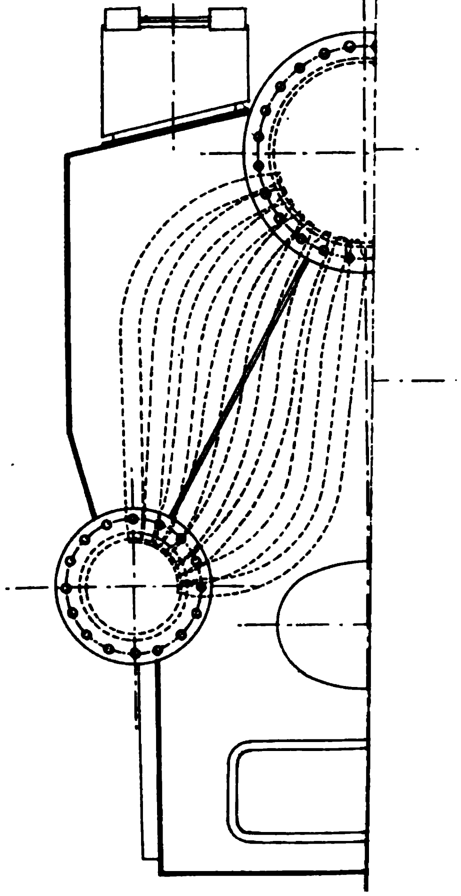







R LINE





To Illustrate Mr. J. Howden's Paper on The comparative Merits of cylindrical and Water-Tube Boilers for Ocean Steamships.

FIG. 1.

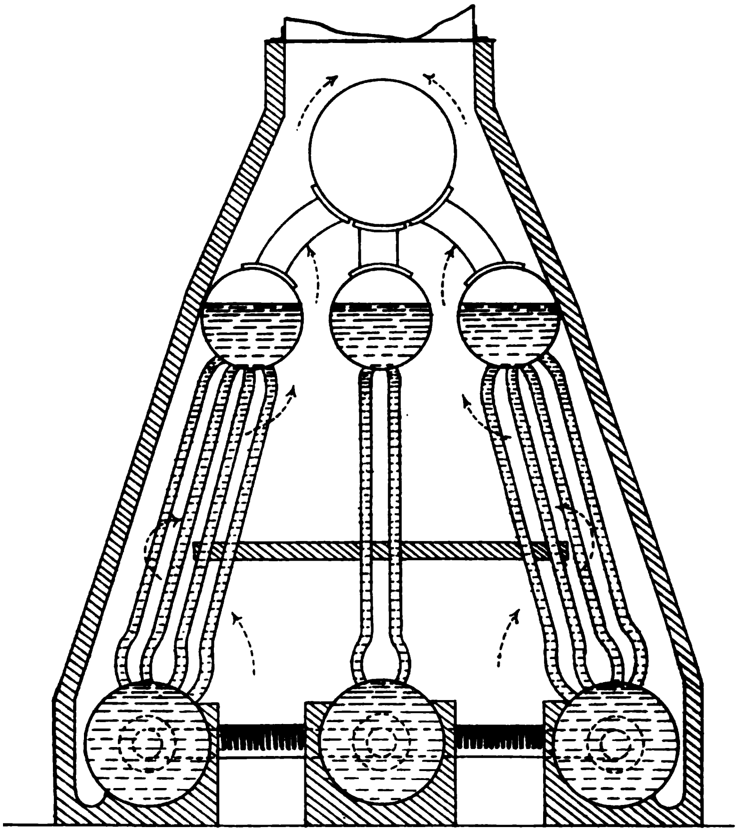


FIG 2.

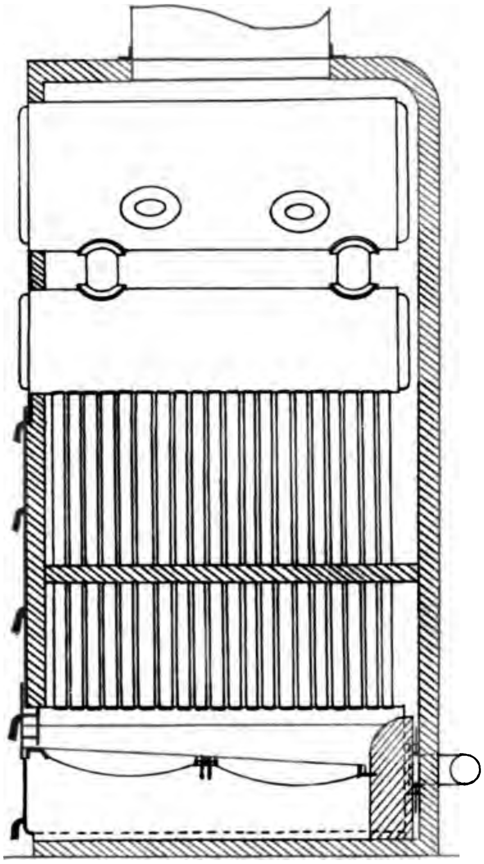


FIG. 5.

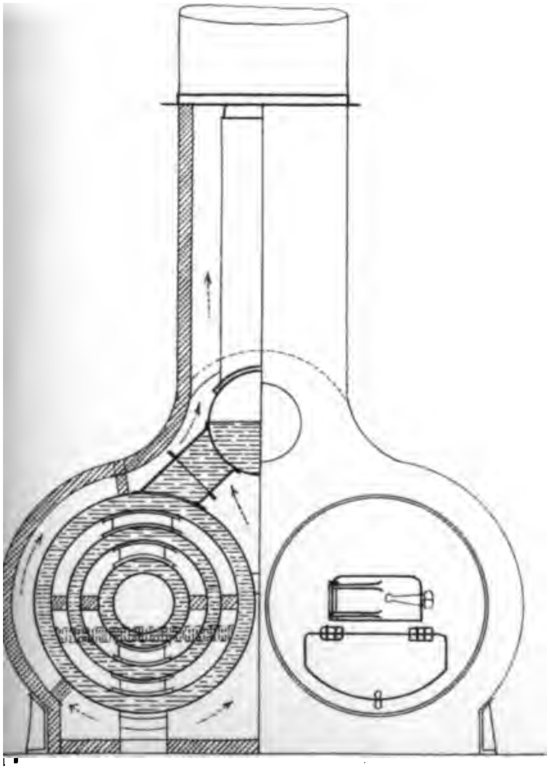
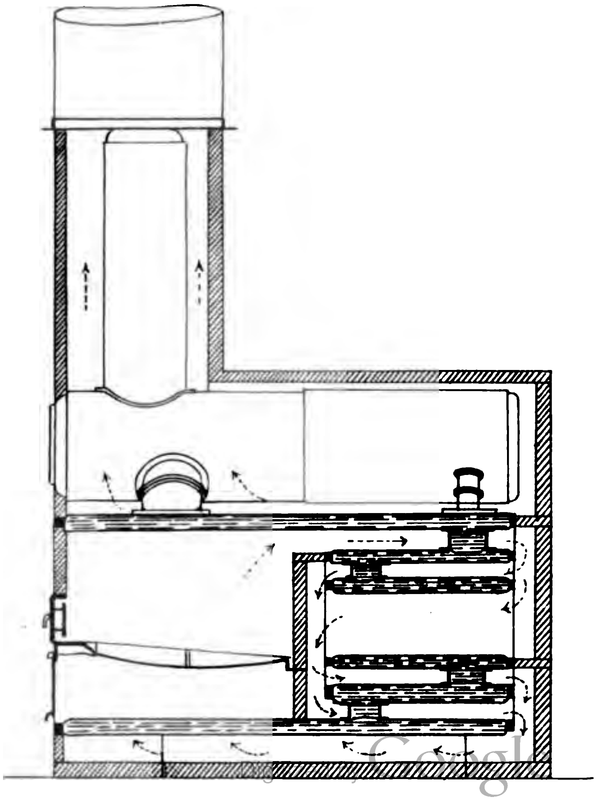


FIG. 6.



To Illustrate Mr. J. Howden's Paper on The comparative Merits of cylindrical and Water-Tube Boilers for Ocean Steamships.

FIG. 3.

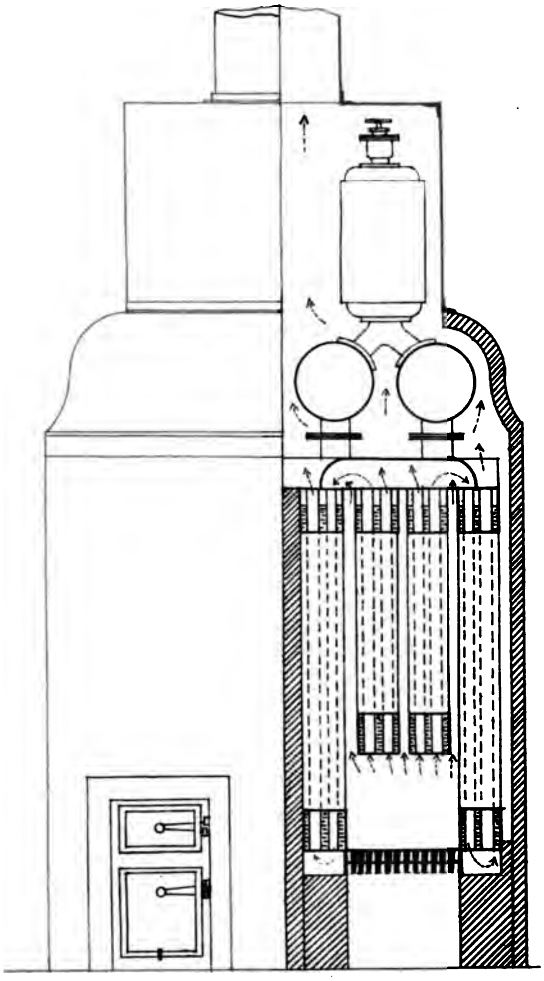


FIG. 4.

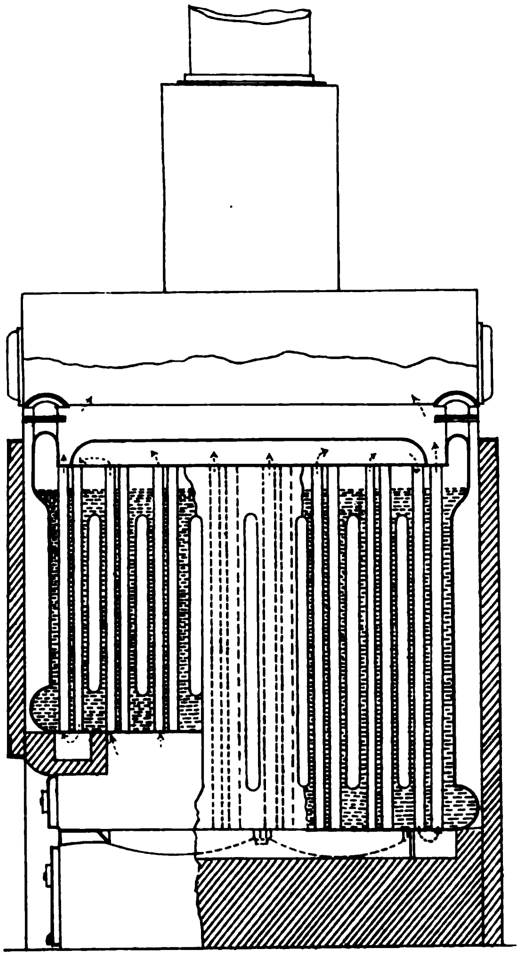
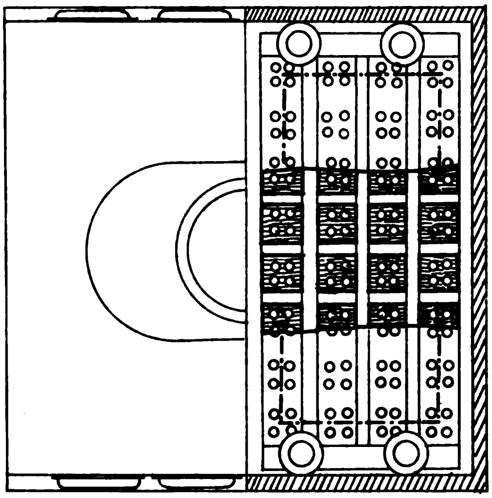


FIG. 4A.



Trans. Inst. Naval Architects, Vol. XXXV., 1894. Plate LXIII.

To Illustrate Mr. J. Howden's Paper on The comparative Merits of cylindrical and Water-Tube Boilers for Ocean Steamships.

FIG. 7.

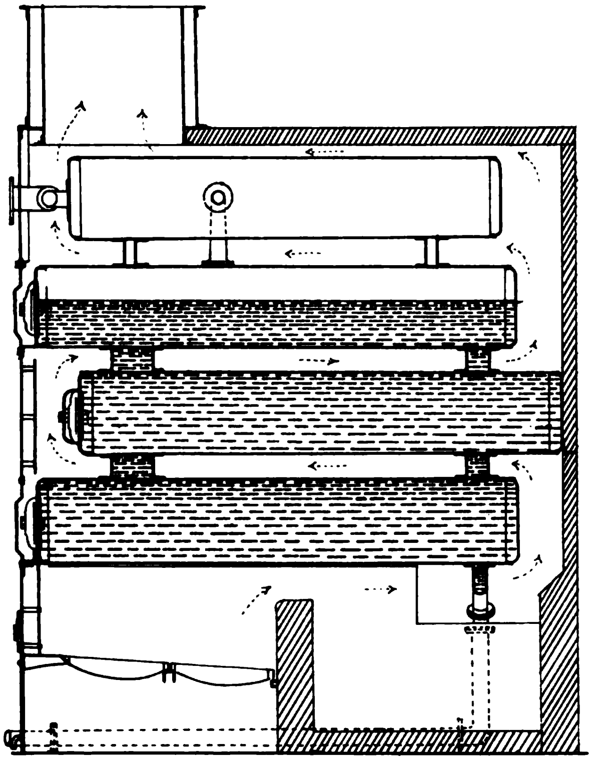


FIG. 8.

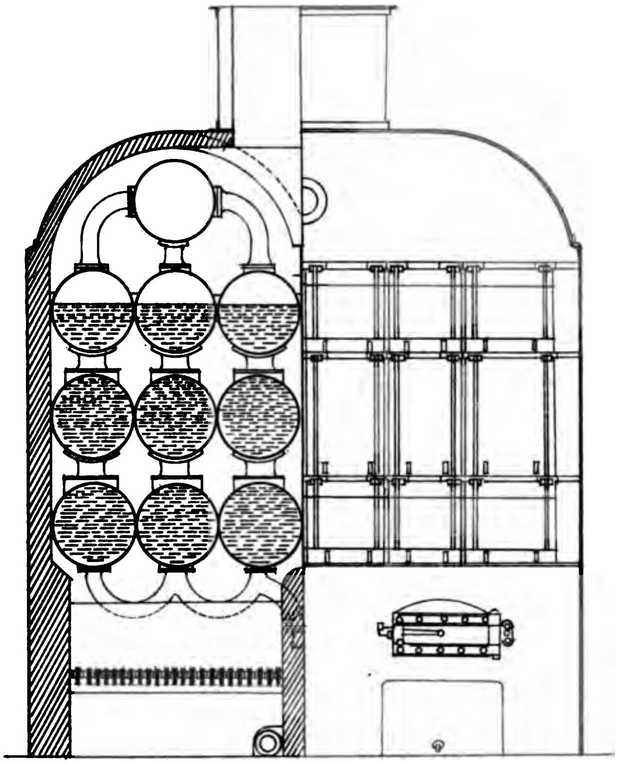


FIG. 12.

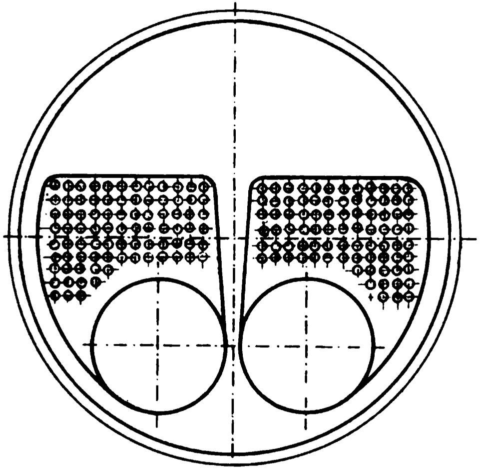


FIG. 13.

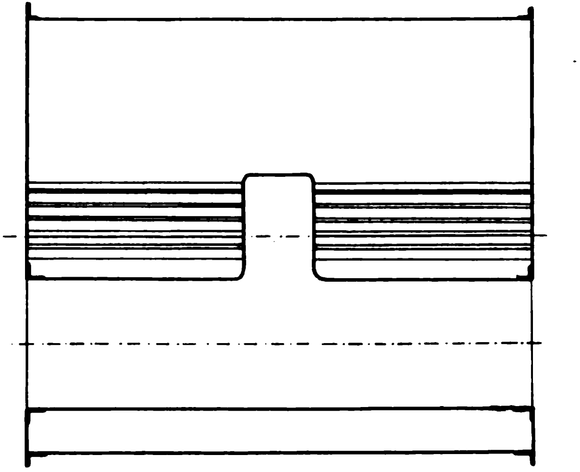


FIG. 14.

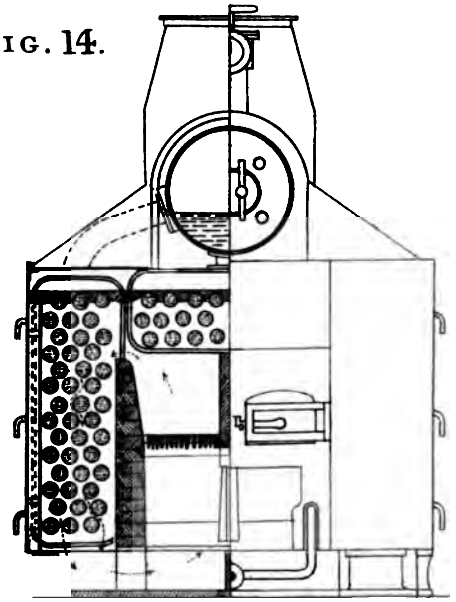
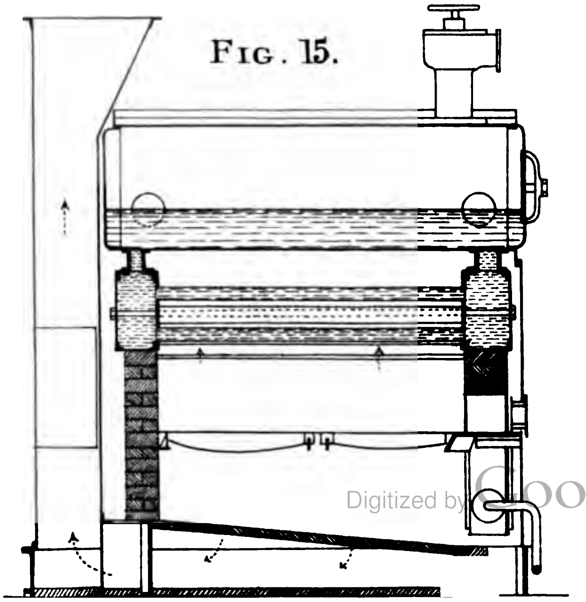


FIG. 15.



To Illustrate Mr. J. Howden's Paper on The comparative Merits of cylindrical and Water-Tube Boilers for Ocean Steamships.

FIG. 9.

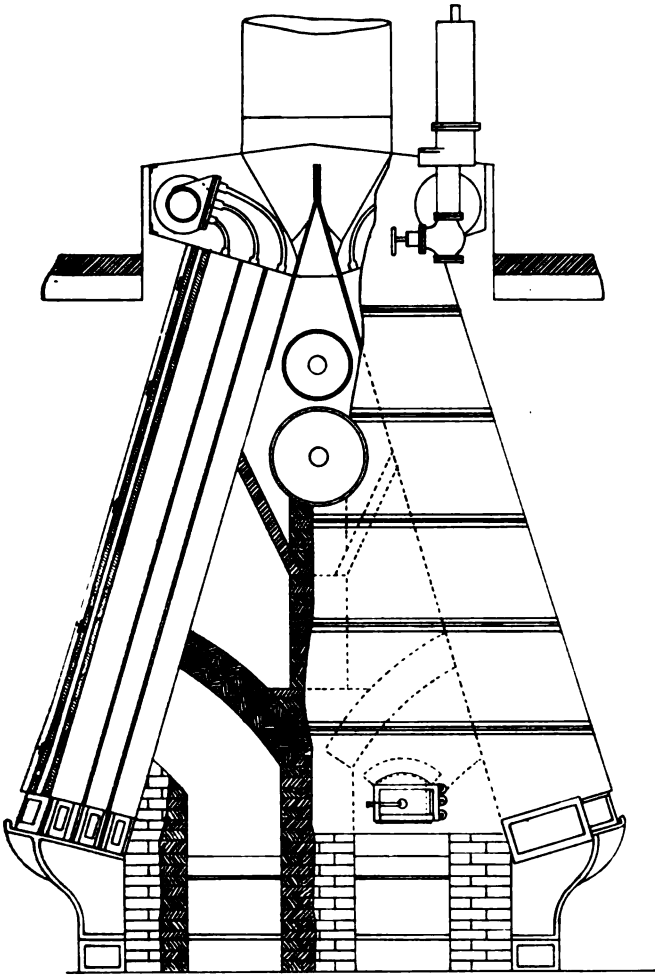


FIG. 10.

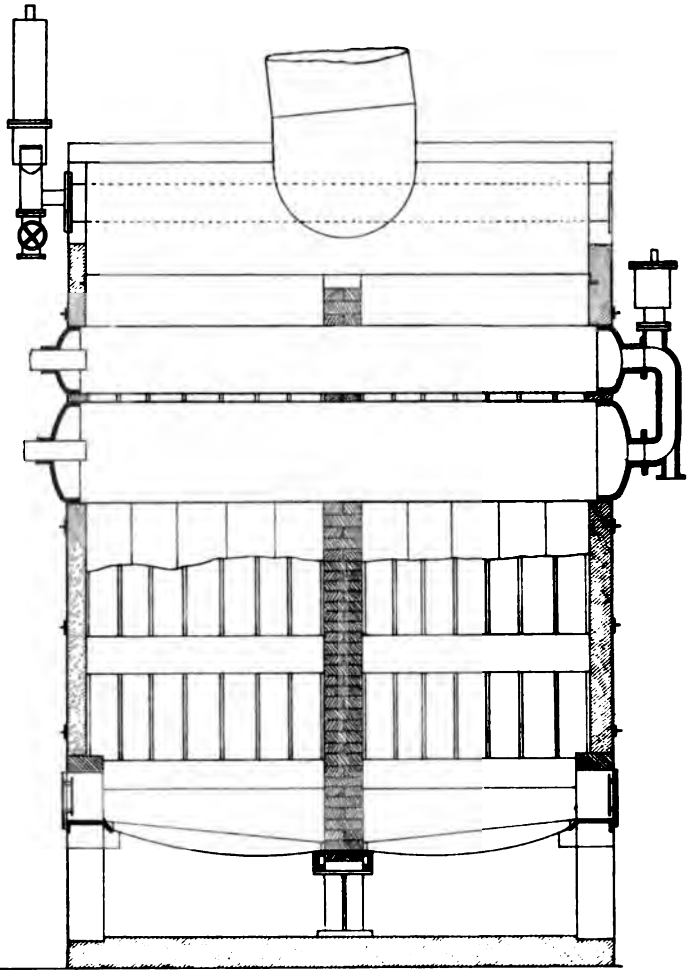
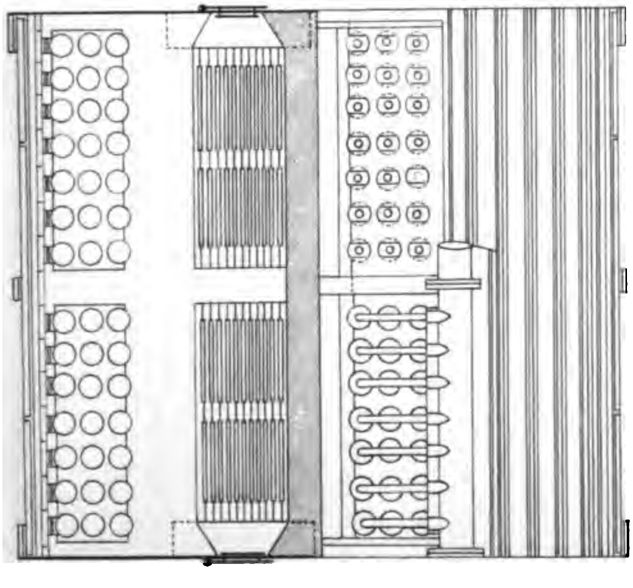


FIG. 11.



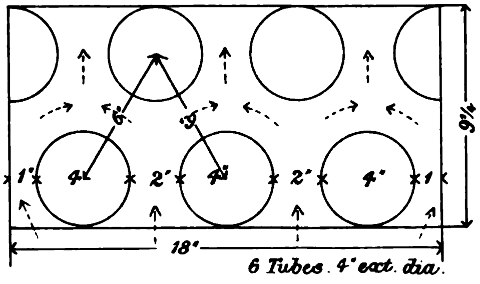


FIG. A.

Area of spaces in one foot length = 72 "
Heating surface in one foot length - 6·2832 "ft.
Water in six 4" tubes one foot long = 23·26 lbs.

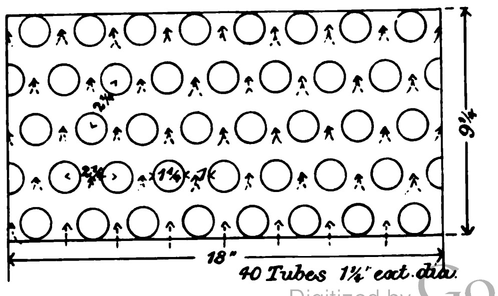
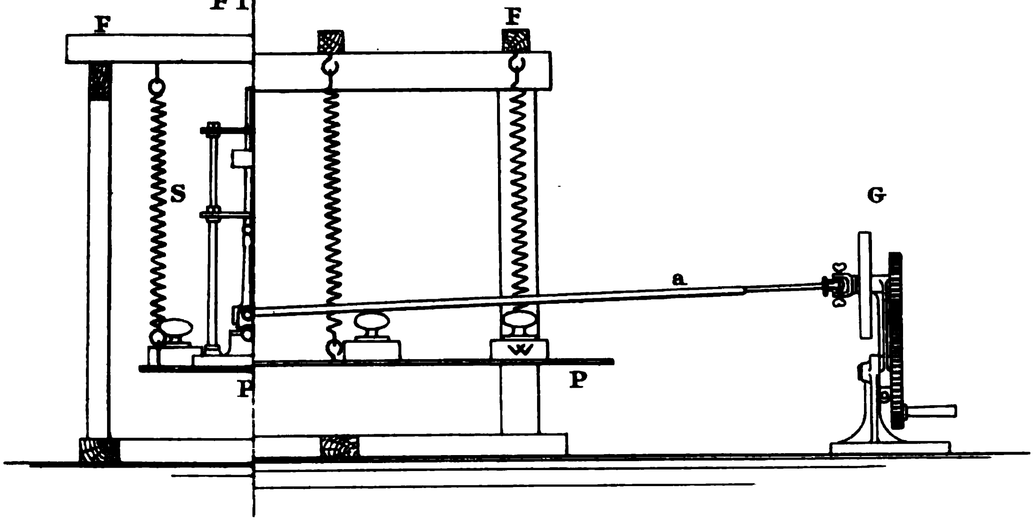


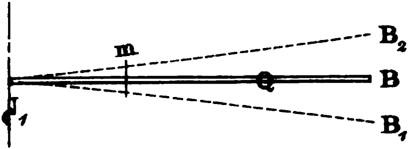
FIG. B.

Area of spaces in one foot length 96 "
Heating surface in one foot length 13·09 sq" ft.
Water in forty 1¼" tubes one foot long 13·6 lbs.

mers.

FI





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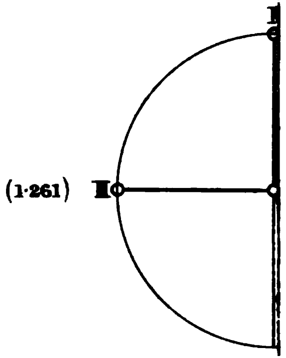


FIG. 8.

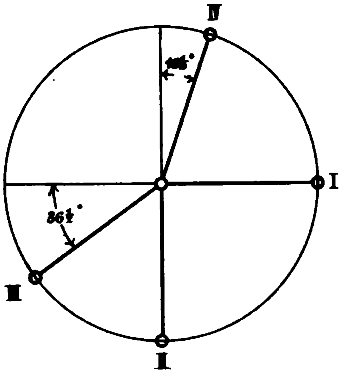


FIG. 9.

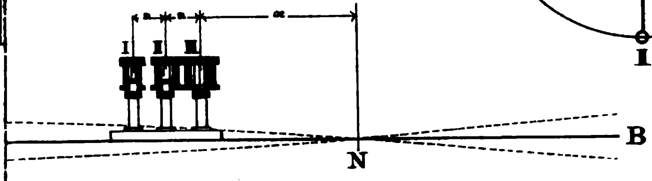
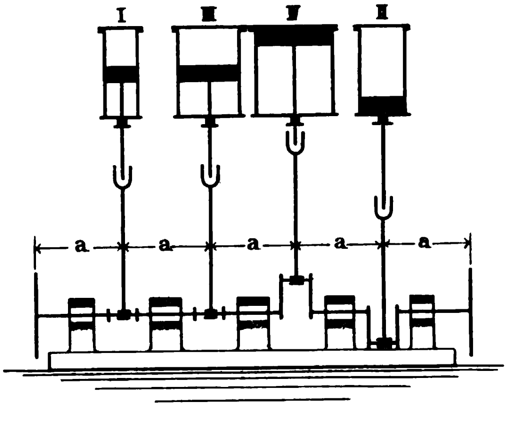


FIG. 5.



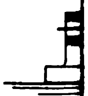


FIG. 4.

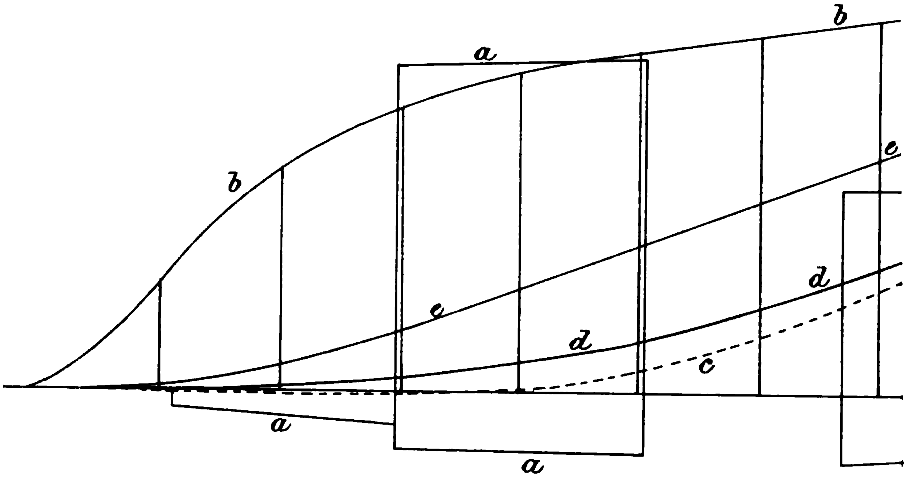
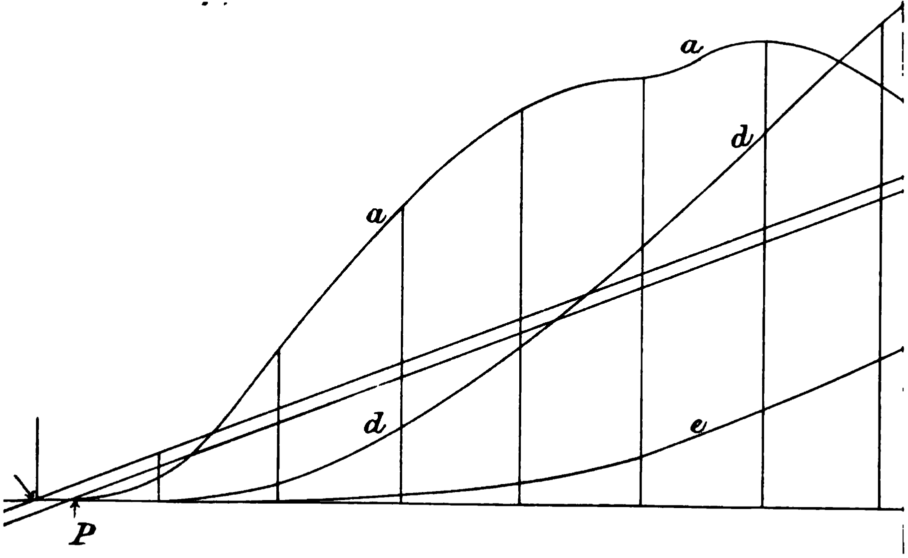


FIG. 5.



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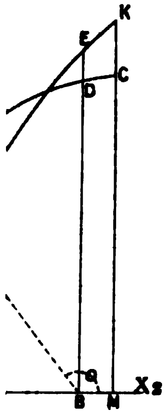
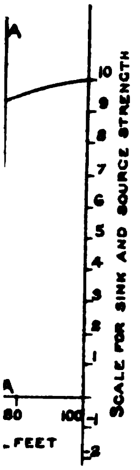
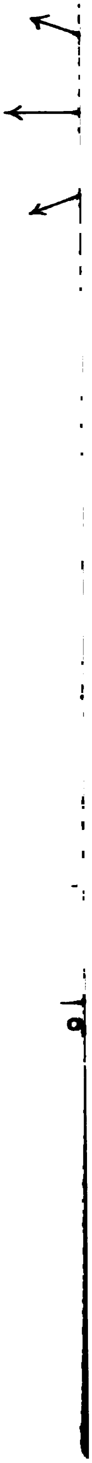




SHOWI



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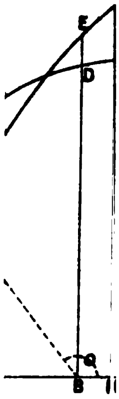

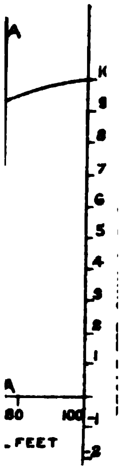

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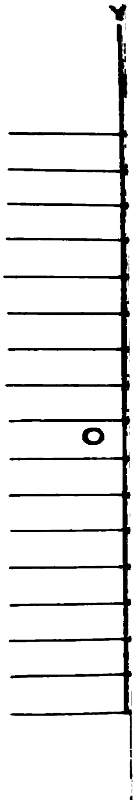
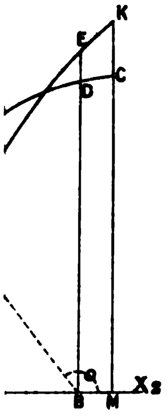
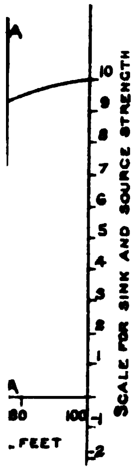

Y
O


K
E
C
D
Q
B
M
X2


A
10
9
8
7
6
5
4
3
2
1
-1
-2
SCALE FOR SINK AND SOURCE STRENGTH
A
80
100
FEET

To Illustrate Mr. D. W. Taylor's Paper on Ship-shaped Stream Forms.

FIG. 8.

SINK AND SOURCE LINE

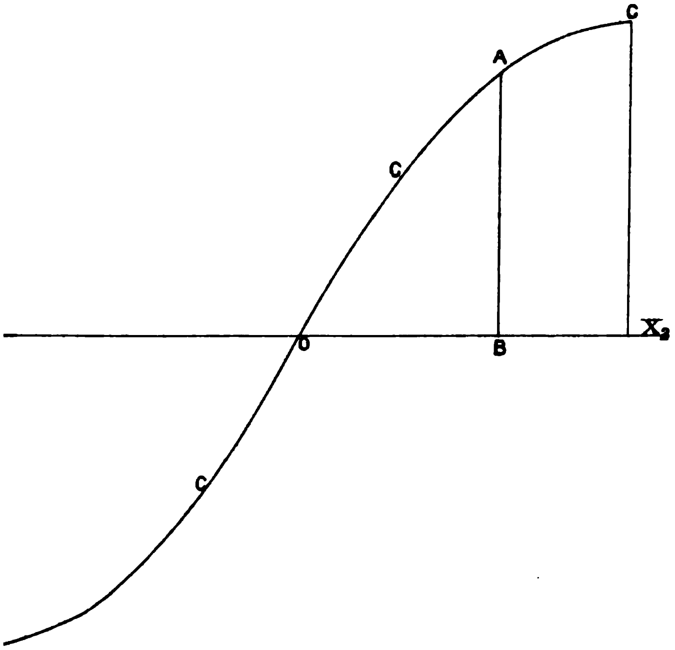


FIG. 9.

METHOD OF DETERMINING STREAM FUNCTION FROM SINK AND SOURCE LINE

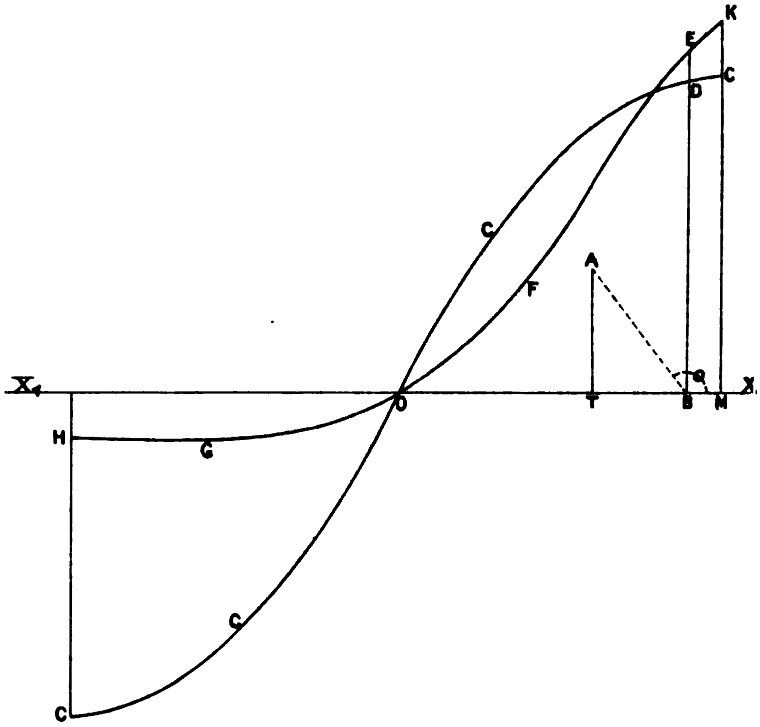


FIG. 10.

METHOD OF DETERMINING STREAM FUNCTION FROM GIVEN SYMMETRICAL SINK AND SOURCE LINE

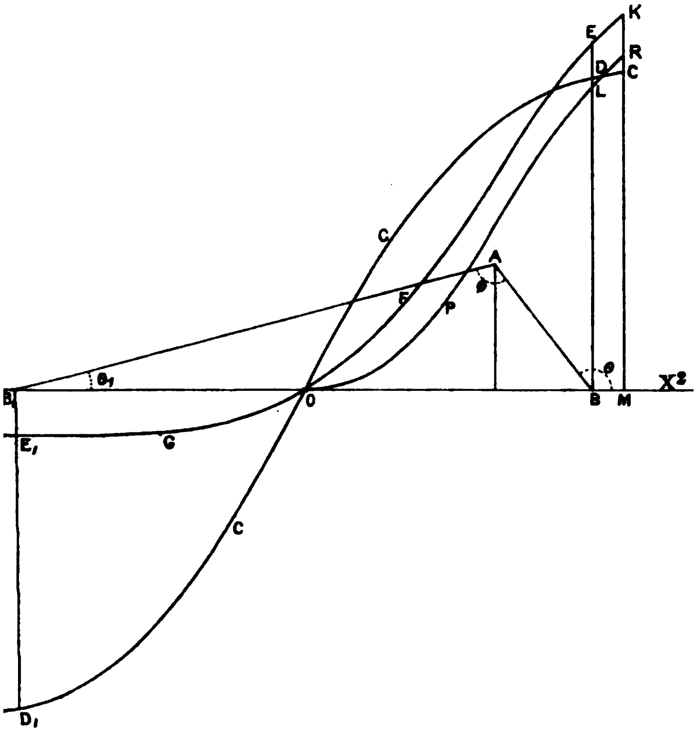
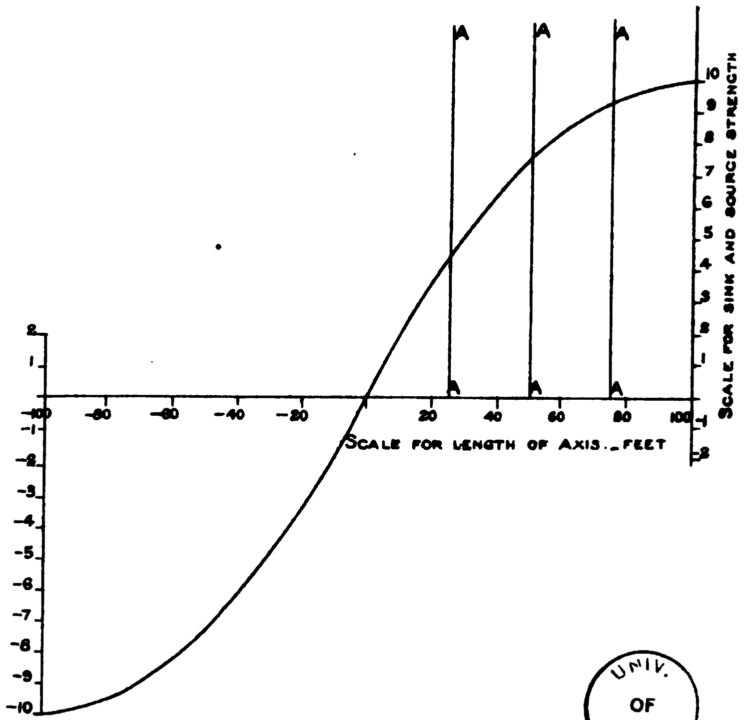


FIG. 11.

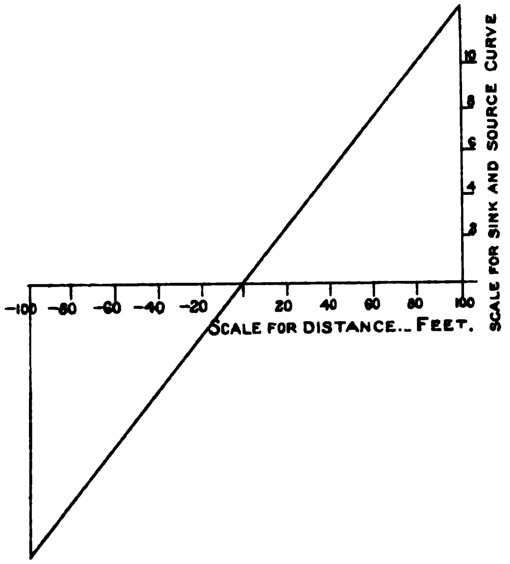
SINK AND SOURCE LINE.



To Illustrate Mr. D. W. Taylor's Paper on Ship-shaped

FIG. 16.

SINK AND SOURCE LINE.



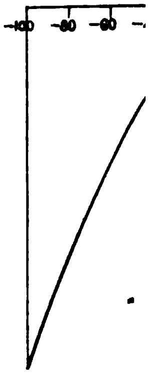


FIG. 20.

STREAM FORMS FROM FIGURES INDICATE

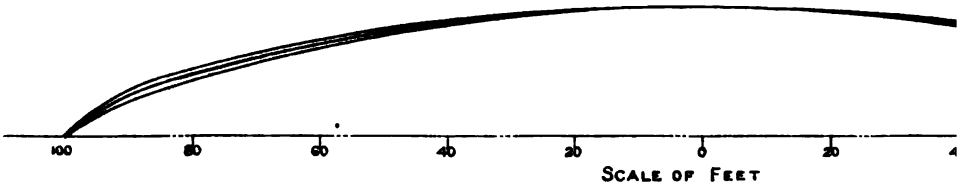


FIG. 24.

VARIATION OF PRESSURE HEAD ALONG STREAM FORMS
FOR SPEED OF STREAM 30 FEET PR. SEC.

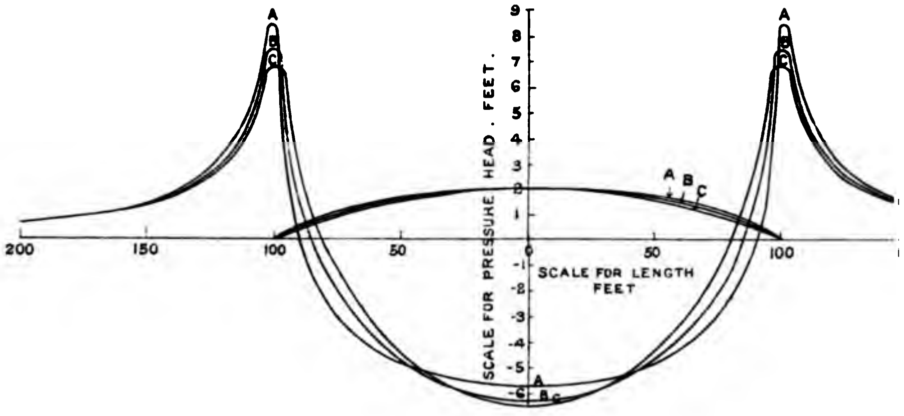
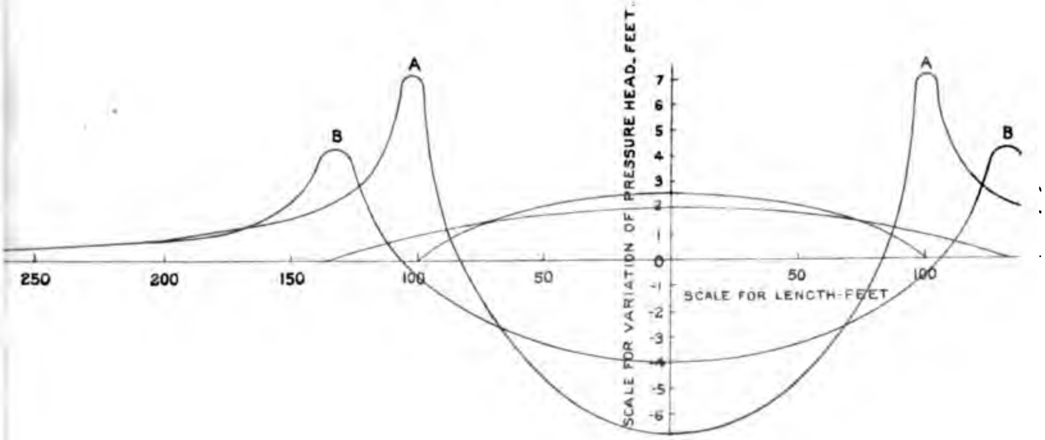


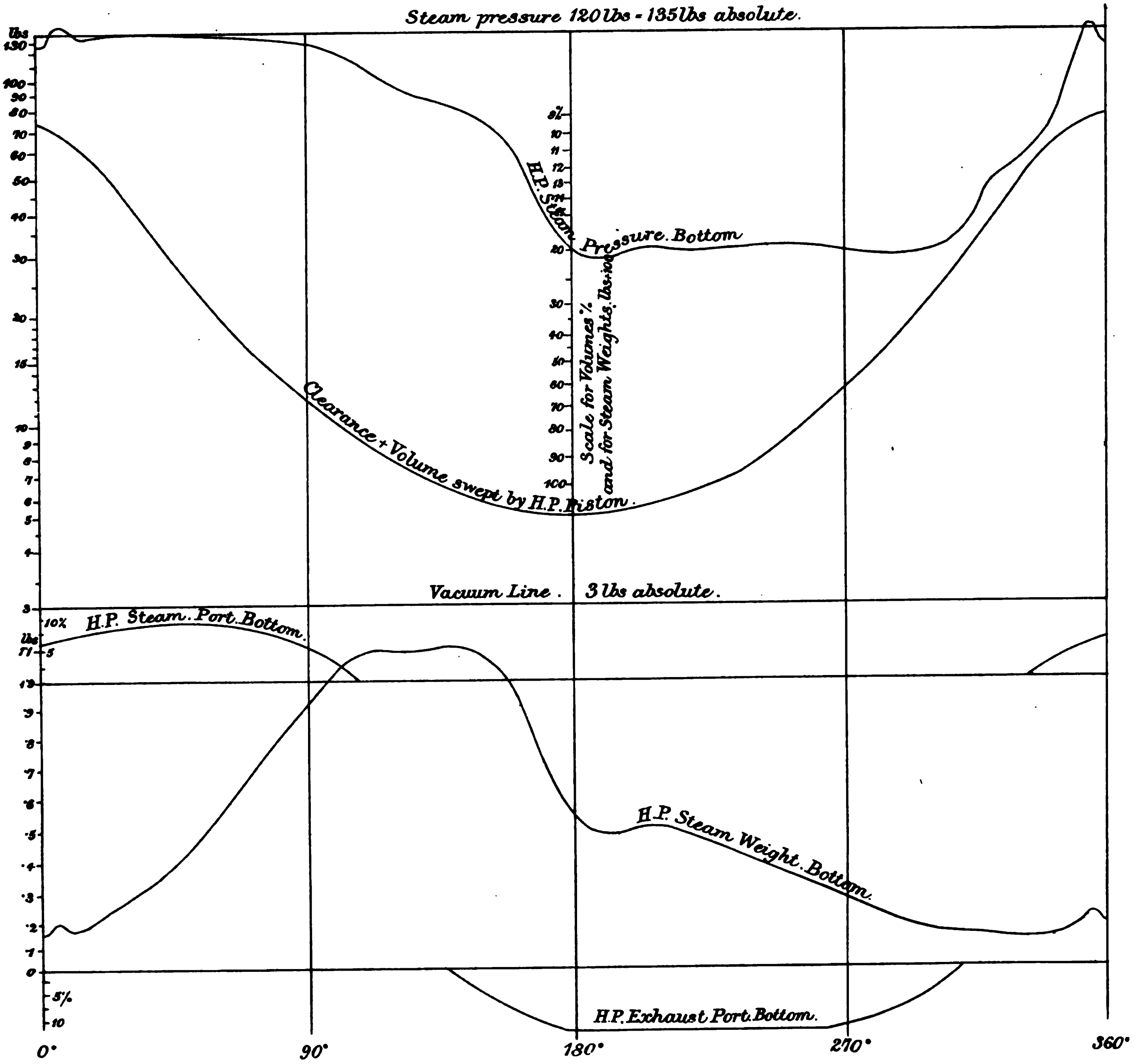
FIG. 25.

VARIATION OF PRESSURE HEAD ALONG STREAM FORMS
FOR SPEED OF STREAM = 25 F.S.



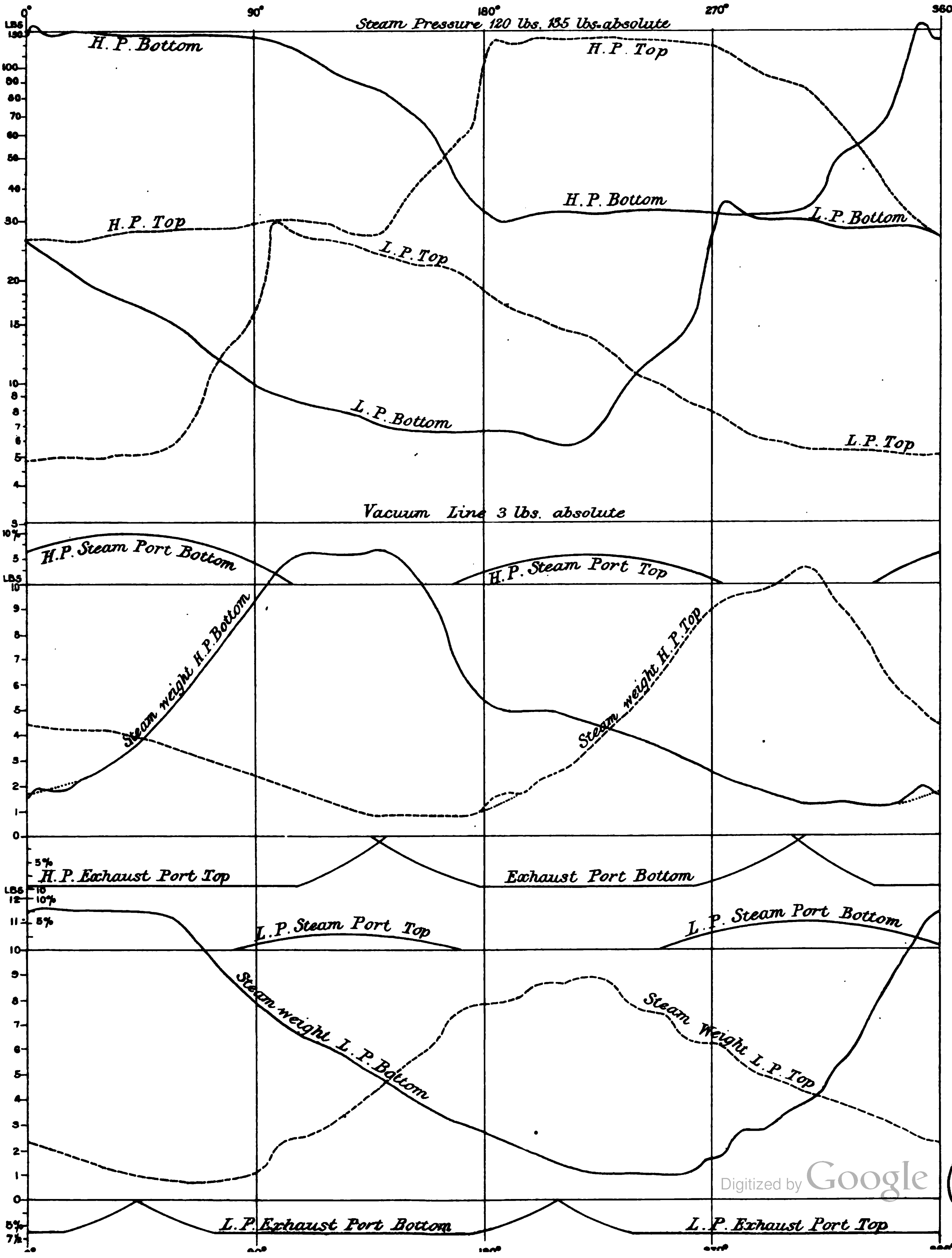
To Illustrate Mr. C. E. Stromeyer's Paper on Steam Pressure Losses in Marine Engines.

ENGINE A. (FULL GEAR)



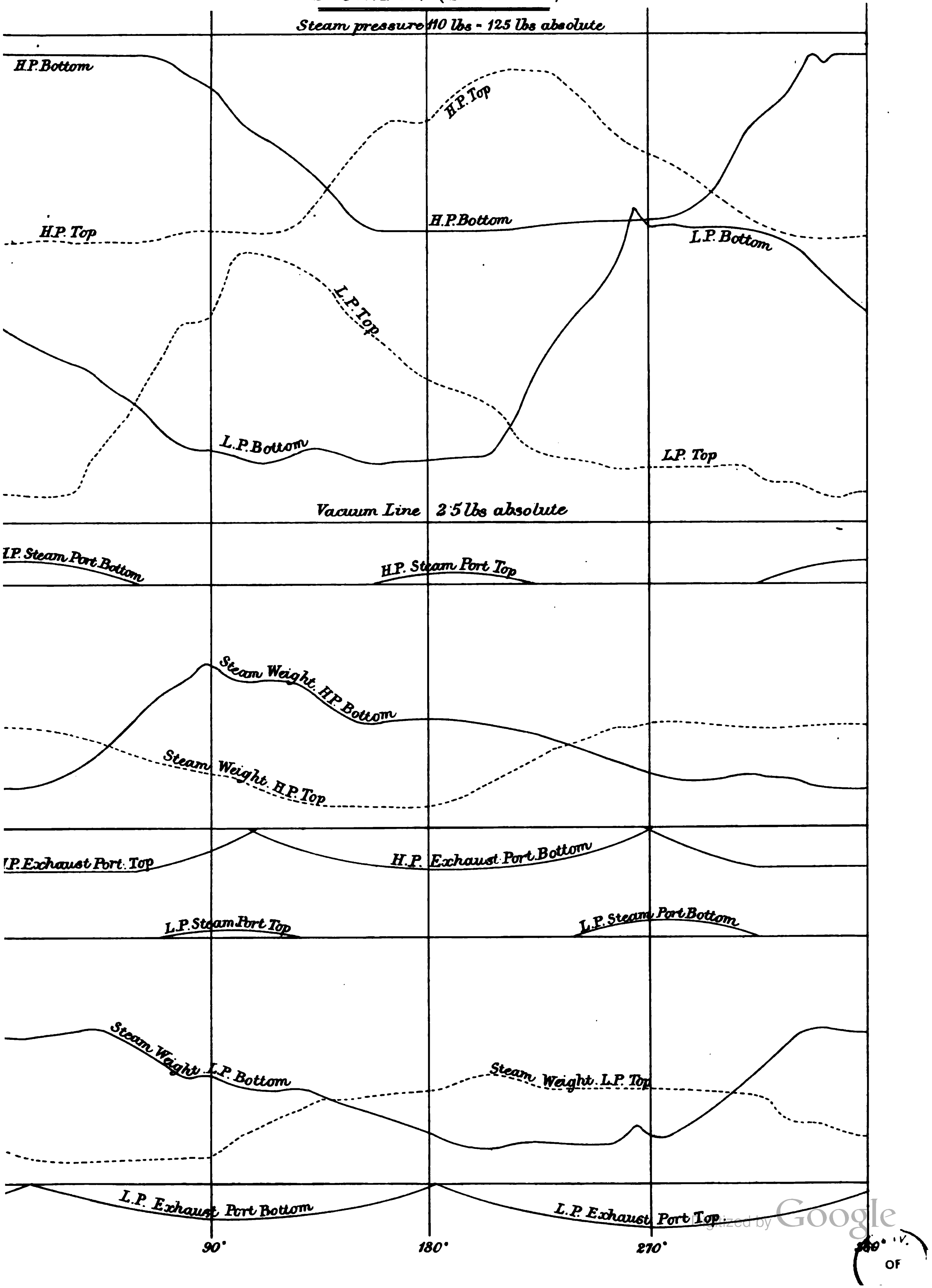
To Illustrate Mr. C. E. Stromeyer's Paper on Steam Pressure Losses in Marine Engines.

ENGINE A. (FULL GEAR)



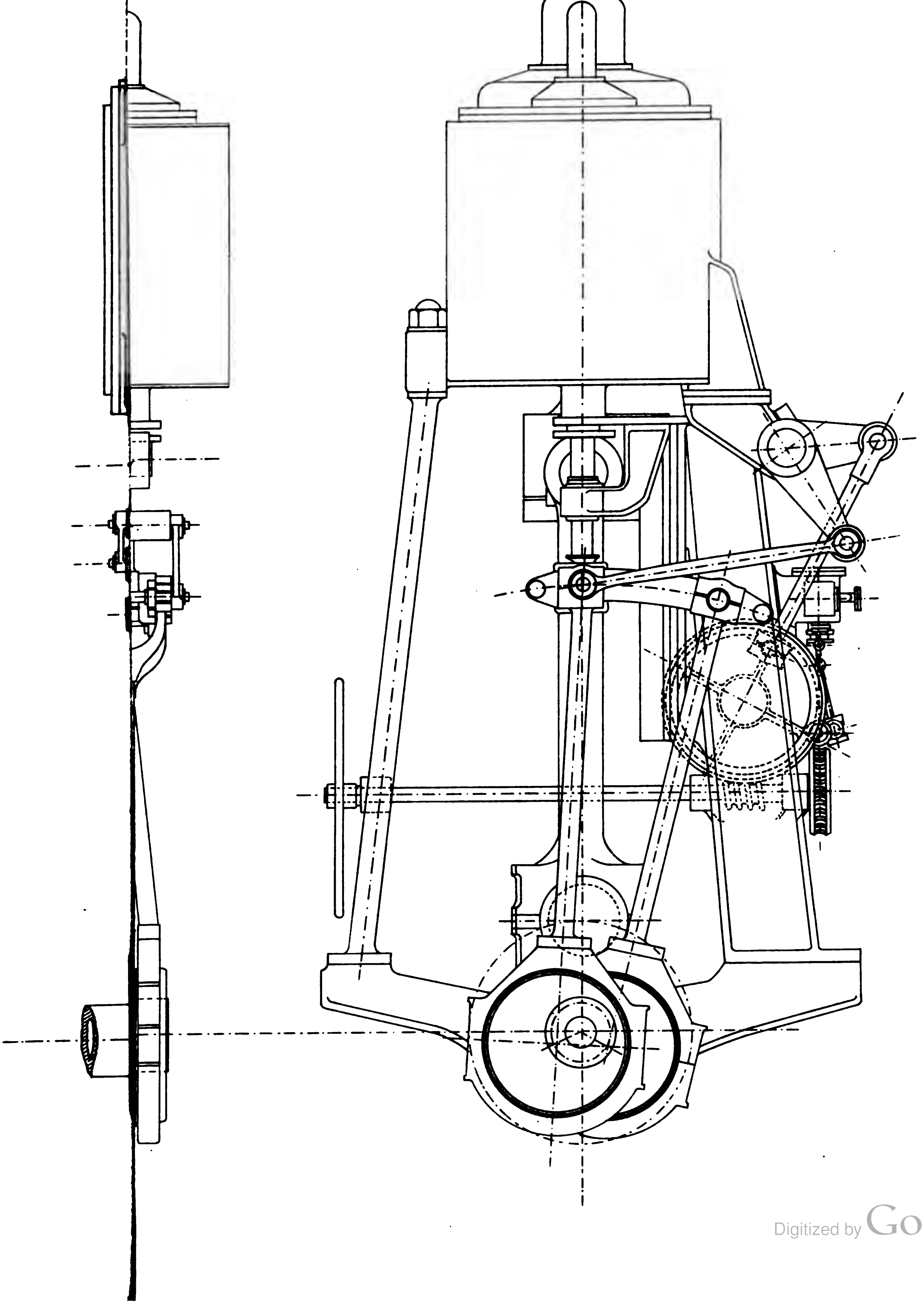
To Illustrate Mr. C. E. Stromeyer's Paper on Steam Pressure Losses in Marine Engines.

ENGINE A. (LINKED UP)



rans.

R".



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