NAVAL ARCHITECTURE:

A TREATISE

ON

SHIP-BUILDING,

AND

THE RIG OF CLIPPERS,

WITH SUGGESTIONS FOR A NEW METHOD OF LAYING DOWN VESSELS.

BY

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INTRODUCTION.

WITHIN the last few years, Naval Architecture has obtained, among the unprofessional members of society, a greater amount of interest than used formerly to be bestowed upon it. The rivalry which exists between the merchant navies of Great Britain, and her offspring in the Western World, has made each party seek, in the quality of their ships, that advantage which they could not obtain in the market. And the competition of the steam companies on the two shores of the Atlantic has given an impulse to research, also, in that department of science. It is but a short time since the clipper builders of England have been taught that the science of ship-building has not progressed with the rapidity which it has attained in America, nor reached the same eminence in practice. In the architecture of merchant vessels alone, England can justly at present claim precedence. It is, however, to yacht-building that I shall more particularly devote the following pages; but the remarks made upon this small department of the science can, as far as they are true, be applied to the other descriptions of vessels. With few exceptions, these pleasure-vessels are constructed with the object of speed, even at the expense, to a certain extent, of comfort and accommodation. In merchant vessels, on the other hand, there are two ends proposed, capacity and velocity. These are conflicting interests; the flat floor which is conducive to the former is detrimental to the latter—the sharpness and fine lines requisite to the latter, of course obliges the builder to content himself with a less amount of bulk. In these craft, it becomes desirable to attain to the maximum in the combination of these qualities: to balance the capacity and velocity, so that the volume of cargo transported each year shall be the greatest possible—to increase the beam, for instance, instead of having so flat a floor (thus giving an equal bulk and a greater velocity), and to fill the lines of the bow a little more, because this has not so great an effect in impeding the way, as lessening the taper of the stern. But yet merchant vessels labour under many disadvantages: those which frequent our shallow mud harbours *must* have flat floors; and of the rest, the nature and disposition of the cargo, in a vessel which had not a flat floor, would raise the centre of gravity of the ship higher than is desirable. And again, as these vessels are, in general, underhanded, it is necessary both to be content with small sails, and to keep the centre of effort rather low. This latter requisition again reacts on the construction by requiring, with the full bow and run, a more upright stern-post and buttock-lines.

But yet, on the other hand, it is, on prudential grounds, important even in merchant vessels to provide for a certain velocity. For the effect of a wind in carrying away spars, or in careening a ship, is much greater on a slow vessel than on a fast one. Suppose the wind had the force of a considerable storm (viz., 14·88 lbs. on each square foot), and moving at the rate of fifty-five miles an hour. Then, if one of two vessels advanced five miles an hour, and the other at the rate of ten miles, the relative velocity of the wind to the first would be fifty miles, and to the second, forty-five miles; and the relative pressures would respectively be as $\overline{50|}^2$ and $\overline{45|}^2$; or, as 2500, and as 2025. The pressure, in the first case, being 12·3 lbs. per square foot, and in the second, 9·9 lbs.; so that the whole pressure on a sail of 20 feet by 20 feet, or 400 square feet would, in the first case, be 4920, and in the second, 3960 lbs; and the quick vessel would have to sustain a force less by 960 lbs, acting at the end of a long lever. And, moreover, a ship with a rising floor might be going about her business when off a lee-shore, whilst one with a flat floor would be going bodily to leeward.

But besides these prudential reasons, there are also mercantile considerations which would induce an increase of speed in our merchant vessels. By a month's delay in a passage from China, a merchant might have to brook the loss of a considerable sum in interest, or he might even miss the market altogether.

In men-of-war more accommodation, in proportion, is necessary than in yachts, and stowage for a large amount of stores. The weight of the armament also requires a large displacement. But, after the attainment of these objects, speed becomes the paramount consideration. It becomes a question then, whether placing the guns further apart, should not give the necessary displacement, and also allow the attainment of greater speed; whether, I mean, the ships of each class should not have a greater length in proportion to their breadth and depth.

The reader will see that the science of ship-building becomes a more complicated question when it treats of merchant vessels or men-of-war. Conflicting interests have then to be reconciled in such a manner, that the maximum of advantage should be attained. For these reasons, I prefer confining my attention to the pure science, and leaving the modification, to suit each particular case, of the rules here laid down, to those most interested in the result, or best qualified to judge of the end to be sought.

When revolving in my mind these and other considerations, and seeing the importance of obtaining velocity, and perceiving the interest which is at present attached to this subject, I thought to find an excuse for offering a few suggestions upon it, and venturing to add to the number of books which are already flooding shop and stall. I hope it may not seem presumptuous in me to advance opinions on a subject to which naval architects have lately devoted increased exertions. The generality of ship-builders have not acquired a knowledge of the higher mechanics, and of the motion of fluids. These will, perhaps, excuse me for hoping that a study of mathematics, combined with the consideration of various theories on Naval Architecture, and the observation of models of known vessels, may enable me to start some new idea on the subject. And the more learned in the profession will pardon my desire to bring forward a principle which I hope may prove useful, and believe to be new. And I may further venture to express a wish that its simplicity may not be taken for worthlessness, nor disregard attend that which does not appear striking. Last winter I got upon the track of this invention, and, after much attention and some experiments, I thought to have discovered a fundamental error, which vitiated mathematical inquiries, and caused the results of experiments to be wrongly applied.

The Great Exhibition contained many models of noted vessels, by which I might test the value of my theory; and receiving corroboration from these examples, I ventured to publish a few pages in elucidation of it; and the former part of this work is, in fact, a second edition of that pamphlet. But if that which I then wrote be really true (which I may be allowed to flatter myself is the case) it becomes necessary to adapt the old forms of calculation to my new notion, and apply the results of former experiments to the method now proposed. Those mathematical formulæ which had relation to vessels at rest, are unaffected by the present theory; but those of which the subject was the motion of a vessel through the water, must all be altered. For they were calculated on the assumption that the water passed along the surface of the vessel in the direction of the water-lines, or in horizontal planes; while, in fact, the curve which any particle of water would describe is totally different.

The results of experiments have also been wrongly applied, in consequence of a confusion which arose from the following cause: most of the pieces of wood used in these experiments were either solids of revolution, or had a form, such that the sides were vertical. In these, the lines described by the water in dividing and closing around the body when in motion, were the same curve as the line of flotation when the body was at rest. The results depended in reality on the shape of the former line, as the latter had nothing to do with the water when the solid was not at rest. But they were supposed to depend upon the shape of the latter; and the same qualities were wrongly assumed to belong to any ship which possessed water-lines of a similar curve.

Hence, if my fundamental principle be right—if it prove not to be a hasty deduction—if it be not an overweening conceit which makes me imagine that I could invent anything more correct than that which the most eminent ship-builders have unsuspectingly practised, then is this work plainly not uncalled for, and its introduction needs no apology. If, on the other hand, any mistakes which may have escaped my notice, should prove to be fundamental errors, then let those who have spent their time in the perusal of the following treatise, take the pleasure of assisting the cause of truth as the reward of their labour, nor blame me for failing in my endeavours to be useful to society.

R. M.

CROMORE, COLERAINE,
FEBRUARY 5, 1852.

A

TREATISE ON SHIP-BUILDING.

CHAPTER I.

An inquirer into the science of Naval Architecture may either confine himself to the dry theories of mathematicians, or follow the surer method of experiment and induction. Mathematicians have demonstrated the curve which offers the least resistance in its passage through the water; but they have not sufficient data to ascertain either the shape for a vessel which would offer least resistance, nor the best form of midship section, nor various other requisites for a perfect vessel. Their attempts to construct vessels have, for these reasons, been, for the most part, abortive.

The empiricist, on the other hand, collects from different countries models of the fastest vessels, whether ships or boats, square-rigged or fitted with the various forms of fore-and-aft sails. He inquires into the capabilities of each as proved by experiment, and tries to discover their bad points. But he soon becomes as much bewildered as the mathematical inquirer. Among the swiftest vessels, he sees some with full, and some with sharp bows; some with great beam, others narrow; some with a great draught of water, others shallow; some with much rise in the floor, others comparatively flat; some with little gripe, or the forefoot almost entirely cut away, while others have been improved by the addition of a greater gripe, and a bow lengthened below the water.

Is there then any principle in building? he may ask; is it all the work of blind chance? The theorist rants about capacities and equal areas. The common sailor laughs and assevers that it is impossible to know what salt-water may fancy. But is it altogether as hopeless a task to discover some one principle pervading *every* swift vessel of whatever form, as it would be to take the dimensions of Neptune's car, or find equations to the surfaces of waves? Why have such different forms of building attained to an equal success? And why do many vessels, built according to theories and the results of experiment, fail so signally when tried with vessels built by common smugglers?

Builders form their vessels by the water-lines, ribbon- and buttock-lines; and consider that the curves of these lines are of paramount importance. But they have not asked themselves why they should be so; whether any of them can have much to do with the passage of the water along the vessel's body; whether the water divides, in fact, in the direction of any of these lines. Why have they not inquired into the real direction which the water takes when it divides, and bestowed all their care upon the improvement of these lines? And then they might take the models of famous vessels, and find what shape it was proper to give to the dividing-line, and extract a principle from chaos and confusion; and perceive the unity in a mass of apparently antagonistic facts and conflicting results.

And how then does the water divide? It may be expected, *à priori*, that a flat film of water, from the cutwater, will pass along the body of a ship in the same direction as that which any other flat thing would naturally take—as a thin plank, for instance.* This is not a conclusive argument, but a natural supposition. But there is a fact which materially strengthens this assumption: I allude to the fact

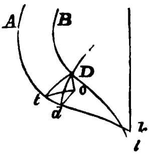
* The plank is supposed to be of indefinite breadth, because the dividing-lines are not parallel. In a clinker-built boat, the planks are cut with a "sney," for this reason, the lower edges only representing the dividing-lines.

that clinker-built vessels have a decided superiority over carvel-built vessels of the same form. Now, if the water does not divide in the direction of the planks, the land of every plank must offer considerable, very considerable resistance to the progress of the vessel. But, on the other hand, if the water does really escape, according to our *à priori* notion, in the natural direction of a plank, then these lands will offer no resistance. And as the mere clinker-building gives a decided superiority, it is clear that the lands do not offer resistance, and that the water naturally divides along the planks. Now, over timbers which are vertical—as in the run of the stern, for instance—the water, or a narrow plank, will pass in a horizontal direction; and over timbers which are quite horizontal, the water, or narrow plank, would take a line lying in a vertical plane parallel to the line of the vessel's motion. In each of these cases, the line described by the plank or by the water in its motion is at right angles to the timbers. And if a timber be forced out a little from the vertical position, so as to make a small angle with the vertical, the line described by the water or plank will take a slightly downward direction. And as the angle of inclination of the timber increases, the water or plank will take a more and more downward direction; but it will always cut the timbers at right angles. (I am of course supposing the timbers to lie in vertical planes perpendicular to the direction of the vessel's motion; and I am not at present supposing the surface of the water as anything but a perfectly plane surface.)

The reason why the water passes along the body of the ship in lines which cut the vertical sections at right angles, is that the ship's sides at every point (when the ship is in motion) give an impulse to the water which impulse is normal to the surface of the side at that point. And therefore the plane in which the directions of the impulses from two adjacent points must be contained, must of necessity cut at right angles the surface of the ship's side which lies between.

View the argument in another light. It is a philosophical principle that nature performs every thing with the least effort; and fluids in motion between two points on any surface will take the shortest line on that surface. Now, the diagonal line is the shortest line which can be drawn on the surface of a vessel from any given point on the stem-post to the stern. This will be manifest if the line in question be projected on a plane parallel to the planes of the timbers (i. e. to the body plan), if the sections are perpendicular to the [illegible] the water [illegible]

Let [illegible] be two adjacent [illegible] Then the line [illegible] Dd be a [illegible] water-line.



shortest line that can be drawn from the point D, in the circumference of the section Bk, to the circumference of the section Ak; for, if not, let Dt be shorter. Draw DO perpendicular to the planes of the sections, and let it meet the section Ak in O. Join Od, Ot. Then, as the distance between the sections is supposed to be small, and the dividing-lines are supposed to have an easy curvature, we may suppose the arcs, Dd, Dt, to be arcs of circles. Now, as the dividing-lines cut the circumferences of all the sections at right-angles, and as DO is perpendicular to the plane of Ak, therefore the plane DdO is perpendicular to the plane of Ak, and at right angles to the circumference Ak; and therefore Od is at right-angles to the circumference Ak; and Od is the shortest line which can be drawn from the point O to the circumference Ak.

$$\therefore \quad Od < Ot$$

and $$\underline{DO^2 + Od^2} < \underline{DO^2 + Ot^2}$$

or $$\text{chord } Dd^2 < \text{chord } Dt^2$$

and $$\text{arc } Dd < \text{arc } Dt.$$

Similarly, Dd is less than any other arc drawn from the point D to the circumference Ak.

The same may be proved with reference to that part of a dividing line which is intercepted by any other two sections. And hence the whole of any dividing-line is the shortest line which can be drawn from the same point in the stem-post, over the surface of the vessel to the stern.

This consideration will afford us the readiest way of describing a dividing-line in the body plan of a vessel. Instead of the established system of laying down the plans of vessels by the water-lines, and applying to the water-lines the shapes indicated by experiment to be the best for the dividing-lines, I would propose the following method, deduced from the principles advanced above:

1. For the sheer-plan, draw the keel, the stem and the stern-post, and mark in the line of flotation, or load-water-line. Then erect the sections at right angles to the load-water-line.*

2. Next determine the shape of the midship section, and lay it down in the body-plan. Draw a straight line across it for the load-water-line.†

* If the sections were drawn, as is usually done, at right-angles to the keel, the dividing-lines would not cut the sections at right-angles. In the copy of the lines which is afterwards made for the use of the builder, the sections may be altered (in the sheer- and body-plans) so as to represent sections perpendicular to the keel.

† The plane on which the sections are projected, for the body-plan, is perpendicular to the water; not perpendicular to the

From a point in the stem-post, somewhere about the height of the load-water-mark, or a little above it, draw a curved line to a point in the midship section, to represent the direction in which the particles of water, from the surface at the stem, are to be made to divide along the body. This is the principal dividing-line.* I have said "a *curved* line," because, if the line were straight, the circumferences of the sections at their points of intersection with this line, would be parallel to each other, because any dividing line cuts them all at right-angles. This *is* the case with some vessels, but it *need* not be so. To determine the nature of the curve this must be done:

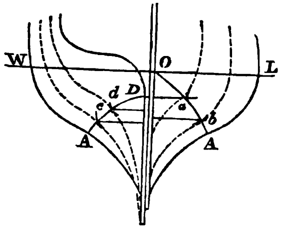
3. In the sheer plan lay off the points in the stem-post midship section and stern-post through which this line is to pass. Through these assumed

rabbet of the keel," as in the established method. Hence the water-lines, in the body-plan, are straight lines, and the sections do not terminate in one point.

* It must be borne in mind, that a dividing-line is not a single line, like a ribbon-line. The dividing-lines are as numerous as the particles of water which surround the ship. The whole surface of a ship's bottom may be supposed to be made up of an infinite number of dividing-lines. But we choose one only to work with, and choose that one which will be about the largest on the whole surface of the vessel. When the drawing is finished, it must be proved with other dividing-lines.

points draw a fair curve by means of the batten. Then,

4. In the body-plan lay off the heights at which this curve cuts all the other sections, and draw through these several points lines parallel to the water-line. (The intersections of these lines with the dividing-line will, of course, be the points of intersection of the sections with the dividing-line.) The form of the curve in the body-plan comes now to be determined.



5. This is done by laying off, in the half-breadth plan, the three points already mentioned, through which the line must pass, and drawing through these points the curve which may be given to the batten. This gives the breadths to be measured, in the body-plan, along the lines which we have drawn at certain heights parallel to the water-line; and the curve may then be described.

That dividing-line which commences at the load-water-mark on the stem-post, is now laid down—the greatest dividing-line, most probably, which the proposed vessel will have. In the above figure, let *OAD* be this curve, as determined by the sheer and half-breadth plans; *a, b, c, d,* its intersections with the lines drawn parallel to the water-line.

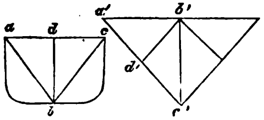
6. To sketch in these sections is our present object. For this purpose, take for centre the point *O*, (the point on the stem-post from whence the dividing-line is taken), and draw the arc of a circle through the point *a*. Next take *a* for centre, and draw an arc through *b*. Then take *b* for centre, and draw an arc through *A*; if this arc should cut the circumference of the midship section instead of touching it at *A*, then the point *A* must be moved so that the arc should only touch. This operation must be continued for the after-body by taking successively for centres the points *A, c, d.* The circumference of each of the sections must be tangential to each of the arcs respectively at their intersections with the dividing-line. The remaining part of each section is, at first, sketched in by eye, and then proved by other dividing-lines at various elevations. In sketching the sections, a pliable steel spring is of great use. It makes all the sections of a fair and similar curve, and so saves much trouble afterwards in correcting. The whole has now to be proved by water-lines, ribbon-lines and buttock-lines (according to the established method), and corrected where any inequalities in the surface may appear.

This is the principle which I would propose for guidance in the construction of vessels. This principle explains the success of vessels of such various forms. Vessels with full bows, for instance, have a dividing-line running in such a direction that its projection on the sheer-plan shows a greater curvature than that in the half-breadth plan; while the dividing-line of sharp bows shows a greater curvature when projected in the half-breadth plan than in the sheer-plan. In each of these cases, however, the curvature, taking all in all, may be the same.

THE MIDSHIP SECTION AND STERN.

From the foregoing remarks, it will appear that the whole form of the vessel depends very much upon the shape of the midship section, of the stern, and of the sheer-plan. In fact, these three are the only parts of the vessel of which the form is entirely assumed at pleasure. Of these, the midship section is the most important; and we shall therefore commence by considering it.

The part of a midship section which is below the water, has in general, been of a form approaching either to a square or to a triangle. The former obtained very extensively some years ago, but is now only retained in merchant vessels and some men-of-war. As the water is displaced with greater ease near its surface than deeper down, it is clear that the chief breadth should be near the load-water-line. And besides this, it is well-known that a sharp ship, even under close-reefed topsails, will be going ahead, while a flat-floored ship drives bodily to leeward. The midship section which approaches to the triangular form, requires, of course, in order to have the same displacement, a greater beam than that which approaches to a square. And it is a great, although common error, to suppose that, in order to reduce the plane of resistance, the breadth must be diminished. This is not at all the case. A vessel of the same length and tonnage must displace exactly the same volume of water, either in breadth or depth. And a narrow vessel, to have the same displacement, must have a flat floor. Let the diagram* represent the immersed part of the midship section of two vessels, each of which is divided into four equal rectangular triangles:



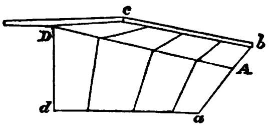
$a'b'$ being equal to ab. $b'd'=bd$. $a'd'=ad$, &c.

Now, the plane of the midship section is clearly

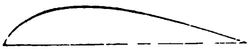
* The following observation is contained in an article contributed by my father, in the year 1824, to a periodical styled "Papers relative to Naval Architecture."

the same in each. The question, therefore, arises: 1. Which gives a body of least resistance? 2. Which has the most stability?

1. The broad midship section will be made to have a body which, in motion, will disturb the water less than any body to which the narrow can belong. [In other words, the curves in which the water will divide can be made narrower with the broad midship section, than with the narrow one.] For the run of the vessel may be tapered off in the form of two wedges; the one from the bilge of the midship section (a part which is narrow and deep down in the water), being tapered off to the stern-post (as *A a*, *D d*). That from the upper part of the midship section,



(which is broad and shallow), being tapered towards a line *nearly* at right-angles to the stern-post (as *A b*, *D c*). [In other words, the water from the lower part of the midship section must move along a curved line lying nearly in a horizontal plane. While the water from the upper part must, in its motion, describe a curve lying in a somewhat vertical plane; for it need not be made to escape at the stern-post, but under the counter *D c*.] The load-water-line can then be



given a form such as that in the diagram; which, with a decrease in resistance, is both productive of greater bearing, and brings the centre of gravity more aft. The centre of effort of the sails can then be more aft, and the bows will be less pressed down. And, as the head-sail will be decreased, the vessel will be eased in pitching. It has often been exclaimed that this fulness in the load-water-line must increase the resistance; but it must be remembered, that the water does not divide along the load-water-line; and we have just shown above how the resistance may therewith be lessened. [The load-water-line of the 'Mary Taylor' is not unlike this.]*

* And an additional reason for the advantage in this form is as follows: the water which has passed along the whole length of the ship is more disturbed than the water more forward would be under similar circumstances; and hence it has less supporting power. Add to this that it has a tendency to fly off at a tangent, and so offers less upward pressure to the stern. Or this may be put into other words; the density of the water at the bows is increased by the motion of the vessel, while that at the stern is diminished; the centre of gravity of the displacement, when the vessel is in motion, will therefore be thrown in advance of the point where the centre of displacement happens to be when the vessel is at rest, and before the centre of gravity of the ship; the

On the other hand, the run, in a vessel with the narrow and flat midship section, must be tapered almost entirely in one direction, from the bilge to the counter. Whence the water from under the floor must escape upwards, in the direction of the buttock-lines, to the counter; describing a curve whose breadth is equal to the whole depth of the vessel. And the water near the surface closes horizontally, describing a curve the breadth of which is the half-breadth of the vessel. These two currents converge, and meeting at the stern, cause an eddy and dead-water, which the vessel has to drag in her wake.*

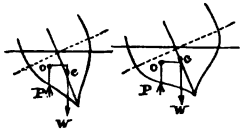
bows consequently are pressed up and the stern subsides. This would always take place in vessels with little bearing aft, if the centre of effort of the sails were not either before or above the *point velique*. For this malposition of the *point velique* tends to press the bows down, and so counteracts the tendency of the stern to settle. But a great deal of power is lost in this useless antagonism. A broad stern, a more buoyant after-part to the vessel with the centre of effort of the sails no higher than the *point velique*, nor in advance of the vertical through the centre of gravity of the ship, would be much more conducive to velocity. (We hope the reader bears in mind that although the water-line is to be very full at the stern, yet it is requisite that the dividing-lines should be very fine.)

* What we have just been saying applies, of course, chiefly to sailing-vessels. Those which do not require a hold upon the water may be broad and very shallow; in which case the objection to a flat floor does not obtain.

Again, when the vessel with the rising floor is heeled over, an increased surface is presented for support; and the water, pressing against a much larger volume to leeward than to windward, assists in making the vessel weatherly. This is the case with the Bermuda boats, which are said to "fetch to windward of the place they look up for." An extreme rise in floor, however, only holds good for small yachts. For, if the power is only at the surface of the water, the vessel in falling over, meets, from the great increase of immersion, with a considerable reaction; she is buoyed up and rendered uneasy. For this reason it is better, except in small boats with the centre of gravity very low, to preserve the same breadth for 15° above and below the load-water-line; so that, when inclined, the immersion and emersion should he about the same, without the centre of gravity being raised. Sir W. Symond's vessels and the New York pilot-boats have very rising floors.

2. Which form is most conducive to stability? Stability may be acquired either by beam or by depth. By beam, because the upward pressure of the water acts upon a longer lever; and by depth, because the ballast acts at the end of a longer lever. In both these requisites the second form of midship section is clearly superior.

The stability which arises from breadth of beam is, for the same tonnage, to be preferred for all vessels, except perhaps mere racing craft. The stability arising from depth is rather advantageous only for vessels which are always running gunwale under, and assists, of course, in going to windward.* The power from the former principle is *constantly* tending to prevent inclination; but the power decreases as the inclination increases. In the latter, it would appear, at first sight, that the power only begins to act as the vessel begins to list, and increases with the inclination; and this would be the case if the vessel were without weight, and the ballast only were considered.

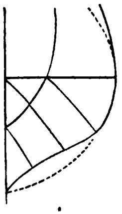


But as the weight of the vessel must also be taken into account, it will be seen that the only real advantage in the depth is, that the ballast can be stowed lower, and so the centre of gravity of the

* Mr. Wanhill of Poole, builds, with success, vessels of great depth and narrow; of course merely for racing. He also, has practised, without being aware, the principle which I propose; for when he commenced building, he hauled up his vessels which had been some time afloat, and observed where the copper was bright. The next vessel he built less full in that place. And so he did until he found that the copper of his vessels was equally bright all over.

whole ship be brought down. In the diagram, let C be the centre of gravity of the whole vessel, o of the displacement. Then the forces in question are the weight of the whole ship, ballast, &c., which may be supposed to be collected at C; and the upward pressure of the water, P, which may be supposed to act at o with a moment equal to the product of P into the distance from P to a vertical line through C. This will probably be greater even in the broad midship section.

It is well to have a slight concavity in the bilge of the midship section of yachts, or of men-of-war, in order to resist the weight of ballast, and also to shorten the dividing-lines. For the effect will be to make the run commence further forward. But there must be some bow timber in which there is



no hollowness; and the dividing-lines must not converge, that is, the length of circumference of a section intercepted between two adjacent dividing-lines, on the straight or convex bow timber, must not be greater than that intercepted between the same dividing-lines on any section more aft. If the convergence, however, be slight, it is not of consequence, because the increased density in the water, produced by the convergency, will add to the buoyancy at that part of the vessel.

This inflection tends also to decrease lee-way; because an inflected surface offers more resistance for the passage of the water than a simple curve. But there is no exact form of midship section to be prescribed. Some use a semi-parabola with the origin on the water-line, and it has been found to succeed very well.

The point in the midship section to which the chief dividing-line has to be taken, has not been as yet determined. If, from the load-water-mark on the stem-post, it were taken to the nearest point (in the body-plan) of the circumference of the midship section, then the projection of that dividing-line in the body plan, for the fore part of the vessel, would be a straight line, and the bow timbers would, at that part, be parallel. For if the chief dividing-line in this case were not a straight line, it would not meet the midship section at right angles. (This is the case in the 'Mary Taylor,' with the exception of the first two sections in the bow). If the fore body is not to be of such a form, the point must be assumed at pleasure; or the following plan must be adopted in order to find the place to which the chief dividing-line should be brought, that it might be as easy as possible: divide the angle between the bilge and stern-post into as many parts as there are sections before the midship section (the sections being supposed at equal distances). The dividing-line taken over these lines, as if they were sections, will give the best point in the midship section for the dividing-line to be taken through.

THE STERN.

Quarters, which flange off at right angles from the stern-post, are, for two reasons, not good. The first is that, when the vessel is heeled over, they drag in the water; and the other is the very sudden increase of bearing which is thereby produced; and the vessel when thrown down on her stern by a sea meeting her, is pitched forward again with violence; and if the bows happen to be also very full, she will be pitched back till all grins again. If the vessel be very long, this pitching and 'scending will not be so violent; and the quarters then may flange off more suddenly. However, it may be urged with reason, that when a vessel is going very fast through the water, the fluid does not divide quite in the natural curve, but has a tendency, in the after-body, to fly off at a tangent; that the stern has then less support, and will sink unless a rapid increase of bearing is presented to the water. If the quarters make an angle of 15° or 20° with the water, they will not drag, or cause dead-water, when the vessel is careened, and will not be too sudden, although a sufficiently great increase of bearing will be presented to the water.

The stern should be very broad. It increases the stability, brings the centre of gravity of the displacement further aft, and is also better when running before the wind in anything of a sea.

The low, overhanging stern usually given to our yachts is very pretty, but not nearly so safe when going before a sea, as a shorter and higher stern.

THE SHEER-PLAN.

The third feature which is entirely assumed at pleasure, is the sheer-plan. In England it is usual to give nearly an even draught of water fore and aft. In America, on the contrary, they used to give their schooners nearly twice as much depth aft. The latter plan enables a vessel to carry less head-sail, and by this means eases her pitching. The former method gives increased bearing below. The stern-post should, for the sake of the steering, be nearly upright. This rule is, nevertheless, not all-important; and the subsequent arrangements in the form of the body might render necessary a great deviation from it.

The amount of sheer is a matter of fashion and caprice. The use of it is both to throw the water off the deck, and to act like an inverted arch in supporting the extremities of the ship, which have so little bearing below to give them the necessary support from the water. The bows and stern generally sink one or two inches on launching, and continue to do so as long as the ship is afloat. A curvature in the keel, such as that in the 'America,' would also tend to prevent hogging.

It is a matter of importance to have the gunwale no higher out of water than is necessary to prevent the decks being drowned, because every inch of it tends to impede her way on a wind, and to send her to leeward. When a sea meets her bows, it first rises considerably above the load-water-line; but as it passes along, the vessel is heaved up over it, and the stern again sinks into it. Hence the wave, when amidships, is not much higher than the load-water-line, and the deck ought, therefore, not to be very much above that. The stern need not be so high as the bows if it be broad.

CHAPTER II.

The dividing-line, which we have taken as our guide in forming the body of the vessel, has been described by the batten through the three given points. No particular curve has been assigned to it. Its *projections* in the sheer and half-breadth plans have been curves, which the batten naturally assumed. It is necessary, therefore, to ascertain by experiment, what sort of curve, of single or double curvature, should be given to the dividing-lines; or what kind of curve, of simple curvature, its projections in the sheer and half-breadth plans, should assume.

If experiments be made by drawing bodies of certain shapes through the water, noticing both the rates at which they travel respectively, and the weights required to move them, we shall learn which body offers least resistance to the water; and by ascertaining its dividing-lines, we shall know

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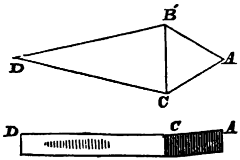
what form a dividing-line should have, and where its greatest breadth should be. And if these bodies are so formed as to have:

1. Two horizontal planes for their upper and under surfaces, and vertical superfices for their sides; then the dividing-lines will be all the same, and of the same form as the water-line.

2. If the sides are vertical planes, parallel to the line of motion, and the under side is a superficies, such, that its intersections with planes perpendicular to the line of motion shall be horizontal lines, then the dividing-lines will be all similar and in vertical planes.

3. If the body be a solid of revolution, the dividing-lines will all be similar, and the same as the water-line.

Numbers of experiments have been made, and it is thence ascertained that, if there be taken two cuniform bodies, *ABDC*, and *BCD*, of which the greater is formed of a part, *BCD*, the same as the smaller body, with another part, *ABC*, of which the upper and under surface is an equilateral triangle; and if the bodies are moved through the water with the end *D* aftermost; and (1) if the bodies are moved slowly, then the body, *AD*,



obtains $\frac{5}{12}$ more velocity than *BCD*, with the same motive power:

But (2) if the motion through the water be much increased by an addition of motive power:

Then the body, *AD*, obtains only $\frac{3}{12}$ more velocity with the same power as that applied to *BCD*.

And, in general, it is ascertained from numerous experiments that, at *high velocities*, a blunt bow-end does not increase the resistance in nearly the same proportion as at low velocities. And as the speed is increased, the bluntness of the bow has less effect in increasing the resistance.

The bodies were also moved through the water at six feet below the surface; and it was found that the body *ABC* (with the flat bow-end,) obtained, when close below the surface, $\frac{4}{10}$ more velocity than when moved at a depth of six feet below, provided the velocity was not great. But at a high velocity, it obtained only $\frac{1}{10}$ more velocity at the surface than it did below.

And the body *AD* (with the sharp bow-end) obtained $\frac{8}{10}$ more velocity, when moved close below the surface, than it did when sunk to a depth of six feet, provided the velocity was not great. But when moved at a high velocity, its speed at the surface was only $\frac{5}{10}$ more than below.

From this it appears that, for a high velocity, it is no great advantage to have a sharpness at much depth below the surface.

Also, it is a fact that when bodies are moved through the water, the resistance of the fluid to the bows does not decrease in the same ratio in which the dividing-lines of the bow are made more acute.

By experiments made in Sweden, it was proved that bodies with sharp bow-ends, obtain greater velocity through the water than bodies with full bow-ends, when, by equal powers, moved *slowly* through the water. But bodies with full bow-ends obtain a greater velocity than bodies with sharp bow-ends, when, by equal powers, forced rapidly through the water. Thus, a body of the form *AD* moves much more easily, at high velocities, with the *butt* end *A*, foremost; but at low velocities it moves more easily with the sharp end, *D*, foremost. And we observe this fact in the works of nature; for whales, cod, dolphins, porpoises, and other fast-swimming fish, have a full entrance and a long, tapering tail.

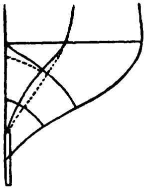
Moreover, it has been ascertained by experiment, that the taper of the stern-end must increase with the velocity at which the body is to be moved, and that the suction is a minimum for all the different velocities at which a ship may sail, when the dividing-lines of the stern make an angle of 13° 17′ with the keel.

A Thames wherry is built so as to go fast when lightly laden, but is formed for a slower pace, with more bearings, when sunk deeper in the water. The parts low down in the water have much more taper than those higher up; and when greatly immersed, the part at the surface of the water presents a sharp appearance in the bow, but full aft.

It is supposed in theory, that the resistance to the bows varies as the square of the velocity. Experiment shows that it does not increase quite so rapidly as this law would indicate. Neither does the suction at the stern increase in the same ratio.

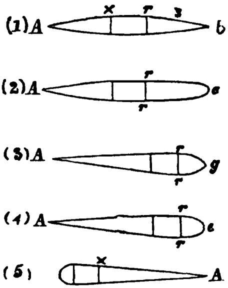
From all this we learn that, for high velocities, the dividing lines of the bow may be made fuller, and those of the stern *must* be more tapered; that, for the same resistance, they can be fuller in the bow, at a part deep down in the water, than at the surface. Also, it has been found advantageous that in the half-breadth plan, the greatest dividing-line should have, at least, six times the length before the midship section, that it has half-breadth at the midship section.

If the dividing lines of the bow be made very sharp, and there be a great rise in floor at the midship section, and the stern-post be perpendicular, then there will be a hollow in the water-lines of the bow. If this concavity be too great, then two converging currents of water will be formed, and an eddy, or rather increase of density in the water, is produced, just abaft the bow. But if the concavity is so slight that any two adjacent dividing-lines do not converge, then it is not deleterious. The dividing-lines must be made fuller at the bows until this object is attained.



Just as these papers were about to be placed in the publisher's hands, I have been enabled, by the kindness of the Rev. Hervey Goodwin, to get a sight of the first volume of Beaufoy's "Nautical Experiments." A great number of the results in this book are not applicable to our business, because of the straight lines and angles in the forms of the bodies used, while in ships there are employed only curves of different kinds. A summary of the results arrived at would, however, be useful.

The diagram represents the top or bottom surfaces of five of the models used in the experiments.



In (1), *XA* is a triangular cuneus of 3 feet in length; *rb* is also 3 feet in length; *rs* being a segment of a circle of 8 feet radius; *sb* being a tangent 1 foot in length.

In (2) *rc* is also 3 feet in length.

In (3) *rg* consists of segments of a circle of 1 foot radius.

In (4) *rcr* is a semi-cylinder of 6 inches radius.

In (5) *XA* is 4½ feet in length.

		Motive power in lbs.	Relative velocity.	Motive power.	Velocity.	Motive power.	Velocity.	Resistance without friction, at 3 feet per second.	Resistance at a velocity of 13·527 feet per second, or 8 knots per hour, excluding the friction.
A being the head-end	No. (1)	12	3·922	48	7·339	96	10	1·777	35·54
	No. (2)	—	3·693	—	7·124	—	9·895	2·8576	35·05
	No. (3)	—	3·6075	—	6·9156	—	9·575	3·3299	51·74
	No. (4)	—	3·7534	—	7·0785	—	9·7208	2·5967	49·21
A being the stern-end.	No. (1)	—	3·9269	—	7·3540	—	10·0638	1·7656	34·35
	No. (2)	—	3·7897	—	7·2354	—	9·9973	2·3927	32·91
	No. (3)	—	3·8760	—	7·3155	—	10·0502	2·0891	34·93
	No. (4)	—	3·8316	—	7·2104	—	9·8914	2·2599	42·27
	No. (5)	—	3·8314	—	7·2120	—	9·8948	2·2148	41·21

In this model, the bow end is elliptical, the semi-transverse diameter being 10 feet 33 inches. The conjugate diameter 3·668 feet.

With a motive weight of	58·277lbs.	the velocity was	6ft.	per second
„	„	402lbs.	„	„	14·499ft.	„

But when the elliptical bow-end was reduced to two circular segments, then at the same velocities the motive weights were, respectively, 36·642 and 402 lbs., which shows that, at low velocities, a dividing-line of the form of a circular arc meets with less resistance than an elliptical one; but that, at a velocity of nine knots an hour, we can afford to have an elliptical dividing line without increasing the resistance, while the momentum is increased.

Numerous experiments proved that it was a very decided advantage when the water was made to divide in a vertical, instead of a horizontal direction, particularly in the stern.

Also it was found that, bodies when moved at a depth of six feet below the surface, experience less retardation than at the surface, *if the friction be excluded*, but the friction is very greatly increased. This is more particularly discernable if the bodies be very obtuse. A square plane, however, meets with more resistance at the depth of six feet, than at the surface. A plane of one foot square, moving at the rate of eight knots, meets with a resistance of 196·245 lbs.

Again, it is shown that when the length of the stern-end is nine times the half-breadth, then the minus pressure, or suction, is nearly imperceptible; but the friction on this length exceeds the friction and suction together on a shorter stern end.

The increase of friction, which is due to the augmentation of velocity, is a maximum at a velocity of 11 feet per second, and afterwards diminishes. The friction on an area of 77·16 feet, at a velocity of 13·527 feet per second, being 40·17. The friction on a surface of 50 feet, at different velocities, is exhibited in the following table, showing the results of two different sets of experiments:

Velocities per sec.	2	3	4	5	6	7	8	9	10	11	12	13.5
Friction	0·6142	1·338	2·323	3·56	5·039	6·757	8·709	10·89	13·3	15·931	18·779	23·54
	0·7101	1·588	2·795	4·357	6·237	8·442	10·97	13·81	16·96	20·424	24·195	30·576

In conclusion, it has been ascertained that the powers of the velocities, according to which the friction varies, are:

Velocities	2	3	4	5	6	7	8
Powers of velocity to which friction is proportional	1·82	1·80	1·78	1·76	1·74	1·72	1·71

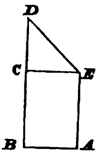
The *head-pressure* is always a little above the duplicate ratio of the velocity, but the ratio decreases as the velocity increases.

The *suction* is always less than the duplicate ratio, but this ratio increases slightly with the velocity.

The *whole resistance* is sometimes greater, and sometimes less than the duplicate ratio, according to the form of the body; but in most cases it is above the duplicate ratio at low velocities, and its ratio is less than the duplicate at high velocities.

CHAPTER III.

ON THE CALCULATION OF AREAS, VOLUMES, AND CENTRES OF GRAVITY.



LET $ABDE$ be a trapezium, of which the angles A and B are right angles. It is required to find the distance of the centre of gravity of the trapezium from the side AE.

Let the base $AB=m$, $BD=b$, $AE=a$.

Draw EC parallel to the base. Then AC is a rectangle, and ECD is a right-angled triangle.

Now the area of $AC=ma$

and the area of $ECD=\frac{m}{2}(b-a)$

and the distance of the centre of gravity of AC from the side AE is $=\frac{m}{2}$

That of the triangle from the same line is $=\frac{2}{3}m$.

Then, if the distance of the centre of gravity of the whole trapezium from AE be called $\bar{x}$, we have

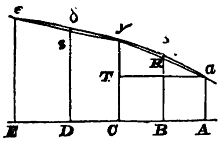
$$\left\{ma+\frac{m(b-a)}{2}\right\}\bar{x}=ma\cdot\frac{m}{2}+\frac{m}{2}\cdot(b-a)\cdot\frac{2}{3}m$$

or $$\frac{m}{2}(a+b)\cdot\bar{x}=\frac{m^2}{6}(a+2b)$$

$$\therefore\quad \bar{x}=\frac{m}{3}\cdot\frac{a+2b}{a+b}$$

The following are Attwood's rules for finding the centre of gravity of a vessel's displacement.

To calculate approximately the area contained by any curvilinear plane figure.



Let $A\,\alpha\,\beta\,\gamma\,\delta\,\varepsilon\,E$ be a part of the given curvilinear figure.

Draw αA, βB, &c., perpendicular to the line AE, and at equal distances from each other. Join $\alpha\gamma$, $\gamma\varepsilon$, and draw αT perpendicular to γC.

Let AB or BC, &c., be called $=m$. $A\alpha=a$; $B\beta=b$, &c.

Now, without any considerable error, we may suppose the portions $\alpha\gamma$, $\gamma\varepsilon$, &c., of the curve to be parabolic; AE being perpendicular to the axes of the parabolas. Then βB, δD, &c., will be diameters, and $\alpha\gamma$, $\gamma\epsilon$, double ordinates.

$$\text{Now, area } AR\gamma\beta = \frac{2}{3}\beta R \,.\, \alpha\gamma \sin \angle \beta R\alpha$$

$$= \frac{2}{3}\beta R \,.\, \alpha T$$

$$= \frac{2}{3}\beta R \,.\, AC$$

$$= \frac{2}{3}\left(b - \frac{a+c}{2}\right) . \, 2m$$

$$= \frac{4b - 2a - 2c}{3} \cdot m$$

$$\therefore \text{ area } A\alpha\beta\gamma C = \frac{4b - 2a - 2c}{3} \cdot m + \frac{(a+c)}{2} \cdot 2m$$

$$= \frac{a + 4b + c}{3} \cdot m$$

Similarly,

$$\text{area } C\gamma\delta\epsilon E = \frac{c + 4d + e}{3} \cdot m$$

Therefore, if A be the area of the whole curvilinear plane figure, we have

$$A = m \cdot \frac{a + 4b + 2c + 4d + 2e + \,.\,.\, + 4l + n}{3}$$

To find the distance from $A\alpha$ of the centre of gravity of the same figure.

The distance from $A\alpha$ of the centre of gravity of the trapezium $A\alpha R\gamma C$ is

$$=\frac{2m}{3}\cdot\frac{a+2c}{a+c}$$

and the distance from the same line of the centre of gravity of the parabolic segment is $=m$.

(For the whole surface of this parabolic segment may be supposed to be divided into elemental laminæ by chords parallel to $\alpha\gamma$; and each of these is bisected by $R\beta$.)

And if x_1 be the distance of the centre of gravity of $A\alpha\beta\gamma C$, we have

$$x_1\cdot\frac{a+4b+c}{3}\cdot m=\frac{2m(a+2c)}{3\ (a+c)}\cdot m(a+c)+$$
$$+m\cdot\frac{4b-2a-2c}{3}\cdot m$$

$$\therefore\ x_1\,(a+4b+c)=2m(a+2c)+m(4b-2a-2c)$$
$$=m(4b+2c)$$
$$\therefore\ x_1=m\frac{4b+2c}{a+4b+c}$$

Similarly, the distance from $C\gamma$ of the area $C\varepsilon$ is

$$x_2=m\frac{4d+2e}{c+4d+e}$$

and the distance, from $A\alpha$, of the same point

$$=m\frac{4d+2e}{c+4d+e}+2m$$

$$=m\frac{2c+12d+4e}{c+4d+e}$$

And the distance from *Aα* of the centre of gravity of the next similar area will likewise be

$$=m\cdot\frac{4e+20f+6g}{e+4f+g}$$

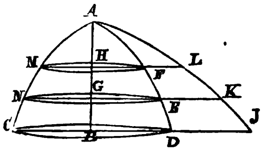
Therefore, the distance from *Aα* of the common centre of gravity of the whole curvilinear plane figure is

$$=m\frac{4b+4c+12d+8e+20f+\dots}{a+4b+2c+4d+2e+4f+\dots}$$

$$=m\frac{o\cdot a+1\cdot 4b+2\cdot 2c+3\cdot 4d+4\cdot 2e+5\cdot 4f+\dots+\overline{n-1}\cdot n}{a+4b+2c+4d+2e+4f+\dots+n}$$

$$=\frac{m^2}{3}\cdot\frac{o\cdot a+1\cdot 4b+\dots}{A}$$

Let *ACD* be the solid of revolution of the curve, *AC*, round its axis. Through any points *G*, *H*, in the axis, *AB*, draw *EGN*, *FHM*, perpendicular to the axis, and parallel to *CD*.



Through *A*, draw a curved line, *ALKI*, such that the ordinates may be proportional to the areas of the corresponding sections, perpendicular to the axis, in the solid of revolution.

Produce *MF, NE, CD* to meet the curve in *L, K, I,* respectively.

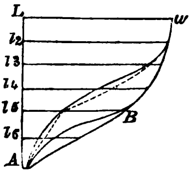
$$\text{Then,}\quad \frac{HL}{2\pi\,.\,\overline{HF}^2}=\frac{GK}{2\pi\,.\,\overline{GE}^2}=\frac{BI}{2\pi\,.\,\overline{BD}^2}$$

Then the area, *HBIKL,* expresses the solid contents of *MCDF;* and the distance of their respective centres of gravity from *A,* measured along the axis, *AB,* is the same.

In a similar manner, this proposition might be proved, if the given solid be not a solid of revolution.

To apply the above propositions to the calculation of the solid contents and centre of gravity of a vessel's displacement.

Let *ABWL* represent the immersed part of any of the sections in the body plan. *LW* being the



load-water-line. Draw other lines parallel to *LW,* and at equal distances apart; let that distance be m; and let the length of these lines be represented respectively by L, l_2, l_3, . . . &c.

And let the breadth at A be K, which is the half-breadth of the keel.

Then the area of,

$$ALW = m\frac{K + 4l_6 + 2l_5 + 4l_4 + 2l_3 + 4l_2 + L}{3}$$

In the same manner must be found the area of every other section in the body-plan.

If the curve should happen to be inflected between A, and the next water-line but one, as between A and the end of l_5; then we must draw a straight line from the end of l_5 to the outside of the breadth K, and produce l_6 to meet this line.

Then the area of that part of the section below l_5 becomes

$$(k + l_5)m - \frac{4l_6 - 2k - 2l_5}{3}m$$

$$= \frac{m}{3}(5k - 4l_6 + 5l_5)$$

Where l_6 is measured beyond the circumference of the section, to the straight line joining the extremities of K and of l_5.

And the whole area is

$$\text{Area } LAW = m \cdot \frac{5K - 4l_6 + 6l_5 + 4l_4 + 2l_3 + 4l_2 + L}{3}$$

$$\text{or,} \qquad = m \cdot \frac{K + 4l_6 + 2l_5 + \ldots + L + 4(K - 2l_6 + l_5)}{3}$$

If there be a contrary flexure extending from the extremity of l_3 downwards, we must draw a straight line joining the extremities of l_3 and l_5, and another between the extremities of l_5 and K, and the area of the section becomes

$$=m\left(K+l_5-\frac{4l_6-2K-2l_5}{3}+l_5+l_3-\frac{4l_4-2l_5-2l_3}{3}+\ldots\right)$$

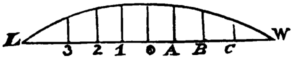
$$=\frac{m}{3}(5K-4l_6+10l_5-4l_4+6l_3+4l_2+L)$$

$$=\frac{m}{3}\left\{K+4l_6+\ldots+4l_2+L-4(K-2l_6+2l_5-2l_4+l_3)\right\}$$

where both l_6 and l_4 are measured out beyond the circumference of the section.

When the areas of all the sections in the body-plan have been found, the next operation which must be performed is, to make a similar calculation for the load-water-line. But, that the result may be the volume of the displacement, it is necessary to substitute, respectively, the areas of the immersed part of each section for the breadth of the section at the load-water-line.

Let the figure represent the load-water-line of



a vessel; $C, B, A, \phi, 1, 2, 3,$ being the several sections; and $A_c, A_b, \ldots.$ their areas respectively.

And let the draught of water aft be $=\mu,$
and that forward . . $=\nu$
So that the half area of a section of the
stern-post at L . . . . . $=k\mu,$
That of the stem at $W=$ $=k\nu,$

And let n be the distance between each section. Then if D be the displacement, we have

$$D=n\frac{k\nu+4A_c+2A_b+\ldots.+4A_3+k\mu}{3}$$

and the displacement in tons

$$=\frac{D}{35}$$

since 35 cubic feet of salt-water weigh 1 ton.

And the distance from L to the centre of gravity of the part abaft ϕ

$$=n\frac{o+1\cdot 4A_3+2\cdot 2A_2+\ldots.+4A_\phi}{k\mu+4A_3+\ldots.+A_\phi}$$

and the distance from W of the centre of gravity of the forepart

$$=n\frac{o+1\cdot 4A_c+2\cdot 2A_b+\ldots.+4A_\phi}{k\nu+4A_c+\ldots.+A_\phi}$$

therefore the distance from L of the centre of gravity of the forepart

$$=LW-\frac{o+1\cdot 4A_c+\ldots.}{k\nu+4A_c+\ldots.}n$$

$$=8n-\frac{o+1\,.\,4A_c+\ldots.}{k\nu+4A_c+\ldots.}n$$

Hence, if $\bar{x}$ be the distance of the centre of gravity of the displacement from L, we have

$$\bar{x}\,.\,\frac{k\mu+4A_3+2A_2+\ldots+4A_c+k\nu}{3}=$$

$$=\frac{k\mu+4A_3+2A_2+\ldots+A\phi}{3}\cdot\frac{o+1.4A_3+\ldots+4A_\phi}{k\mu+4A_3+\ldots+A\phi}\cdot n$$

$$+\left\{8-\frac{o+1.4A_c+\ldots+4A_\phi}{k\nu+4A_c+\ldots+A\phi}\right\}\frac{k\nu+4A_c+2A_b+\ldots+A}{3}$$

$$\therefore\ \bar{x}(k\mu+4A_3+2A_2+\ldots+4A_c+k\nu)=$$
$$=n\{o+1\cdot 4A_3+2\cdot 2A_2+\ldots+4A_\phi+$$
$$+8(k\nu+4A_c+2A_b+\ldots+A_\phi)-$$
$$-(1\cdot 4A_c+2\cdot 2A_b+\ldots+4A_\phi\}$$

$$\therefore\ \bar{x}=n\,.\,\frac{o+1.4A_3+2.2A_2+3.4A_1+4.2A\phi+5.4A_a+6.2A_b+7.4}{k\mu+4A_3+2A_2+4A_1+2A\phi+4A_a+2A_b+4A_c+k}$$

$$=\frac{n^2}{3D}\cdot(o+1\cdot 4A_3+2\cdot 2A_2+\ldots.)$$

If the number of sections happens to be even, then we must make the above calculations only for the part abaft the first section of the bow; then calculate the volume of the portion before that first section, and take the common centre of gravity of these two portions.

The rule for calculating the volume of displacement, and the centre of gravity of the same, is very simply deduced from the above.

To find the Displacement.

1. Calculate the area of the immersed part of each section in the body plan.

2. If the number of them be odd write them all in two columns alternately; which columns we will call *a* and *b*.

3. Multiply each in column *a* by 4, and each in column *b* by 2.

4. Write these products alternately in a third column *c*, so that in *c* the sections (multiplied alternately by 4 and 2) come in their own order.

5. Add up column *c*, and add together this sum, and also the areas of a section of the stem, and a section of the stern-post (viz.: $k\nu$, $k\mu$).

6. Multiply this sum by the distance between the sections, and divide by 3. The result is the volume of displacement.

The volume of displacement, divided by 35, gives the tonnage.

To find the Centre of Gravity of the Displacement.

7. Write at the top of column *c* the area of the section of the stem-post ($k\nu$); the other sections being written in their order, with the last section of the stern at the bottom.

8. Multiply each of these successively, beginning at the bottom, by the natural numbers 1, 2, 3, &c.

9. Multiply the sum of these products by the square of the distance between the sections, and divide by three times the displacement.

10. In this calculation it is better to use feet and decimals of feet for all measurements (instead of inches); the answer will then give the distance, in feet and decimals, of the centre of gravity from the point *L*, and all the trouble of the reduction of inches, square inches, and cubic inches, to feet, square feet, and cubic feet, is then dispensed with.

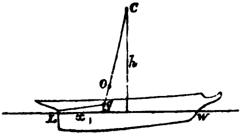
In some cases it may, perhaps, not be necessary to find the centre of gravity with any great accuracy. When this is the case, it may be found with great facility by the following method. Take a block model of the vessel, and suspend it to a string, by driving a nail into its upper surface at different places, until a point of suspension be found such that the load-water-line shall remain horizontal. This point is in the vertical through the centre of gravity of the displacement.

The volume of displacement can also be measured approximately, by pushing the model down with the hand, into a box *full* of water, until the model is sunk up to the load-water-line. The model is now removed. A quantity of water has been made, by this operation, to overflow out of the box. The quantity in the box before and after the experiment can be calculated, and the difference of these quantities, in decimals of feet, gives the volume of displacement of the model. The displacement of the ship is found by multiplying that of the model by the cube of their relative size.

We have now ascertained the position of the vertical line passing through the centre of gravity of the displacement; and we know that the centre of gravity of the whole ship, when loaded, is in the same vertical; and that the weight of the whole ship is equal to the weight of water displaced. It still remains for us to determine the quantity of ballast (or cargo and stores) necessary to bring the vessel down to her load-water-line; and the position of the centre of gravity of this ballast, in order that the centre of gravity of the whole ship may be at that distance above or below the surface of the water, which may be thought most desirable.

I. In the first place, then, we must find the centre of gravity of the whole hull. This is done by supposing the hull to be one homogeneous mass; and the centre of gravity of the real hull will be nearly in the same place. The required operation is performed in a manner exactly similar to that given for finding the centre of gravity of the displacement; except that the areas of the whole sections must be calculated, instead of merely that of the immersed part.

Let the centre of gravity of the hull be at G;



and let the distance of G, in a horizontal direction, from the aftermost part of the load-water-line be $=x_1$, and let the height of G above the water $= y_1$.

II. Secondly, we must make an estimate of the weight of the hull. Let it $=w$.

III. And, thirdly, we must find the weight and centre of gravity of the masts, spars, rigging and sails. Let the weight be w'; the height of the centre of gravity above the water $=h$; and its horizontal distance from the aftermost point of the load-water-line $=k$.

IV. Then the centre of gravity of the whole ship is thus found:

Let: Y be its vertical height above the water.
X its horizontal distance from the after-most point of the load-water-line.

Then:

$$X(w+w') = w.x_1 + w'.k$$
$$Y(w+w') = w'.h \pm w.y_1$$

The negative sign being used if G is below the surface of the water.

$$\therefore X = \frac{wx_1 + w'k}{w+w'}$$

$$Y = \frac{w'h \pm wy_1'}{w+w'}$$

And if T be the tonnage-displacement, and

$$T - (w+w') = \beta$$

then β is the required weight of ballast and stores.

And if the distance of the centre of gravity of the whole ship a-float, with ballast, &c., is to be $\pm H$ above the water; its distance from L, measured in a horizontal direction, being

$$\bar{x} = n.\frac{o + 1.4A_3 + 2.2A_2 + \ldots .}{k\mu + 4A_3 + \ldots .}$$

And if x', $-y'$, be the co-ordinates of the centre of gravity of the ballast, which it is required to determine, we have

$$T.\bar{x}=(w+w')X+\beta\cdot x'$$

$$\pm T\cdot H=(w+w')Y-\beta y'$$

$$\therefore\ x'=\frac{T\cdot\bar{x}-(w+w')X}{\beta}$$

$$=\frac{T\cdot\bar{x}-(w+w')X}{T-(w+w')}$$

$$y'=\frac{(w+w')Y\mp T\cdot H}{T-(w+w')}$$

which gives us the necessary weight and position of the ballast, in order that the centre of gravity of the ship, when afloat, may be at any point previously determined.

It is necessary to make some remarks on the nature of the hull and rigging, in order that the values of the quantities w, w', &c., may be found.

The weight of the timber of which the hull is composed may be reckoned, in round numbers, at 50 lbs. per cubic foot (White). The frames of the timbers are usually 2½ or 3 feet apart, in America (Griffiths). In England, they are sometimes as much as 3½ feet apart.

The size of the timbers may be estimated from the following table (extracted from one given by Mr. James Peake, of Woolwich) for a schooner of 180 tons.

	Sided.	Moulded.	
The floors, first and second futtocks	8 inches	6 inches	
Third futtocks . .	7 „	5 „	
Main keel . . .	8 to 12 inches thick		Moulded as per sheer-draught.
False keel . . .	6 inches	„	Moulded as per sheer-draught.
Main stem at head .	12 „	„	Moulded as per sheer-draught.
„ „ below .	8 „	„	Moulded as per sheer-draught.
Stern-post at head .	11 „	„	Moulded as per sheer-draught.
„ „ at keel .	8 „	„	Moulded as per sheer-draught.
Kelson	10 „	square	
Plank at bottom .	$2\frac{1}{2}$ „	thick	
„ wales . . .	4 „	„	
Deck beams . . .	8 „ sided	7 inches moulded	

Forty pounds of iron and copper fastenings, metal knees and stanchions, &c., may be reckoned on for every ton of displacement, if the vessel is square-fastened (two bolts in every timber).

The weight of spars and masts may be estimated at 40 lbs. per cubic foot. The average lengths of masts will be found at the end of the book.

The weight in lbs. of a hempen rope, per foot in length, is equal to the square of its circumference in inches, multiplied by 0·045.

The load in lbs. which a rope will bear with safety is equal to the square of its circumference in inches multiplied by 200. Hence, from the strength required, the size of rope can be determined, and thence its weight.

A table of the weight of chains will be found at the end.

In round numbers, ships from 5 to 800 tons weigh $\frac{2}{4}$ of their displacement; from 1000 tons and upwards they weigh about $\frac{1}{2}$ of their displacement. Iron vessels weigh about $\frac{1}{9}$ less than those of timber. (Griffiths).

As the draught only shows the inside of the plank, the vessel will actually displace more water than is found by the calculation which we have indicated. The following table of this increase is given by Griffiths. If the plank be oak, the displacement will be increased by

In a ship.	Schooner.	Smaller vessels.
$\frac{1}{18}$ to $\frac{1}{16}$	$\frac{1}{16}$ to $\frac{1}{14}$	$\frac{1}{13}$ to $\frac{1}{11}$

But if the plank be pine, which must be thicker than oak, it will be increased by

In a ship.	Schooner.	Smaller vessels.
$\frac{6}{90}$ to $\frac{6}{80}$	$\frac{6}{80}$ to $\frac{6}{70}$	$\frac{6}{60}$ to $\frac{6}{50}$

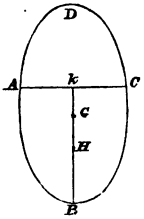
These tables of Griffiths will serve when we need not be very exact. In other cases the thickness of the plank must be delineated in the draught before calculating the displacement, and the weight of the rest of the materials must be accurately noted.

One of the best rules for calculating the tonnage displacement of a vessel in round numbers, was invented by Pook of Massachusetts. From 90° deduct the angle of the floor, (or degrees of dead-rise). Multiply by 0·0075, and the product is called the decimal for capacity. Multiply together the length, breadth, and depth, (from the rabbit to the load-water-line). This product multiplied by the decimal for capacity and divided by 35, gives the displacement in tons.

CHAPTER IV.

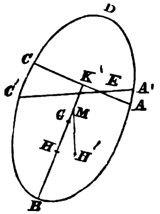
ON THE METACENTRE AND ON STABILITY.

Of the positions of equilibrium of a floating body some are stable, and some instantaneous. These must be carefully distinguished.



Let us first suppose that the floating body be perfectly symmetrical, as to form and density, on each side of the plane *ABCD*. Let *G* be the centre of gravity of the body, (which will be in the section made by the plane *ABCD*.) Let *AC* be the water-line when the body is in equilibrium; and *H* the centre of gravity of the volume of fluid displaced, (which will also be in this section, and will be in the perpendicular through *G* on *AC*). If the body be homogenous *H* will be below *G*; but, by ballast it may be brought above *G*.

Now let the body be turned a little round an



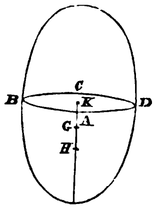
axis perpendicular to $ABCD$, and then left to itself without any initial velocity. The section $ABCD$ will always remain vertical, whatever motion the body may acquire, and will always contain the centre of gravity of the displacement. In this new position let $A'C'$ be the line of floatation, cutting AC in E; so that $\angle AEA' = \angle CEC'$.

Now, by a deduction from d'Alembert's principle, the centre of gravity G will move as if the mass of the body were there collected, and the weight of the body and the resultant pressure of the fluid there applied. But, as these two forces are equal and opposite, G has no motion to be considered. Let H' be the centre of gravity of the fluid displaced. This point will be in the section $ABCD$, but not in the same vertical as the point G. Hence the pressure of the fluid will tend to turn the body round an axis passing through G and perpendicular to $ABCD$; either tending to bring it back to its state of equilibrium or to turn it away still more.

Draw the vertical $H'M$, meeting BK in M. Then the pressure of the fluid acting along $H'M$, will tend to bring the body back to its original position if M be above G. And if G be below H', M must necessarily be above G; and the equilibrium is *stable*. If G is above H', M may either be above

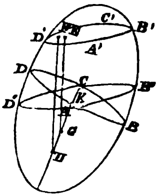
G or below it; in the former case, the equilibrium is stable; if the latter be the case, the original position is one of ***instantaneous*** equilibrium. M is the metacentre when the angle of inclination is indefinitely small.

Again let us consider a body in equilibrium at the surface of the water, in which $ABCD$ is the line of floatation:



Let M denote the mass of the body and V the volume of water displaced, so that if ρ be the density of the fluid

$$M = \rho V.$$



Let $ABCD$ be a little pressed under water while the body receives also a slight displacement so as to make $ABCD$ inclined to the horizon; and, to be quite general, let a small initial velocity be imparted to the particles of the body. The equilibrium will be disturbed; and the question is whether $ABCD$ will tend to return to its position of equilibrium by oscillating up and down. At any instant of the motion let $A'B'C'D'$ be the plane of floatation. Let $AB''CD''$ be a section parallel to $A'B'C'D'$, and passing through the centre of gravity of the section $ABCD$. Let θ

be the inclination of these two sections to each other, ζ the distance of $AB''CD''$ from $A'B'C'D'$. Both of these are variable quantities, and small at the beginning of the motion.

Let u be the variable velocity of an element dm of the body. The sum of the *vis viva* for each point will be

$$\int u^2 . dm$$

between limits. Hence, if ϕ be a function of co-ordinates dependent on the forces applied to the body

$$\int u^2 . dm = c + 2\phi \quad . \; . \; . \; . \; . \; . \; . \quad (1)$$

The forces on which ϕ depends are, the force of gravity acting on each element of the body, and the pressure of the fluid on the part immersed. Instead of this last force we may suppose a number of vertical moving forces, acting on each element of the body below the plane of floatation, and equal to the weight of water which it would displace.

Then if g represents the constant force of gravity; dv an element of volume corresponding to the element of mass, dm; then the moving force acting on dm is

$$g . dm - g\rho dv$$

if the element be below the plane of floatation; and

$$g . dm$$

if it be above water-mark. Hence we must have, if z be the variable distance of dm below the plane of floatation,

$$\phi = \int zgdm - \int zg\rho dv$$

the first integral extending all over the body; the second only over the part immersed. Let $GE = z_1$ then

$$\int zgdm = gMz_1.$$

Let the second integral be divided into two parts: the volume V below $ABCD$, and the volume between $ABCD$ and $A'B'C'D'$; and let k be the value of $\int zdv$ extending, in limits, over all the elements of this portion. Let z' be the variable distance of the centre of gravity of the volume V from the surface of the water $= HF$; then

$$\phi = gMz_1 - g\rho Vz' - g\rho k$$

now $\angle EGK = \theta$. Hence if $GH = a$ we have

$$z_1 = z' \pm a \cos \theta$$

The upper or lower sign being taken according as G is below or above H.

Hence

$$\begin{aligned}\phi &= gM(z' \pm a \cos \theta) - g\rho Vz' - g\rho k \\ &= \pm g\rho Va \cos \theta - g\rho k\end{aligned}$$

where k yet remains to be determined.

Let $ABCD$ be divided into elements $d\lambda$; the projections of these elements on $A'B'C'D'$ will be

$$d\lambda \,.\, \cos\theta$$

and if the volume between these two planes be divided into elementary cylinders with these projections for bases, and these cylinders be divided again by horizontal planes very near to each other, then the value of each of these latter elements will be

$$dv = dz d\lambda \cos\theta$$

now $\int z dv$ relatively to one cylinder

$$= d\lambda \cos\theta \times \int z dz$$
$$= \tfrac{1}{2} y^2 d\lambda \cos\theta$$

if y be the height of the cylinder

$$\therefore \qquad k = \tfrac{1}{2}\cos\theta \int y^2 d\lambda$$

the limits being those given by the area $ABCD$.

Now,

$$y = \zeta + l\sin\theta$$

if l be the distance of the element in question from AC, the intersection of $ABCD$ and $AB''CD''$; this quantity being positive or negative according as $d\lambda$ is above or below $AB''CD''$.

$$\therefore \qquad k = \tfrac{1}{2}\cos\theta(\zeta^2 \int d\lambda + 2\zeta\sin\theta \int l d\lambda + \sin^2\theta \int l^2 d\lambda)$$

Let $ABCD = \int d\lambda = b$. Now since the centre of gravity of this section is in AC

$$\therefore \quad \int l d\lambda = o$$

and let $$\int l^2 d\lambda = b\gamma^2$$

γ being a line dependent on the figure and extent of $ABCD$

$$\therefore \quad k = \tfrac{1}{2} b \cos\theta(\zeta^2 + \gamma^2 \sin^2\theta)$$

which is approximately the value of k if the body be only inclined and depressed in a small degree.

Hence by substitution in the value of ϕ and putting the exponential values for $\sin\theta$, and $\cos\theta$,

$$\phi = \pm g\rho Va \mp \tfrac{1}{2} g\rho Va\theta^2 - \tfrac{1}{2} g\rho b\left(1 - \frac{\theta^2}{2}\right)(\zeta^2 + \gamma^2\theta^2)$$

$$= \pm g\rho Va \mp \tfrac{1}{2} g\rho Va\theta^2 - \tfrac{1}{2} g\rho b(\zeta^2 + \gamma^2\theta^2) \text{ very nearly.}$$

Hence equation (1) becomes, if $c' = c \pm 2g\rho Va$

$$\int u^2 dm + g\rho\{b\zeta^2 + (b\gamma^2 \mp Va)\theta^2\} = c' \quad . \quad . \quad . \quad (2)$$

which is positive if $b\gamma^2 \pm Va$ is positive. And at the commencement c' is very small, depending on θ, u, ζ, which at the commencement of the movement are supposed to be very small, and hence the equilibrium of the body is stable if $b\gamma^2 \pm Va$ is positive.

Now $$b\gamma^2 = \int l^2 d\lambda$$

and must be positive, as all the elements are positive.

Hence if we take the positive sign to Va, that is if G is below H, the equilibrium must necessarily be stable. If G is above H we must have

$$b\gamma^2 > Va.$$

Now the magnitude of γ varies as the magnitude of AC which must always pass through the centre of gravity of $ABCD$. But in one position AC is least. Hence if we calculate γ for this position, we may be sure, if for that value $b\gamma^2 > Va$, that the equilibrium is stable.

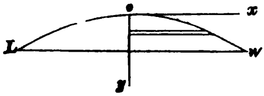
In a ship the line for which γ is least, and therefore $\int l^2 d\lambda$ is a minimum, is a line in the direction of the keel; or "the middle line" in the plane of the load-water-line. Hence we must find $\int l^2 d\lambda$ for the load-water-line; and in proportion as this is greater than the product of the volume displaced into the distance between G and H, so the equilibrium is stable.

If the water-line be a parabola with the origin at the greatest breadth, and the axis in the direction of that section (according to Mr. White's practice), and if

$$x^2 = my$$

be the equation to the parabola.

Then the area of the plane of floatation may be divided into elemented laminæ, $d\lambda = x \, . \, dy$, parallel to the middle line, around which the *vis viva* is taken.



And if b be the half-breadth of the vessel at the plane of floatation, and l the variable distance of each lamina from the middle line, LW, then,

$$l = b - y$$
$$= b - \frac{x^2}{m}$$

But from the equation to the parabola.

$$2xdx = mdy$$

$$\therefore \qquad d\lambda = \frac{2}{m} x^2 dx$$

and $$l^2 d\lambda = \left(b - \frac{x^2}{m}\right)^2 \cdot \frac{2}{m} x^2 dx$$

$$= \frac{2}{m^3}\left(mbx - x^3\right)^2 dx$$

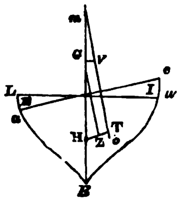
and $$\int l^2 d\lambda = \frac{2}{m^3}\int_0^{\sqrt{mb}} (mbx - x^3)^2 dx$$

$$= \frac{2}{m^3}\left\{\tfrac{1}{3}\overline{mb}\right|^{\frac{7}{2}} - \tfrac{2}{5}\overline{mb}\,|^{\frac{7}{2}} + \left.\tfrac{1}{7}\overline{mb}\,\right|^{\frac{7}{2}}\Big\}$$

$$= \tfrac{16}{105}\sqrt{mb^7}$$

But it must be remembered that the sum or difference, $\int l^2 d\lambda \pm Va$, is the measure of stability of a ship only when inclined at an indefinitely small angle; that is, it shows the power of a ship to resist the first instantaneous force of the wind. When the ship is inclined at a finite angle, other reasoning must be applied, in order to determine her stability.

Let $L\,W$ be the plane of floatation before inclination; $a\,c$ the plane of floatation when inclined; ϕ the angle of inclination; G the centre of gravity of the whole ship; H the centre of gravity of displacement previous to inclination; o the centre of displacement when the ship is inclined.



Draw $O\,m$ perpendicular to $a\,c$, meeting $H\,G$, produced in m. Draw $H\,T$ perpendicular to $O\,m$, and $G\,Z$ parallel to $O\,m$, and meeting $H\,T$ in Z.

Let the solids of immersion and emersion be I and E respectively. And let us suppose the whole weight of each collected at its centre of gravity. And for simplicity let $E=I$; and let the distance between the centres of gravity of E and I be $=b$.

Now, although it is the wind that in reality causes the inclination, yet the same effect would be produced if the weight of E were transferred to the other side, with the same moment.

And, therefore, the moment causing inclination is $I \cdot b$, or $E \cdot b$.

And, if D be the weight of the whole ship, or the displacement, then the moment tending to right the ship is

$$D \cdot G v.$$

For G is the centre of revolution of the whole ship. But

$$\begin{aligned} D \cdot Gv &= D\,(HT-HZ) \\ &= D \cdot HT - D \cdot HZ. \end{aligned}$$

But since O is the centre of the new displacement caused by passing E over to the other side

$$\begin{aligned} \therefore \quad b \cdot E &= D \cdot HT \\ \therefore \quad D \cdot Gv &= b \cdot E - D \cdot HZ \\ &= b \cdot E - D \cdot GH \sin \phi. \end{aligned}$$

If we suppose ϕ to be infinitely small, then m is the metacentre. And in this case, I and E may be considered to be infinitely small prismatic triangles. And the planes of floatation before inclination, and when the vessel is inclined, may be supposed to intersect in the *longitudinal* axis of the ship, which intersects the line GF (and the plane of the paper) at right angles.

Also, $$b = 2 \cdot \frac{2y}{3} = \frac{4y}{3}$$

(if $y = \frac{1}{2} LW$.)

Let $$CW = aL = \phi$$

Then the elementary triangles of the prismatic solids, E and I, are

$$\frac{1}{2} y\phi dx$$

If the axis of x be the longitudinal axis of the ship, in the plane of floatation.

Hence, the moment of one of these elementary triangles

$$= \frac{1}{2} \phi y \, . \, dx \times \frac{4}{3} \cdot y$$

$$= \frac{2}{3} y^2 \phi dx$$

And, $$b \,.\, E = D \,.\, HT$$

$$= \frac{2}{3} \int y^2 \phi \,.\, dx$$

but, $\varphi : y :: HT : Hm$ (by similar triangles.)

$$\therefore \quad \phi = \frac{HT}{Hm} \cdot y$$

$$\therefore \quad D \,.\, Hm = \frac{2}{3} \int y^3 \, dx$$

and $$HM = \frac{2}{3D} \cdot \int y^3 dx$$

From the foregoing calculation we find that the equilibrium is stable if

$$Hm > HG$$

or if $$\frac{2}{3 \cdot D} \int y^3 \,.\, dx > HG$$

or if $$\int y^3 dx > \frac{3}{2} HG \,.\, D$$

But from page 67 we find that the equilibrium is stable if

$$\int l^2 d\lambda > D \,.\, HG$$

or if, as above, we suppose the plane of floatation to be the plane of xy, the axis of x being parallel to the longitudinal axis of the ship, and the axis of y being transversely to the length of the ship, the origin being in the line HG; then l becomes y, and $d\lambda$ becomes ydx,

$$\therefore \quad \int l^2 d\lambda = \int y^3 . dx$$

Hence, the equilibrium is stable, also, if

$$\int y^3 . dx > D . HG$$

Comparing these results, we find that the meta-centre may be below G, and yet the equilibrium remain stable, provided that

$$Hm > \frac{2}{3} HG.$$

We may here remark that the stability depends upon the lowness of the centre of gravity of the ship, and the height of the centre of displacement; and also (in order that m may be high) on the breadth of the load-water-line. This will be made more clear by what follows.

We will resume the former expression for the moment producing stability, when the ship is inclined through a finite angle

$$D . GV = b . E - D . GH \sin \varphi$$

Now let us suppose that, in the half breadth plan, the lines representing the vertical sections are produced and made proportional to the areas of those sections respectively; and let a curve be drawn through the extremities of these lines. Then, with the same rectangular axes as before, we have

$$D = K\int y dx,$$

(where K is some constant by which the areas were divided, so that the line representing each area respectively equals $\frac{\text{area}}{K}$; and y, in this instance, extends over the whole of the latter curve.) Also

$$b.E = \frac{2}{3}\phi\int y^2.dx$$

$$\therefore \quad D.GV = \frac{2}{3}\phi\int y^2 dx - K.GH \sin \phi\int y dx$$

where the first integral extends over the load-water-line alone, and the second over the whole area contained by the other curve.

Hence we see that, in order for the stability to be great, we must have $\int y^2 dx$ as great as possible, and the negative term as small as possible; or the area of the load-water-line must be as great as possible, the centre of gravity of the whole ship very low, and the vessel's bottom as lean as possible. This is a very curious result, and contrary to the almost universal assumption of ship-builders. But it will not astonish us if we consider the direction of the supporting efforts of the water at different heights along the surface of the vessel, and the moments of these efforts. These moments being much greater in the vessel with the lean bottom; and nearly all of them tending to bring the vessel back to her original position, which is not the case when the bilge is fuller.

It has been a matter of wonder, why the flat-bottomed coasting vessels of America should be so much stiffer than their other vessels (*vide* Griffiths); but the above fact quite explains the phenomenon.

We see, hence, that it would be a good plan to build small sailing-boats very shallow, and with a very straight floor, forming an angle of at least 60°, with the plane through the stern-post and keel. And, in order to prevent them from being leewardly, a lee-board could be provided, with a tackle to keep that lee-board vertical when the vessel is inclined.

A good practical mode of ascertaining the relative values of $\int l^2 d\lambda$ in different vessels, would be to make a model of half the water-line, and make it oscillate around the middle-line *WL* (which must be quite horizontal); and the time of a single oscillation must be found by counting the number of oscillations in one minute. Let the time of an oscillation be t' seconds, suppose

(t' being a small fraction). And if G be the centre of gravity of the surface, and $\bar{y}$ its distance from the line WL, and if L be the length of pendulum corresponding to that time, then

then, $$L=\frac{\int l^2 d\lambda}{\bar{x}\,.\int d\lambda}$$

and, $$t'=\pi\sqrt{\frac{L}{g}}$$

$$=\frac{\pi}{\sqrt{g}}\cdot\sqrt{\frac{\int l^2 d\lambda}{\bar{x}\,.\int d\lambda}}$$

$$\therefore\quad \int l^2 d\lambda=\frac{t'^2 g}{\pi^2}\cdot\bar{x}\int d\lambda$$

where $\int d\lambda$ is the area of the semi-water line; and $\frac{g}{\pi^2}=3{\cdot}26$. But this gives us only the stability of a vessel the size of the model: unless the quantities $\bar{x}$ and $\int d\lambda$, are measured by the scale for the whole vessel. And, in this case, t' must also be calculated for the full-sized water-line. The time, t, of an oscillation of a load-water-line the full size of the vessel, is thus deduced from t'. Let the dimensions of the vessel be m times that of the model, then

$$t=\frac{\pi}{\sqrt{g}}\cdot\sqrt{\frac{\int k^2 dK}{x_1\int dK}}$$

Where $k^2 = m^2 l^2$ and $\int dK = m^2 \int d\lambda$

Also, $x_1 = m\bar{x}$

$\therefore \quad t = \sqrt{m} \cdot t'$

And for the whole vessel

$$\int k^2 . dK = \frac{g}{\pi^2} \ t^2 . x_1 \int dK.$$

The stability of a vessel depends upon the difference between this quantity, and the product of the volume of displacement into the distance between the centre of gravity of the ship and that of the displacement. But for general comparison, the calculation of this quantity will be sufficient; if it be borne in mind that the same value for this quantity represents a greater amount of stability in a vessel which is lean below, than in one which is narrower and full below.

Again we observe that if the stability and area of canvass for a vessel of a certain size be calculated; then the stability of a vessel, built on the same lines, but to a scale which makes her n times as great, will be increased in a much greater ratio. For let the stability of the former be $\int l^2 d\lambda - Va$

(where $\int l^2 d\lambda = \frac{t^2 g}{\pi^2} \cdot \bar{x} \int d\lambda$)

and the area of the sails $= A$ square feet.

Then if the stability of the larger vessel be $\int L^2 d\Lambda - \Upsilon\alpha$.

$$\text{where} \qquad \int L^2 d\Lambda = \frac{T^2 g}{\pi^2} \cdot \overline{X} \int d\Lambda$$

and $T^2 = nt^2$; $\overline{X} = n\overline{x}$; $\int d\Lambda = n^2 \int d\lambda$; $\Upsilon = n^3 V$; $\alpha = na$

Therefore the expression for the stability is increased n^4 times while the area of canvass which would be given to her, if the sail-draught were measured by the same scale, would be increased only n^2 times.

But the height of the centre of effort of the sails is increased n times, and therefore the moment of the sails is only increased n^3 times while the stability has increased n^4 times. And hence the sail-draught should be measured by such a scale that the area of the sails be increased n^3 times. Or the scale instead of being a $\frac{1}{n}$th scale should be a $\frac{1}{n^{\frac{3}{2}}}$th scale.

For the same reason small boats, having so much less stability in comparison to large ones, and yet being furnished with a disproportionate area of canvass, meet with so many accidents.

And hence also the advantage of a large vessel; for the resistance increases as the square, the propelling force as the fourth power, and the momentum as the third power.

Again, if the centre of gravity of the area of the load-water-line be not in the same vertical section as the centre of gravity of the displacement, but before it; suppose, then $\int l^2 d\lambda$ limited to the portion of the load-water-line behind the centre of gravity of the displacement is not so great as the same expression limited to the rest of the area. Or the vessel is not so much supported against heeling in the after as in the fore part. Hence her stern will both be depressed, and fall off from the wind.

CHAPTER V.

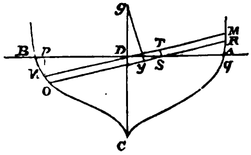
ON UNEASY MOTION AND ROLLING.

When a ship is inclined, she revolves round her centre of gravity. Then a part of the ship is immersed, which was formerly out of water, and a part is emersed, which was formerly below the surface. The solid immersed may consequently be of a different form from that emersed. Now there are two things to be remarked as possibly taking place co-instantaneously with this motion :

1. If the centre of gravity of the part immersed, and that of the part emersed, be not in the same vertical transverse section of the ship, then the centre of gravity of the new displacement is either before or abaft of the centre of gravity of the ship ; and either the bows or stern are raised. The axis of rotation of the ship is, in fact, inclined to the

longitudinal axis of the ship; the latter axis being parallel to the surface of the water.

(2). If the solid of immersion be greater than that of emersion, the centre of gravity of the ship will be raised in space as the vessel is inclined, and will fall again as she rights herself. As this makes a ship very uneasy, we will consider the conditions under which it does not take place.



Let G be the centre of gravity of the ship. AB the water-line when she is upright. Through G draw GC perpendicular to AB, cutting AB in D; and from G draw Gy, making $\angle CGy$ equal to the angle of inclination. Take $GY = GD$, and through Y draw OR perpendicular to GY. Then as G is not to rise or fall during the inclination, OR must be the new water-line. Let OR intersect AB in S. Through D draw NM parallel to OR; and draw Np, Mq, perpendicular to AB, and ST perpendicular to MN.

Then, if we suppose that the centre of gravity of the solid of emersion, and that of the solid of immersion are in the same transverse section, we must have the line DS the same in every transverse section; or the intersection of the two planes of floatation is a straight line parallel to the longitudinal axis of the ship.

Again, we have the solids of immersion and emersion equal.

$$\therefore \text{ volume } BSO = \text{vol. } ASR$$
$$= A \text{ suppose.}$$

And
$$ADM = ASR + RSDM$$
$$BDN = BSO - NDSO$$

$$\therefore ADM - BDN = RSDM + NDSO$$
$$= NORM$$
$$= MN \cdot DS \sin \angle \text{ incl.} \quad \text{nearly.}$$

$$\therefore DS = \frac{ADM - BDN}{MN \sin \angle \text{ incl.}}$$

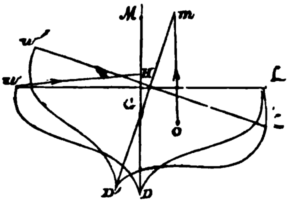
$$= \frac{ADM - BDN}{Np + Mq}$$

This gives the line of intersection of the two planes of floatation upon the supposition that the two solids with their apexes along this line are equal. If on calculation, however, they are found not to be so, it will be necessary to make an alteration in the form of the vessel.*

We must now proceed to determine the most suitable position for the centre of gravity of the whole ship.

Let *WDL* be a transverse section of a ship;

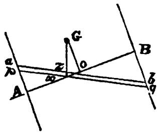
* This calculation is from the Encycl. Britt.



LW being the water-line. *G* the centre of gravity of the ship, about which the rolling takes place. *M* the metacentre; *m* the point where a vertical through the centre of displacement *o*, when the vessel is careened through a given angle, meets the middle line *DGm*. (Perhaps, for the sake of brevity, we may be allowed to name this point antimetacentre). *W'L'* the water-line when the vessel is inclined.

Let *WH* be the direction of the force which causes rolling (which is perpendicular to the side, and near the surface of the water). The moment of this effect is in proportion to *GH*. And the moment of the force tending to right the ship is in proportion to *Gm*. We will suppose that the solids of immersion and emersion are equal, so that *G* neither rises nor falls. Rolling is caused by the inequalities in the surface of the water, and takes place chiefly when the wind is about aft, having previously blown from another quarter; in other words, when there is a cross sea. It sometimes extends to as great an angle as 30° on either side. Now, if *G* be on the load-water-line, the rolling will be less severe, because then *GH* will be smaller, and the moment of the force which makes her roll will be less. And in this case, if the figure of the vessel be made similar for nearly 30° both above and below the load-water-line (the centre of the circle being in the middle point of the line *LW*), then we shall attain two objects at once: the solids of immersion and emersion will be equal, and the direction of *WH* will be along the line *WL*. A third object will also be attained by raising the centre of gravity of the ship as high as the load-water-line; the keel and lower parts of the vessel, fore and aft, are the "cleanest," and consequently their surfaces offer the most direct resistance to rolling; and as these will be further from the centre of rotation, the moments of their resistance will be increased. But yet, on the other hand, the stability will be somewhat less than if the centre of gravity were lower.

Even if the sides be of such a form amidships that the tangents to the surface at the level of the water on both sides of the ship are parallel, yet the solids of immersion and emersion will not really be equal, because the bows and stern cannot have this



form at the load-water-line. Hence the centre of gravity must rise a little. Let that quantity be z, for a very small inclination. As the inclination is very small, we may measure the arc of the angle of inclination on the tangent plane instead of on the surface itself. Now, suppose a ship which is *perfectly* similar, fore and aft, for as great an arc above and below the load-water-line; *then* if the centre of gravity were in AB, it would neither rise nor fall. But let it be above AB, at such a distance, $GO=y$, so that the centre of gravity, when the vessel is inclined, shall fall a distance equal to k.

Through G draw $Gx=GO$ and making $\angle OGx=$ the angle of inclination. Through x draw pxq perpendicular to Gx: through O draw ab parallel to pq.

Then, $$\triangle AaO=\triangle BbO$$

therefore the solids of immersion and emersion are equal, and ab is the new water-line.

Let ab cut Gx in Z.

Then the centre of gravity has fallen a distance

$$xZ=k$$

But since $$GO=Gx$$

$$\therefore \quad \frac{xZ}{GO}=\text{vers: angle of inclination}$$

$$\text{or} \quad k=GO.\times\text{vers}:\angle\text{ of incl.}$$

$$=y.\text{vers}:\ \angle\text{incl.}$$

which will be the proper height for the centre of gravity to make the rolling a minimum.

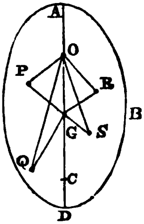
If the sides are not parallel at the load-water-line, but "tumble in," then the centre of gravity may be lower than the surface of the water, for rolling to be as little as possible. If on the contrary the sides lean out above the water, the centre of gravity must be higher.

With regard to the proper longitudinal position of the centre of gravity of the ship and of the displacement, it is evident that the middle point of the ship's length is the best. Because in that position the vessel will be the most prompt in coming round. For the resistance from the water which the two extremities experience, when the ship is coming about, is as the squares of their distances from the centre of rotation. And this is a minimum when the centre of rotation (which is the centre of gravity) is in the middle of the length. In the 'America,' the centre of gravity (which is at the partners of the mainmast), is, I should imagine, too far aft for her to come about freely; I should think the impulse of the water against her clean bow, and with such a long lever, must make her fall off with difficulty after being in stays.*

Recurring to the figure of p. 83. It is evident that the rolling is stopped by a force equal to the displacement, acting at *O* (the centre of displace-

* The above theorem is from Chapman.

ment) in a direction *Om*. This force is constant, but its moment increases with the angle of inclination. As the vessel oscillates round *G* with this constant force acting at *m*, there is an analogy to a pendulum, of which *G* represents the point of suspension, and *m* represents the centre of gravity of the pendulum, at which the force of gravity constantly acting accelerates the fall, and retards the ascent of the pendulum.



Let *ABD* be a plane without weight. And suppose several weights, *P, Q, R, S,* fixed in that plane; *G* being their common centre of gravity, and *O* being the point of suspension of the plane, and *C* the centre of oscillation.*

Then the length of the pendulum is *OC*, and

$$OC = \frac{P \,.\, OP^2 + Q \,.\, OQ^2 + R \,.\, OR^2 + S \,.\, OS^2}{OG(P + Q + R + S)}$$

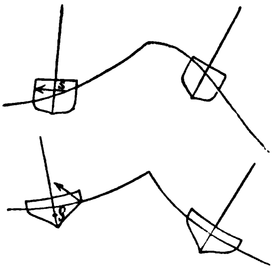
Hence the length of the pendulum is greater the further the weights are from *O*, and the nearer *G* is to *O*. Hence, if the analogy be true, the rolling will be less severe the further the ballast is moved *towards the sides* away from the centre of gravity. This last condition may be deduced from the inves-

* From Chapman.

tigation in p. 83, and shows that the conditions for slowness in rolling, and those for stability, are contrary to each other. In some vessels, as large men-of-war, it is necessary to decrease rolling; in others, as racing yachts, stability is far more requisite. (Chapman says, that for men-of-war, the metacentre need not be more than six feet above the centre of gravity, but should not be less; also Boguer, Clairvoie, Inman.)

It may be well to remark, that twenty-one tons of the 'America's' ballast were winged up as recommended above.

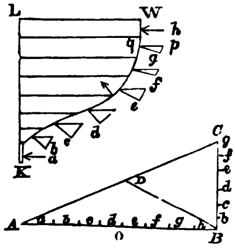
This figure represents the conduct of two vessels with different forms of midship section; the one rolls less violently and is less stable; the other has great stability, and it is her constant straining to keep perpendicular to the surface of the water, which makes her roll so much after the shock of each wave on her side. This endangers the masts, but the sea is less likely to break over her. The former, in consequence of her lack of stability, will roll less, but can also carry less canvass.



CENTRE OF LATERAL RESISTANCE.

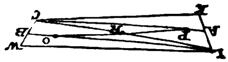
The centre of gravity of that part of the plane section in the sheer-plan, which is below the load-water-line, may be considered as the centre of lateral resistance. But the centre of lateral resistance is in reality the centre of effort of all the forces on the ship's side, which prevent her from moving in a direction at right angles to her course. The resultant of these forces will take an upward direction, and should pass through, or a little above, the centre of gravity of the ship. We may find the direction of this resultant by taking, at the circumference of each section, the resultant of all the horizontal forces acting in a transverse direction to the ship's motion, and then finding the resultant of all these resultants.

The former of these operations is thus performed: divide the middle line, *LK*, of each section into a certain number of equal parts. Through these points of division draw lines parallel to the load-water-line, which will cut the circumference in portions each inversely proportional to the sine of the inclination of that



portion to the water-line. Hence the whole transverse force, resolved horizontally, which acts on each of these portions, may be considered equal, and acting at the middle point of each portion in a direction parallel to the water-line. Now draw at the middle points of these portions of the circumference lines parallel to the water-line, and equal to each other, as *pq*, to represent the horizontal parts of these forces. Also at the same points draw normals to the circumference as *qg*; and from the extremities of the lines representing the horizontal forces, let drop perpendiculars on the normals, as *pg*. Then the portion of the normal thus cut off represents the actual force which acts on each portion (*i. e.*, the pressure multiplied by the sine square of the angle of inclination). Now, to find at what point the resultant acts, take a line *AB*, parallel to *LW*, and lay off along it portions equal to the forces *qg*, &c., so that the line *AB* is equal to the sum of these normals. Let *O* be the middle point of this line, then the position of *O* indicates the point at which the resultant acts (*i. e.*, in the figure between *e* and *d*). To find the direction of the resultant, draw *BC* perpendicular to *AB*, and equal to the sum of the perpendiculars on the normals, as *pg*. Join *AC*, bisect *AC* in *D*, join *BD*. Then *BD* is the required direction. This operation must be performed for each section. Then the resultant of all these resultants must be found in the same way. These might have been done in the common method of calculation; but this operation is more quickly performed with the protractors and square, than by calculation; and as the common way is well known, we preferred mentioning this method. If it is not required to find the centre of lateral resistance with great accuracy, we may find it on the sheer-plan, by supposing the immersed part of the vessel to be a plane, and finding its centre of gravity.

Let *LKCW* represent the immersed part of the vessel. Join *LC*, bisect *LK* in *A*, and *CW* in *B*. Join *CA* and *LB*. In *AC* take *P*, so that $AP = \frac{1}{3} AC$; similarly let $OB = \frac{1}{3} LB$. let the area of $LCK = A'$, that of $CLW = B'$. Join *PO*, and in *PO* take *R*, so that



$$A' : B' :: OR : PR$$

Then is *R* the centre of gravity of the plane, *LKCW*.

It may be found experimentally by sinking a model up to its load-water-line in a trough of water, and drawing it along in a lateral direction by a string fixed to a little pin driven in the side. The bearings of the head of the model, both before and after drawing it transversely, must be taken;

and the pin must constantly be altered and moved towards the end of the model, which, by the bearings taken, is found to have moved most slowly, until such a point of traction is found, that the model can be drawn slowly, in a lateral direction, to any distance without the bearings being altered.

If the centre of lateral resistance does not lie in the same vertical transverse section as the centre of gravity, then the stem-post, keel, and stern-post must be altered to make it do so. For if it be not in the same tranverse section as the centre of gravity, it will act as a couple in turning the vessel round the vertical axis through the centre of gravity of the ship. If it lie in the same transverse section as the centre of gravity, but cut the vertical line drawn through the centre of gravity, somewhere below the centre of gravity then it will decrease the vessel's stability. If it were brought above the centre of gravity, by lessening the depth of the keel, it would increase the stability.

CHAPTER VI.

ON RESISTANCE.

BEFORE we enter on any investigations about the resistance offered by the fluid to the progress of the vessel, it will be necessary to state two or three preliminary facts.

1. The direction of an impulse is normal to the impelled surface; or the direction of a resistance is perpendicular to the surface, against which the resistance takes place.

2. In theory, resistance varies as the squares of the velocities of the body resisted. Thus, if one horse draw a vessel through the water at the rate of one mile per hour, it would require a hundred horses to draw the same vessel at the rate of ten miles an hour. Similarly, a great increase of canvass produces a very small increment in speed.

Likewise also a wind which travels at the rate of three miles per hour is scarcely felt; at six miles it is a pleasant breeze; at twenty a gale; and at sixty miles a great storm. For the same reason, slow ships suffer more in a sudden "lump of wind" than vessels which are easily propelled.

The law which we have just stated is theoretically true, and is nearer the fact than any other law which can be stated; and it is therefore used in all calculations. But in practice it is not *quite* correct.

3. In theory it is also proved that resistances vary as the squares of the sines of the angles of incidence; but this is not found to be quite the case in practice, as the following table will demonstrate.

Angle of incidence.	Resistance by theory.	Resistance by experiment.
9° 44′ 10″	24·71 lbs.	30·67 lbs.
14 28 10	37·06	35·34
19 25 15	49·42	41·71
30 0 0	74·13	51·44

But nevertheless, in all calculations we are compelled to assume the theory as correct.

4. The resistance of a fluid varies as the depth. For although the several particles of the fluid strike with the same force against the body (the velocity

being the same), yet at a greater depth more particles meet the body, on account of the greater density of the fluid. Thus, if a parallelopiped be moved at the rate of two miles per hour at a depth of 6 feet below the surface, it will require $\frac{10}{11}$ more motive power than was necessary to move it at the same rate when close below the surface. But yet, if the velocity be increased to six miles per hour, it will require only $\frac{7}{29}$ more motive power at the depth of 6 feet than at the surface.

5. When a vessel is at rest, the pressure before and behind, and on all parts at the same depth is equal. But when put in motion, the pressure is increased in front and diminished behind. There is, in fact, at certain velocities, dependent on the form of the vessel, a negative pressure or suction acting on the after body. And in the calculation of the whole resistance to a vessel, it is necessary to take this suction into account, as well as the increase of pressure forward. If tapering spars are towed in smooth water, it is found more difficult to start them when the butt-end is foremost, than when the small end is first; but it requires *less* power to keep them in motion. This is still more apparent at high velocities. The reason is, that there is less suction on the small end than on the

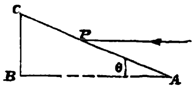
butt; and the direct resistance forward appears, therefore, of less account than the suction aft.

6. The cause of resistance is threefold: the friction of the water against the ship's sides; the cohesion of the particles of water to each other, which must be overcome; and the capillary attraction to the sides of the vessel. With regard to the last of these, it would be well to say a few words in explanation: If a drop of water be rubbed on the surface of a solid, it will wet that surface, and cannot be made to roll off in globules like mercury, for instance. This shows that the particles of water, experience a greater attraction for the particles of a solid than they have between themselves. Because of this it is, that wine or water in a glass rises higher at the sides than towards the middle; and if, instead of a tumbler, we use a tube of less than $\frac{1}{20}$th of an inch in diameter, the water will run up into it for some distance, and the height to which it will mount increases as the diameter of the tube decreases. From this last phenomenon, the attraction of the particles of fluid for those of a solid, has been termed capillary attraction.

The friction and capillary attraction of the water must, however, in the subsequent calculations, be altogether neglected.

The following papers on the solid of least resistance, are by the Rev. H. Goodwin.

In the case of a right-angled triangle, which is drawn through the water with a certain velocity, in the direction BA; let v be the velocity of motion, then the velocity normal to AC is $v \sin \theta$.

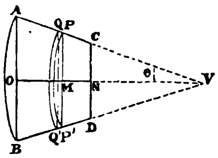


$\therefore$ the resistance at any point $\propto v^2 \sin^2\theta$

$\therefore$ the whole resistance in a direction normal to $AC \propto AC \cdot v^2 \sin^2\theta$

$\therefore$ the resistance in the direction of the motion
$\propto AC \cdot v^2 \sin^2\theta \cdot \sin\theta$
$\propto BC \cdot v^2 \sin^2\theta$

To find the frustum of a cone of given base and given height, for which the resistance is a minimum.*



Let AOB be the diameter of the base, $AO=r$; $ON=h$, the given height. And let θ be the required semi-angle of the cone.

Let us consider the resistance upon an annulus $PQP'Q'$. M the centre of the annulus. $MN=x$; dx the breadth of the annulus.

* Newton's prop.

The area of this annulus $=2\pi\,.\,PM\,.\,PQ$

$\therefore$ the resistance $\propto 2\pi PM\,.\,PQ \times v^2 \sin^2\theta\,.\,\sin\theta$ (as before).

and, if V be the vertex of the cone,

$$PM = MV \tan\theta$$
$$=(OV-OM)\tan\theta$$
$$=(r\cot\theta-h+x)\tan\theta$$

$\therefore$ the resistance

$$\propto 2\pi(r\cot\theta-h+x)\tan\theta \times dx\sec\theta\,.\,v^2\sin^3\theta$$

and the whole resistance on the curved surface

$$\propto 2\pi v^2\sin^2\theta\tan^2\theta\int_0^h(r\cot\theta-h+x)dx$$

$$\propto 2\pi v^2\sin^2\theta\tan^2\theta\left\{(r\cot\theta-h)h+\frac{h^2}{2}\right\}$$

and resistance on the flat end CD

$$\propto v^2\,.\,\pi CN^2$$
$$\propto \pi v^2(r\cot\theta-h)^2\tan^2\theta$$

$\therefore$ the whole resistance

$$\propto \tan^2\theta\left\{(2hr\cot\theta-h^2)\sin^2\theta+(r\cot\theta-h)^2\right\}$$

$$\propto \tan^2\theta\left\{r^2\cot^2\theta-(2hr\cot\theta-h^2)\cos^2\theta\right\}$$

$$\propto r^2-(2hr\cot\theta-h^2)\sin^2\theta$$

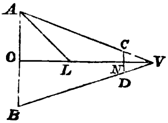
$$\propto r^2-hr\sin 2\theta+h^2\,.\,\frac{1-\cos 2\theta}{2}$$

This is to be a minimum

$$\therefore \quad hr \cos 2\theta - \frac{h^2}{2} \sin 2\theta = o$$

$$\text{or,} \qquad \tan 2\theta = \frac{2r}{h}$$

Newton gives this construction:



Bisect the given height ON in L. Make $LV = AL$ and join AV.

In this case we have

$$\tan 2\theta = \tan 2 \cdot AVO$$
$$= \tan (LAV + AVO)$$
$$= \tan ALO$$
$$= \frac{AO}{OL}$$
$$= \frac{2r}{h}$$

Let us consider what the angle of the cone becomes when the height is indefinitely small.

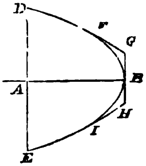
In this case $h = O$

$$\therefore \tan 2\theta = \infty$$
$$2\theta = 90°$$

or $\theta = 45°$ and $ACN = 135°$.

Taking the geometrical view, L coincides with O, and $OA = OV$, $\therefore$ $AVO = 45°$.

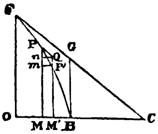
Hence follows the very curious proposition which Newton has given, and which he suggests may be useful to ship-builders.



Let a solid be generated by the revolution of the oval DBE about its axis AB.

Let GBH be the tangent at the vertex B, and let GF, HI be tangents to the oval such that FGB, IHB each $= 135°$. Then the resistance upon the solid generated by the figure $DFGBHIE$ revolving about AB, will be less than that met by the original solid.

To prove this we must draw part of the preceding figure on a large scale.



Let PP' be two adjacent points; and let res : PP' signify the resistance upon the annulus generated by the revolution of PP'. And let $R =$ res. FB, $R' =$ res. $FG +$ res. GB.

Then we have to prove that $R > R'$.

Draw PQ parallel to FC, and the ordinates MP, $M'P'Q$; and draw Qn, $P'm$ perpendicular to PM.

Then by our preceding proposition we know that

$$\text{res. } PP' > \text{res. } PQ + \text{res. } QP'.$$

$\therefore$ if we can shew that the sum of all the res. PQ + res. QP', is greater than R', then *à fortiori* R will be $> R'$.

$$\text{Now, res. } PQ \propto 2\pi \,.\, PM \,.\, PQ \,.\, v^2 \sin^2 45° \,.\, \sin 45°$$

$$\propto \pi v^2 \,.\, PM \,.\, MM'$$

$$(\text{because } PQ \sin 45° = Qn = MM')$$

and $$\text{res. } QP' \propto 2\pi \,.\, P'M' \,.\, QP' \,.\, v^2$$

$$\propto 2\pi v^2 \,.\, PM\,(Pm - Pn)$$

$$(\text{for } PM = P'M' \text{ ultimately})$$

$$\propto 2\pi v^2 \,.\, PM\,(Pm - MM')$$

$$\therefore \text{res. } PQ + \text{res } QP' \propto \pi v^2\,(2PM \,.\, Pm - PM \,.\, MM')$$

$$\propto \pi v^2\,(2ydy - ydx)$$

$$(\text{if } BM = x,\ \ MP = y)$$

$\therefore$ whole sum of

$$\text{res. } PQ + \text{res. } QP' \propto \pi v^2\,(y^2 - \textstyle\int ydx)$$

$$\propto \pi v^2\,(FO^2 - \text{area } FOB).$$

Again, by putting $\theta = 45°$ in our general expression for the resistance on a cone, we have

$$R' \propto \pi v^2 \left\{ FO^2 - FO \, . \, OB + \frac{OB^2}{2} \right\}$$

but $$FO \, . \, OB - \frac{OB^2}{2} = OB \left\{ \frac{FO + FO - OB}{2} \right\}$$

$$= OB \cdot \frac{FO + OC - OB}{2}$$

$$= OB \cdot \frac{FO + BC}{2}$$

$$= OB \cdot \frac{FO + BG}{2}$$

$$= \text{area } FOBG$$

$$\therefore \quad R' \propto \pi v^2 \, (FO^2 - \text{area } FOBG)$$

Now, area $FOBG$ is $>$ area FOB.

$\therefore$ sum of res. PQ + res. $P'Q > R'$

$\therefore$ *a fortiori* $R > R'$

Q.E.D.

The equation of the curve, which by its revolution generates the surface of least resistance, may be investigated easily by the calculus of variations. It is worked out in Professor Airy's Tract on that calculus.

The equation, according to the differential notation, is this, as given by Airy,

$$\frac{2yp^3}{(1 + p^2)^2} + C = O$$

In the fluxional notation

$$y\dot{y}^3\dot{x}=a(\dot{x}^2+\dot{y}^2)^2$$

Newton's construction comes to this:

$$\frac{y}{c\cdot\frac{ds}{dy}}=\frac{ds^2}{4dxdy^2}$$

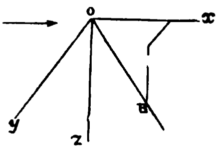
$$\frac{y}{c}=\frac{ds^4}{4dxdy^3}$$

$$=\frac{(dx^2+dy^2)^2}{4dxdy^3}$$

$$=\frac{(1+p^2)^2}{4p^3}$$

which agrees with the former by changing the value of the constant.

ON THE RESISTANCE AGAINST A VESSEL'S PROGRESS.

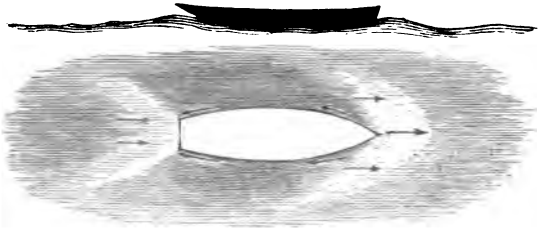


Let OB be an infinitely small part of a dividing-line of the bow (which may be supposed straight). O the origin of co-ordinates, of which the axis of x is in a line with the keel, and the axis of y transversely to it. A particle of water impinging on the vessel at O, must, in accordance with our definition of a dividing-line, have no tendency to leave the line OB; but it will travel along the surface of the vessel in the direction OB. Every succeeding particle striking the vessel at O will do the same. We talk of the particles of water being in motion and meeting the vessel, for this will clearly lead to the same result as the contrary, but will cause less confusion in the consideration. Successive particles of water, then, meet the vessel at O with a certain velocity, and exert a certain pressure. This pressure consists of two parts: (1.) The statical pressure, or that which is exerted equally all over the surface when the vessel is at rest (which altogether equals the weight of the vessel, and the resultant of which acts vertically through the centre of gravity); and (2) a pressure due to the velocity with which the particles meet the vessel, and varying with the inclination of OB to the direction of the motion (*i. e.* the inclination of OB to the axis of x). The direction of this pressure is perpendicular to the plane in which OB lies, and which is a tangent-plane to the surface of the vessel.

If there were no friction, the velocity along OB would be the same as the velocity with which the particles impinge (as the particles of water have really no initial motion, there is no momentum to be considered); but the friction, which is generated by the pressure, retards the motion; add to this, that other particles impinge on the line *OB* at different points besides *O*, and hence the particles of water get piled and huddled upon the line *OB*. The whole surface of the vessel may be supposed to consist of dividing-lines infinitely near each other; and the same takes place on each of them. What then is the effect, as far as the bows are considered, of the motion of the vessel? The water at the stem-post is gradually increased in density up to a certain point. But as the water is an elastic fluid, this density is instantly communicated to the water, on all sides, in front of the ship; and also forces up, at the stem-post, numerous particles of water above the surface. The consequence of the former will be to give the water all about in front of the vessel, a certain velocity in the same direction as that in which the vessel moves. The effect of the latter will be a wave, which will rise up at the stem-post, and travel with the vessel. But the dividing-lines, as they approach nearer to the middle of the vessel, become less inclined to the direction of the motion, until at last that inclination becomes a minimum. At this place, then, there is no increased density; for the pressure becomes zero (that is to say, the additional pressure, not the statical pressure), and the water flows away much more rapidly. This causes the surface of the water to sink; and the water from the nearest part of that which has an increased density rushes in, with a certain velocity in a direction contrary to that of the vessel, to supply the vacancy.

In a dividing-line at the stern, there is no friction. Nay more, the statical pressure is diminished, so that there is not exerted even the whole of the friction which is due to that. For the particles of water, moving along the curves of the dividing-lines at the stern, tend to leave the line, and fly off at a tangent. And thus the density of the fluid abaft the vessel is decreased. The water immediately behind the midship section rushes in, and thus causes an additional depression of the surface of the water amidships, and gives the water under the stern a certain velocity contrary to that of the vessel. This current meets another current from behind the vessel, which also rushes in to fill the vacuum, and a wave is caused, which follows the vessel at the stern-post.

In these diagrams, I have attempted to show the form of the surface. The object of Mr. Russell, in his wave principle (if I understand aright), was to make the water, for some distance, divide in a direction parallel to the keel; and then to let the increment of inclination be very gradual at first, so that the wave should not be before, but immediately behind the stem-post, and so support the vessel. He increased the stern wave, by making the vessel



of such a form, that the dividing-lines should close with less taper, supposing that this wave would help the vessel onwards. But, as his mathematics are not always quite correct, it is hard to appreciate the result. And moreover, this object could be obtained by any curve at first parallel to the keel, and gradually leaving that direction; so that I do not quite comprehend why he should fix upon the curve of sines for the *water-lines*. But it seems that an inflected line must offer more resistance than a simple curve. He says, that the wave at the bow is of the form of a curve of sines; that is, the section by a vertical plane presents that curve. Assuming that this be true, why does he apply this curve to the horizontal plane of the water-line? There is no regular publication on the subject from his own pen (except in a periodical, in the year

1838); so that, very likely, he is not rightly understood, and an injustice has been done to him, in making him stand godfather to a principle which is not his own.

Would it not, however, be better perhaps to apply a cycloidal arc to the dividing-lines of the bows (if such a principle as the above must be adopted), and have the dividing-lines aft much more tapered, and as nearly straight as possible; so that the particles at the stern may not fly off at a tangent, or, in other words, that there be caused as little suction as possible to the stern, and that the statical pressure at the stern should not be decreased. (The reason for mentioning the cycloidal arc as a substitute for the curve of sines in the bow, we shall presently investigate.)

Mr. Griffiths adopts the wave theory, and attempts to explain it, while he laughs at the principle upon which it is founded. He sneers at Mr. Russell's "ignorance" for not knowing that steamers have been built in America, which are so sharp as to have no wave. The wave may be so lengthened as not to be remarkable; but there must be some wave. However, he saves any one the trouble of contradicting him, for with a noble generosity, he takes the unpleasant duty upon his own shoulders: he finds it a curious thing that these vessels should run aground when passing swiftly over shallows, on which there is quite sufficient water to float them when at rest. Is not this the result of the wave at the bow and stern, and the hollow in the water amidships? Let any one watch the 'Clasper' eight oars, at Cambridge or Oxford. They are longer and narrower in proportion than any steamer; yet the two waves are quite discernible.

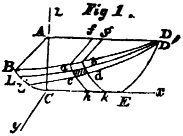
To find the resultant of the increment of pressure, p, *when the vessel is set in motion.*

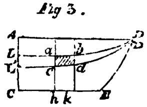
We have seen that the vessel, when at rest, is pressed on all sides by the water; the pressure on a unit of surface varying as the depth, and acting in a direction normal to the surface. The resultant of these pressures is equal to the whole weight of the ship $= D$, and acts in a vertical direction through the centre of gravity of the ship.

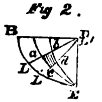
But when the vessel is set in motion, the particles of water would meet the vessel with a velocity v, suppose, and exert on a unit of surface (supposing it perpendicular to the direction of the vessel) some force $p = \frac{v}{t}$ (where p is not a moving force, as there is no momentum to be considered). But, as we have said above, the water at the bows has a velocity with the vessel. Hence, at the bows p

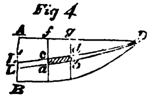
becomes $p-l$. Similarly, from about the middle of the vessel towards the stern, p becomes $-(p+m)$; and the wave following the stern, does not affect enough of the vessel to make it necessary for us to take it into account.

But when the vessel is in motion, the particles strike the vessel in a direction parallel to her course, parallel to the axis of x, suppose, (the axis of y being transversely to the course). And hence p varies also with the inclination of the tangent plane. We will first put p' for the variable pressure on a unit of surface, and afterwards show how to calculate the variation in p', which is due to the bow and stern waves.









Let Fig. 1 represent the bows of a vessel. DL, $D'L'$ two adjacent dividing-lines; fh, gk two adjacent vertical sections; $abcd$ a small area, intercepted between the dividing-lines and the vertical sections. This surface may be considered a plane; and let the angles of its inclination to the planes xy, xz, yz, be respectively λ, μ, ν.

Let Fig 2 represent the body-plan, or the projection of the bows on the plane yz. Fig. 3 the sheer-plan. Fig. 4 the half-breadth plan, or projection on the plane xy.

Then, f area *abcd* in Fig. $1 = m$
abcd in Fig. $2 = m \cos \nu$
abcd in Fig. $3 = m \cos \mu$
abcd in Fig. $4 = m \cos \lambda$

Now the water impinges in a direction parallel to the axis of x, and causes friction in running over the plane in the direction ba, or dc. But as we are not now going to find the amount of the whole resistance, but merely the resultant of forces parallel to the plane of xz, we disregard the friction. Hence the increase of pressure normal to the surface on the area m, which is caused by the vessel's motion

$$= mp' \cos \nu \,.\, \cos \nu = mp' \cos^2 \nu$$

(for the axis of x is at an angle $\left(\frac{\pi}{2} - \nu\right)$ to the surface of ad.)

This is resolved into

$mp' \cos^2 \nu . \cos \nu$	parallel to the area of		x
$mp' \cos^2 \nu . \cos \mu$	,,	,,	y
$mp' \cos^2 \nu . \cos \lambda$	,,	,,	z

of which the second need not be considered, the two sides of the vessel being exactly similar.

Hence, if we call the projection in the body plan of the area *abcd*

$$m \cos \nu = a$$

we have, to represent the two rectangular forces acting on the area m, the expression

$$p'a(\cos \nu + \sqrt{-1} . \cos \lambda) \cos \nu$$

And similarly the forces on the whole bow become

$$p' \{ a (\cos \nu + \sqrt{-1} . \cos\lambda) \cos \nu + a'(\cos \nu' + \\ + \sqrt{-1} . \cos \lambda') \cos \nu' + \quad . \ . \ . \}$$

$$= R(\cos \alpha + \sqrt{-1} . \sin \alpha)$$

If α be the angle which the resultant makes with the axis of x.

Also $$\frac{\text{area } abcd \text{ in fig. } 2}{\text{area } abcd \text{ in fig. } 4} = \frac{\cos \nu}{\cos \lambda}$$

$$m^2 = \overline{\text{area in fig. } 2}^2 + \overline{\text{area fig. } 3}^2 + \overline{\text{area fig. } 4}^2$$

Now, let area in fig. 4, $m\cos\lambda = b$

and $\quad m\cos\mu = c$

then $\quad p'\{a\cos^2\nu + \sqrt{-1}\,.\,b\cos^2\nu + \&c.\} =$

$$= R(\cos\alpha + \sqrt{-1}\,.\,\sin\alpha)$$

or $\quad p'\{(a + \sqrt{-1}\,.\,b)\cos^2\nu + \ldots\} =$

$$= R(\cos\alpha + \sqrt{-1}\,.\,\sin\alpha)$$

But $\quad \cos\nu = \frac{a}{m} = \frac{a}{\sqrt{a^2+b^2+c^2}}$

$$\therefore \quad p'\left\{\frac{a^3}{a^2+b^2+c^2} + \frac{a'^3}{a'^2+b'^2+c'^2} + \ldots\right\} = R\cos a$$

$$p'\left\{\frac{a^2b}{a^2+b^2+c^2} + \quad \ldots\ldots\ldots\ldots\right\} = R\sin a$$

or $$\Sigma\left(\frac{\delta A}{\delta S}\right)^3 . p' = R\cos a$$

$$\Sigma\left(\frac{\delta A}{\delta S}\right)^2 \delta B\,.\,p' = R\sin a$$

If A be the whole area of the body-plan, below load-water-wark; B that of the half-breadth plan from the highest dividing-line (*i. e.*, surface of the water when the vessel is in motion, which is not a plane surface) to the keel. And S the whole surface of the vessel; these all extending over the forepart of the vessel; that is over that part in front of that for which $\cos \nu = o$.

If x', z' are co-ordinates of a point in the direction of the resultant

$$\cot a = \frac{x'}{z'} = \frac{\Sigma . \left(\frac{\delta A}{\delta S}\right)^3}{\Sigma\left(\frac{\delta A}{\delta S}\right)^2 . \delta B}$$

Hence we deduce this rule for finding the tangent of the direction of the resultant. Multiply respectively the cubes of the little areas in the body-plan, by the little areas in the half-breadth plan, and divide by the cubes of the little areas on the whole surface, and add together the results. Add together the cubes of the quotients of the little areas in the body-plan by those on the whole surface, and divide the former sum by this sum. The smaller these little areas are made, the more exact will be the result.

The whole surface may be delineated by the operation of "expanding," as it is called. This is done by pinning a thin batten round the circumference of each section, and marking on it the intersection of every line; then the batten is let to fly straight, and the marks are laid off on paper for the extended surface. The same is done with the water-lines, &c., and thus the whole surface is expanded. The same may be effected by pressing some sheet-lead (such as that which is used to envelope tea) on a block model, and cutting it to the proper shape.

As yet we have found the value of the resultant *R* on the suppositions:

1. That p' is constant on every part of the surface.

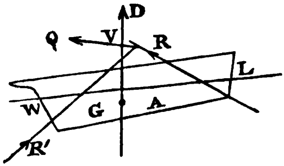
2. That the vessel is not heeled over (which is only the case before the wind).

3. And we have not taken friction into account.

Now first, let us observe that tan α becomes smaller as ΣdB becomes less; or as the area, in the half-breath plan, of the largest dividing-line diminishes. And *R* becomes less, *cæteris paribus*, as ΣdA becomes less, or as the area of the body-plan, in the forepart of the vessel, is small in comparison with the whole surface of the vessel. But friction varies as the surface of the ship.

The resultant for the suction at the stern is found in a similar manner, and the result is similar, remembering that the forces act in the opposite direction.

Hence, to find the resultant of all the forces parallel to the keel (excepting friction), and supposing p' constant, let *WAL* represent the submersed part of a vessel. *R, R'*, the resultants on the fore and after parts; *Q* the resultant of *R* and *R'*. Then if *G* be the centre



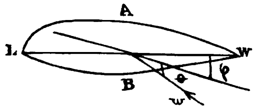
of gravity, we have a pressure equal to *D* acting at

G in a vertical direction. Let the direction of *D* cut that of *Q* in *V*, then the whole forces of the water (excepting friction) during the direct progress of the vessel, may be supposed to act at *V*. We have supposed all these forces to act in the same plane, which would not be the case except the vessel were going straight before the wind, because otherwise the action of the water on the two sides of the vessel would not be similar.

But in whatever direction the motion of the vessel may be in respect to the wind, it is nevertheless always true that the whole resistance of the water in a direction parallel to its surface, and in a line with the course, added to the amount of friction, is equal to the impulse of the wind multiplied by the projection, on a plane perpendicular to the direction of the wind, of the whole area of canvass. And the whole resistance of the water resolved vertically is equal to the weight of the ship (which we have always designated by *D*), added to that part of the action of the wind on the inclined planes of the canvass which is resolved vertically downwards.

In order to calculate the resistance of the water and its resultant, when the vessel is on a wind, it will be necessary to draw the water-lines of the vessel when careened, for the sheer and half-breadth plans; and for the body-plan to project the vessel on to a vertical plane perpendicular to the direction in which the vessel actually moves (which, on account of leeway, forms a small angle with the course she steers). The sections of the vessel for this new body-plan must be made by plances parallel to the plane of projection; and the dividing-lines will then be slightly altered from what they were when the vessel's motion was direct, and the sections made by planes parallel to the former plane of yz. This being done, a similar operation to that last indicated, must be performed. And again:

Let $LAWB$ represent the whole water-line of the vessel; LW being the middle line. Let the sail be at an angle ϕ with the keel; and the wind, w, at an angle θ with the sail.



Then the impulse of the wind on the sail is

$$w \sin \theta$$

and is resolved into

$w \sin \theta \cos \phi$ perpendicular to the keel, and
$w \sin \theta \sin \phi$ parallel to the keel.

And if R be the whole direct resistance of the water, and r the lateral resistance, and A the area of sail, of which the projection on a plane perpendicular to the wind is

$$A \sin \theta$$

$$\therefore \quad Aw \sin^2\theta \cos\phi - r$$
$$Aw \sin^2\theta \sin\phi - R$$

are the whole resolved forces acting on the vessel; and if ρ be the resultant, and ψ its angle with the keel, which is the angle of leeway

$$\therefore \quad \rho \cos\psi = Aw \sin^2\theta \sin\phi - R$$
$$\rho \sin\psi = Aw \sin^2\theta \cos\phi - r$$

To find an expression for the angle of leeway.

Let V be the velocity in a line with the keel.

v „ „ transversely to the keel.

R, r, the direct and lateral resistances as before.

d, e, the projections on the body and sheer-plans respectively of the surface offering these resistances. And let ψ be the angle of leeway as before.

Then if k be the actual velocity of the vessel,

$$k \cos\psi = V$$
$$k \sin\psi = v$$

$$\therefore \frac{V}{v} = \cot\psi$$

and
$$\frac{R}{r} = \frac{d \cdot V^2}{e \cdot v^2}$$

$$=\frac{d}{e}\cot^2\psi$$

$$\therefore \quad \tan\psi=\sqrt{\frac{dr}{eR}\Big)}$$

but $$\frac{r}{R}=\frac{\rho\sin\psi-Aw\sin^2\theta\cos\phi}{\rho\cos\psi-Aw\sin^2\theta\sin\phi}$$

But ρ must be exactly equal and opposite to the impulse of the wind on the whole area of canvass, which is $=wA\sin^2\theta$.

$$\therefore \quad \frac{r}{R}=\frac{\sin\psi-\cos\phi}{\cos\psi-\sin\phi}$$

and $$\tan\psi=\sqrt{\frac{d}{e}\frac{(\sin\psi-\cos\phi)}{(\cos\psi-\sin\phi)}\Big)}$$

which is independent of the force of the wind and of the velocity of the ship.

Since the velocity in any direction varies directly as the impelling force, and inversely as the resistance,

$$\therefore \quad V\propto Aw\sin^2\theta\sin\phi\times\frac{1}{R}$$

and $$v\propto Aw\sin^2\theta\cos\phi\times\frac{1}{r}$$

$$\therefore \quad \frac{V}{v}=\frac{r}{R}\cdot\tan\phi$$

and $$\frac{r}{R}=\frac{V}{v}\cot\phi$$

but $$\frac{V}{v}=\cot\psi$$

$$\therefore\quad \frac{r}{R}=\cot\psi\cot\phi$$

and since $$\frac{R}{r}=\frac{d}{e}\cot^2\psi$$

$$\therefore\quad \tan^3\psi=\frac{d}{e}\cot\phi$$

Also we have

$$\sin\psi=\frac{R}{\sqrt{r^2\tan^2\phi+R^2}}$$

and $$\cos\psi=\frac{r\tan\phi}{\sqrt{R^2+r^2\tan^2\phi}}$$

and $$\rho=R\cos\psi+r\sin\psi$$

$$=\frac{Rr\tan\phi+Rr}{\sqrt{R^2+r^2\tan^2\phi}}$$

[In practice, the angle of leeway may be found by taking the angle formed by the line of the ship's wake with her direction. Or, if her head be kept at the same point of the compass, and the bearing of some object on shore, directly astern, be taken at two separate intervals, the difference of bearings is the angle of leeway.]

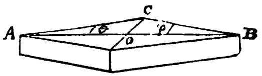
Having investigated the subject of lateral resistance, we must return to the direct resistance.

Let the wave at the bows proceed with a velocity v' with the ship; and, about the middle of the vessel, the water rushes back with a velocity w, suppose. Then the relative velocity at the bow is $v-v'$; and amidships it is $v+w$. And as the resistance varies as the squares of the velocities,

$$R=p(v-v')^2\sqrt{\left\{\Sigma\left(\frac{\delta A}{\delta S}\right)^2\right\}^2(1+\delta B^2)}\text{ for the bow}$$

$$R'=p(v+w)^2\sqrt{\left\{\Sigma\left(\frac{\delta A'}{\delta S}\right)^2\right\}^2(1+\delta B'^2)}\text{ for the stern}$$

But in the case of the bow, p is greater than in the stern, because the density is greater. The velocity v' is due to this increase of density, and w is due to the decrease of density. But neither this quantity p, nor the coefficient of friction can be determined by us at least.



Let a body, formed of two cunei, such as that in the diagram, be moved through the water. Let the semi-angle of the foremost cuneus be θ; that of the other ϕ.

Then in this case,

$$R \propto (v-v')^2 \sin^2 \theta$$

$$R' \propto (v+w)^2 \sin^2 \phi$$

$$\therefore \; R+R' \propto (v-v')^2 \sin^2 \theta + (v+w)^2 \sin^2 \phi$$

$$\propto (v-v')^2 \frac{CO^2}{AC^2} + (v+w)^2 \frac{CO^2}{BC^2}$$

Now, first we observe that, as $R+R' \propto \sin^2\theta + \sin^2\phi$ when v' and w are considered constant; therefore, if AB and CO are given, we shall have $R+R'$ least when O is in the middle, or

$$AO=BO, \quad \text{and } \theta=\phi$$

for $\theta+\phi$ are least when $\angle ACB$ is greatest.

Let $AB=a$; $CO=b$; $AO=x$;

then
$$\tan \theta = \frac{b}{x}$$

$$\tan \phi = \frac{b}{a-x}$$

$$\therefore \; \tan(\theta+\phi) = \frac{ba}{x(a-x)-b}$$

and $\frac{d}{dx} \cdot \tan(\theta+\phi) = ba(2x-a) = O$ for a minimum

$$\therefore \; a=2x.$$

Hence, if the length and breadth of the chief dividing-line (it is the dividing-lines alone which affect the resistance) are determined, then we must put its greatest breadth in the middle.

Take again the expression

$$R+R' \propto (v-v')^2\frac{CO^2}{AC^2}+(v+w)^2\frac{CO^2}{BC^2}$$

$$\propto V^2\frac{b^2}{x^2+b^2}+V'^2\frac{b^2}{(\overline{a-x}^2+b^2)} \quad \text{suppose.}$$

(the velocity v' and w being considered variable).

This is to be a minimum.

Now, as the velocity of the ship increases, v' and w increase. But v' diminishes if the dividing-lines are very sharp forward; and w decreases as the dividing-lines are made sharp aft and of slight curvature. The suction has been found to be a minimum when the dividing-lines aft make an angle of 13° 7′ with the plane through the keel and stern-post.

Now, as x increases, the dividing-line of the body in question is made sharp forward; as x decreases, it is made sharp aft. Hence, if x is made small, v' will increase, and $\frac{b^2}{x^2+b^2}$ will become $=1$ nearly, and the first term will become V^2. Also $\overline{a-x}$ will be large, and w will diminish, and so the second term will diminish. And as the quantity w

is of more importance than the resistance forward, this is an advantage. When the velocity of the vessel is small, v' and w may be disregarded, and then, as we have shewn, x should be equal to $\frac{a}{2}$. But the greater the velocity which the vessel is likely to attain, the fuller should the dividing-lines be forward, and the more tapered aft. This is found true also in practice.

To find the plane of resistance; that is, a plane of such an area, that its resistance when moved through the water at the same velocity as the ship, shall be equal to the resistance exerted against the progress of the vessel. Now

$$R+R'=p\left\{(v-v')^2\sqrt{\left\{\Sigma\frac{\delta A^2}{\delta S^2}\right\}^2(1+\delta B^2)}\right)+$$

$$+(v+w)^2\sqrt{\left\{\Sigma\frac{\delta A'^2}{\delta S}\right\}^2(1+\delta B'^2)}$$

$$=p\,.\,K \text{ suppose}$$

Let the required area $=X$

On which the pressure forward $=pXv^2$

the suction aft $=pXv^2$

$\therefore$ the whole pressure $=2\,pXv^2$

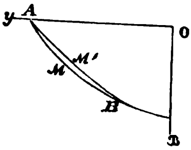
$$\therefore\quad X=\frac{K}{2v^2}$$

This, however, omits the consideration of the friction, which is increased as S is increased. Hence there is a medium between a great breadth of beam (which increases the resistance—unless the draught of water be proportionally diminished—but also enables the vessel to bear a greater propelling power); and between a great length, which increases the friction, but does not enable the vessel to carry more sail in proportion to the increase of her tonnage. This medium must be different for different rigs. The breadth for a cutter, in proportion to the length, which has been found most advantageous, is, $\frac{1}{3}$; of a schooner, $\frac{1}{4}$; of a ship, $\frac{1}{5}$ to $\frac{1}{6}$. It must be remembered, however, that the breadth here spoken of, is breadth of beam. That designated in page 123, by b, is the breadth of the dividing-line. The quantity designated by $\Sigma\delta A$ increases, however, in proportion to the breadth of beam, so that the above conclusion is just.

We must notice also an advantage in sharp bows, in that the resultant, *when the vessel is on a wind, and making some leeway*, will be at a greater angle with the vessel's course, and will thus increase her stability.

In speaking of the passage of a particle of water along the body of a vessel, we suggested that if a part of a cycloidal arc were applied to the commencement of the dividing-lines, the particles of water (it would appear) should traverse that space much more quickly than along any other line; and so the wave at the bow would be formed at a part of the vessel much more aft than if the water were more retarded forward. The wave would then also tend to support the vessel on itself. The following is the proof that the cycloidal arc is the path most quickly traversed by a particle.

Let *AMB* be the curve by which a particle, acted upon by a constant force *p*, parallel to the axis of *x*, would in the shortest time travel from *A* to *B*. And let *M* be the place where the particle is after the time *t*, and *S* the length of the arc, *AM*, which has been traversed.



Then the velocity acquired at *M*, disregarding friction,

$$\frac{ds}{dt} = \sqrt{2px}$$

let $$\frac{\sqrt{dx^2+dy^2}}{dx}, \text{ or } \frac{ds}{dx} = u$$

$$\therefore \quad \sqrt{2px} \,.\, dt = u \,.\, dx$$

and $$\sqrt{2p} \,.\, dt = \frac{u \,.\, dx}{\sqrt{x}}$$

Let β be the value of x at B, and t' the time which the particle takes to arrive there.

$$\therefore \quad t'\sqrt{2p}=\int_o^{\beta}\frac{udx}{\sqrt{x}}=U \text{ suppose}$$

Now, to determine the curve for which this is a minimum; let c be a very small constant, and δy an arbitrary function of x, such that $\delta y=o$ when $x=o$, or $x=\beta$, and shall not become infinite for any intermediate value of x.

Let U and u become U' and u' when

y becomes $y+c\delta y$.

$$\therefore \quad U'=\int_o^{\beta}\frac{u'dx}{\sqrt{x}}$$

which expresses another curve $AM'B$ passing through A and B, and nearly coinciding with AMB.

$$\therefore \quad U'-U=\int_o^{\beta}\frac{(u'-u)dx}{\sqrt{x}}$$

Let $(u'-u)$ be expanded according to powers of c, and let $c\delta u$ be its first term, then the first term of $U'-U$ is

$$c\int_o^{\beta}\frac{\delta udx}{\sqrt{x}}$$

$$\therefore \int_o^\beta \frac{\delta u dx}{\sqrt{x}} = o$$

Because $U' - U$ must be positive, whatever value δy may have, and whatever sign c may obtain.

But $$\delta u = \frac{d}{dx} \sqrt{1 + \frac{dy^2}{dx^2}})$$

$$= \frac{1}{2u} \left\{ 2 \frac{dy}{dx} \cdot \frac{d}{dx} \left(\frac{dy}{dx} \right) \right\}$$

$$= \frac{1}{u} \cdot \frac{dy}{dx} \cdot \frac{d}{dx} \cdot \delta y$$

and the above equation becomes

$$\int_o^\beta \frac{1}{u\sqrt{x}} \cdot \frac{dy}{dx} \cdot \frac{d \,.\, \delta y}{dx} \cdot dx = o$$

But $\delta y = o$ when $x = o$, or $x = \beta$; therefore integrating by parts,

$$\int_o^\beta \frac{1}{u\sqrt{x}} \cdot \frac{dy}{dx} \cdot \frac{d \,.\, \delta y}{dx} \cdot dx = -\int_o^\beta \frac{d}{dx} \left(\frac{1}{u\sqrt{x}} \cdot \frac{dy}{dx} \right) \delta y \, dx$$

$$\therefore \int_o^\beta \left\{ \frac{d}{dx} \left(\frac{1}{u\sqrt{x}} \cdot \frac{dy}{dx} \right) \delta y \, dx = o \right.$$

but δy is arbitrary

$$\therefore \frac{d}{dx} \left(\frac{1}{u\sqrt{x}} \cdot \frac{dy}{dx} \right) = o$$

$$\therefore \frac{1}{u\sqrt{x}} \cdot \frac{dy}{dx} = C$$

or $$\frac{1}{\sqrt{x}} \cdot dy = C\sqrt{dx^2 + dy^2}$$

$$\therefore dy^2(1 - Cx) = Cx\, dx^2$$

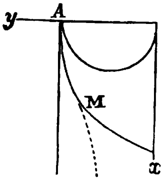
and $$dy = \frac{Cx\, dx}{\sqrt{x - C^2x^2}}$$

if for C we put $$\frac{1}{\sqrt{r}}$$

$$dy = \frac{x dx}{\sqrt{rx - x^2}}$$

which is the equation to a cycloid, the base being parallel to the axis of x; and the radius of the generating circle being $\frac{r}{2}$

Under the supposition that the former reasoning is sound, the stem would be at A, and the middle line of the vessel parallel to the axis of x. Only a part of the cycloidal arc AM, would be applied to each of the dividing-lines; or at least to several, the fairing of the bow would take in the others.



But this has been established on three suppositions, which are not quite true:

1. The particle moving along the curve is supposed to be in a non-resisting medium, in which case alone, the path of quickest descent is a cycloid. Now it is not the water, but the vessel which moves. We have spoken of the motions of the particles of water only for convenience sake. The only actual motion of the particles of water is outwards in a normal direction from the sides of the vessel; the water is cloven, as it were, and becomes in consequence more dense in the vicinity of the bow (which shows itself as we have already said, in the wave which is formed). The curve must therefore be considerably modified from the cycloid; what modification is necessary can only be determined by experiment.

2. In the above calculation we have assumed that there is no friction.

3. The surface of the water is supposed to be flat. The incorrectness of this asumption does not affect the reasoning so much as would at first appear. For the waves of the sea have but a *very* slight onward motion; they perform only vertical oscillations. The wind presses down a column of water in one part, and the elasticity of the fluid compressed, causes a corrrespondent rise in the adjacent parts. It is thus that waves are formed in a field

of corn; the ears do not run away like the Irishman's furrow of potatoes, but merely oscillate up and down.

As the normals at successive points, on a concave surface, converge towards each other, the water impinging on different points of the bow, will receive outward impulses in converging directions; and hence the density at the bows will be very much increased at the expense of the other parts. Is this likely to conduce to velocity? We think these considerations upset any plausibility, which there may appear in the foregoing mathematical calculation. The same objections apply equally to the curve of sines, or any other of the hollow lines which may have been used. But we have been speaking of concavity in the dividing-lines. It is very possible that experiment may demonstrate some superior form of bow, in which the dividing-lines are not hollow, although the water-lines may be so.

Let us suppose two bodies (1) and (2) of the same length, breadth, and depth, and formed as in

Fig 1

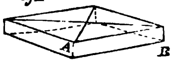
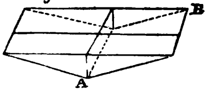


Fig 2



the figure. And that these bodies be propelled through the water by sails, at the same velocity v; the whole of each body being immersed, so that the plane at the top shall be the plane of floatation. Let the length $=2a$, the breadth $=2b$, depth, $=d$; the greatest breadth in (1), and the greatest depth in (2) being at the middle of the length. The angle of the bow in (1) being 2ϕ; in (2) the rake being θ

Then the resistance on a unit of surface forward

$$\left.\begin{aligned} &\propto (v-v')^2 \sin^2\phi \\ \text{,, aft} \quad &\propto (v+w)^2 \sin^2\phi \end{aligned}\right\} \text{in (1)}$$

$$\left.\begin{aligned} \text{,, forward} &\propto (v-v')^2 \sin^2\theta \\ \text{,, aft} \quad &\propto (v+w)^2 \sin^2\theta \end{aligned}\right\} \text{in (2)}$$

Assuming v and w to be the same in (1) and (2).

Also let $\qquad v'=w.$

$$\text{Now area } AB \text{ in (1)} = \frac{b}{\sin\phi} \cdot d$$

$$\text{,, in (2)} = \frac{d}{\sin\theta} \cdot 2b$$

$$\therefore \text{Whole resistance in (1)} \propto 2(v^2+w^2)\sin^2\phi \cdot \frac{2bd}{\sin\phi}$$

$$\text{,,} \qquad \propto 4(v^2+w^2) \frac{b^2d}{\sqrt{(a^2+b^2)}}$$

$$\text{Resistance in (2)} \propto 2(v^2+w^2)\sin^2\theta \cdot \frac{2bd}{\sin\theta}$$

$$,, \qquad \propto 4(v^2+w^2)\frac{bd^2}{\sqrt{a^2+d^2)}}$$

And to find the relative stability of these two bodies, let us take the expression

$$\int y^3 dx$$

$$\text{in (1) } y=\frac{b}{a}x, \text{ and } dx=\frac{a}{b}dy$$

Therefore the above expression becomes

$$\frac{a}{b}\int_o^b y^3 dy=\frac{ab^3}{4}$$

but this is only taken for the bows; therefore for the whole body

$$\int y^3 dx=\frac{ab^3}{2}$$

In (2) $y=b$, and the expression becomes $=2ab^3$

In (1) the volume $=4\frac{abd}{2}=2abd$

In (2) ,, $=2abd$

The depth of the centre of gravity in (1), is $\frac{d}{2}$; in (2) it is $\frac{d}{3}$

And as the centres of gravity of the bodies, and those of displacement are at the same point, the relative stability of (1) and (2), is as 1 : 4.

And the resistance in (1) and (2) is as

$$\frac{b}{\sqrt{a^2+b^2}} : \frac{d}{\sqrt{a^2+d^2}} :: \sin\phi : \sin\theta$$

The lateral resistance in (1) and (2) is as

$$\frac{b^2}{\sqrt{a^2+b^2}} : a$$

Hence (2) would be in every way superior in smooth water; but she would feel the shock of the waves more than (1).

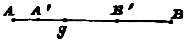
If a vessel is flat, with a light draught of water, she ought to have bluff bows; a sharp fore-body would not be so advantageous—would make her lose in buoyancy and shallowness, and would give worse dividing-lines. This is true, more especially if the vessel be intended for smooth water (as rivers or inland lakes). The stem should be made to rake very much, so that she would, as it were, skate over the water. She must have hollow water-lines aft, for the sake of the steering. With full stern-lines and the water closing in an upward direction, the rudder would not act. It is also necessary that such vessels should possess great beam; for if they careen much, a part of the bilge will be below the keel; and moreover, an increase of beam (from the dividing-lines being in nearly vertical planes) will not cause a corresponding increase in resistance.

In the above solids, if $\theta = \phi$, the dividing-lines are as acute in each, and the resistance the same. But the dividing-lines in (1) lie in horizontal planes; those in (2) in vertical planes. Thus it is that some vessels, with very full bows and great beam, are found to sail very fast, as well as some very sharp and narrow vessels. The dividing-lines in the 'Victorine' (a very fast river sloop) are very narrow, and yet the beam of the vessel is a great deal more than $\frac{1}{3}$ of the length of her load-water-line, and about four times her depth. The water-lines are no test of a vessel's qualities.

With relation to determining the best proportion of the length to the breadth, various considerations must be taken into account. Increase of length increases both the friction and the violence of pitching and 'scending; for the *vis viva* of the weights in the fore and after body vary as the squares of their distances from the axis of rotation; and the strain on the vessel is therefore increased as the squares of the portions before and abaft the centre of gravity, while the power to resist that strain varies inversely as the length. Increase of breadth increases both the resistance, and, *cæteris paribus*, the violence of rolling.

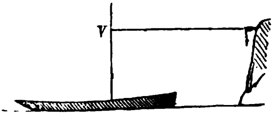
To find the centre of gravity, point velique, and centre of lateral resistance of a vessel afloat.

When the vessel is at anchor in smooth water, let her ballast be taken up, and equal quantities stowed in her bow and stern, in such a manner that she will be immersed up to her load-water-line, both at the stem and stern. The centre of gravity is midway between. If the two quantities of ballast



are not equal, then let them be at A and B when the vessel is down to her load-line; let them be moved to A', B', so that the vessel is still down to her load-line; then take G so that $AG : AA' :: BG : BB'$. Then G will be in the vertical through the centre of gravity.

Let an upright mast be placed at this point, and



let the vessel, when ballasted so as to ride up to her load-line, be taken to a river or rapid tide-way, or towed at some distance after a steamer; and let a rope be made fast to a hoop, on this mast, which can be hoisted up and down. Let the rope be made fast to some object (as the mast of a vessel) so that it shall be nearly horizontal. When the hoop is at the point velique *V* then the vessel will ride down to her load-line; if it be above, the bows will be depressed; if below, the stern will sink. Hence the point is quickly found. The same may be done with a model of the vessel.

To find the centre of lateral resistance, let her be placed across the stream, and the rope made fast successively to different points along the deck, until such a position shall be found that the vessel shall ride across the stream without slueing round. The vessel can then be rigged in accordance with the points thus determined.

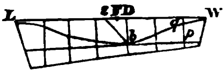
CHAPTER VIII.

THE CURVE OF SECTIONS.

Chapman endeavoured to discover if the areas of the immersed part of the sections of fast-sailing ships followed any regular law. He therefore calculated these areas from the draughts of several notable vessels, divided the area of each section by a constant quantity (the breadth of the principal section), and set off distances, proportional to these quantities, on the sections in the sheer-plan, measuring from the load-line. And he found that the curve which passed through these points was, in all good vessels, parabolic both in the fore and after body; and that sometimes the curve both in the fore and after body was one parabola.

To find the assimilating parabola to the curve of sections.

Let LW be the load-line, LbW the curve of sections. Draw a tangent to the curve of sections parallel to the load-line, and let it touch the curve



at b. And if the curve cut any one of the sections in q, and the tangent cuts it in p, then bp is an ordinate, and pq an abscissa of the curve.

Let the measured value of bp be $= y'$
" " " pq " $= x'$

Similarly, let the values of the analogous lines for the next section be y'', x'', and so on.

Then we have
$$y'^{n} = mx'$$
$$y''^{n} = mx''$$

$$\therefore \quad n \log y' = \log m + \log x'$$
$$n \log y'' = \log m + \log x''$$

$$\therefore \quad n = \frac{\log x' - \log x''}{\log y' - \log y''}$$

and
$$m = \frac{y'^{n}}{x'}$$

$$\therefore \quad \log m = n \log y' - \log x'$$

By repeating this operation with each successive section, we can ascertain how far the curve of sections is parabolic.

If the sections are perpendicular to the tangent or load-line, then $\frac{m}{4}$ represents the focal distance; if not, then it is the parameter of a parabola referred to a diameter and chords as axes of co-ordinates.

A similar calculation must also be performed on the after-body; and if the equation of the assimilating parabola be $y^{n'}=m'x$, then if $n'=n$, and $m'=m$, the whole curve assimilates to one and the same parabola.

From the construction it follows that the area of the curve of sections, multiplied by the constant divisor of the areas of the sections, gives the displacement, and the centre of gravity of the curve is in the same section as the centre of gravity of the displacement.

Taking the foregoing figure, let $LW=l$, $Db=d$. And let the equations to the parabolas in the fore and after bodies be

$$y^n=mx,\ y^n=m'x$$

and if $\angle bED=\theta$, then $d=Eb\,.\sin\theta$.

Then area of $LbWD=\frac{n}{n+1}\cdot ld$

And if B be the constant divisor, then the displacement

$$D=\frac{n}{n+1}\cdot ldB$$

But the area of the principal section at the point $D = B \,.\, d$

$$\therefore \quad D = \frac{n}{n+1} \cdot l \times \text{ area of principal section.}$$

Let E be the middle point of the line LW, F the position of the section containing the centre of gravity, and let $ED = k$, $EF = \alpha$

Then as WDb represents the displacement of the fore-body, and LDb of the after-body, the moments of these two parts will give the common moment.

Now, if $\bar{y}$ be the ordinate of the centre of gravity of DbW

$$\bar{y} = \frac{\int yxdy}{\int xdy}$$

$$= \frac{\int y^{n+1}dy}{\int y^n dy}$$

$$= \frac{n+1}{n+2} \cdot DW$$

And similarly that of LDb is $= \dfrac{n+1}{n+2} \cdot LD$

Hence the moments of these areas round E are

$$\left(\frac{n+1}{n+2} \cdot DW + k\right) DbW$$

$$\left(\frac{n+1}{n+2} \cdot DL - k\right) DbL$$

Now the area of

$$bDW = \int y dx = \frac{n}{m}\int y^n dy = \frac{n}{n+1} bD \,.\, DW$$

and area of $$bDL = \frac{n}{n+1} bD \,.\, DL$$

$$\therefore \quad \text{area } LbW = \frac{n}{n+1} ld$$

And the moment of the whole area round E is

$$EF \,.\, LbW = a \cdot \frac{n}{n+1} \cdot ld$$

$$\therefore \quad al = \left(k + \frac{n+1}{n+2} \cdot DW\right) DW - \left(\frac{n+1}{n+2} DL - k\right) DL$$

$$= kl + \frac{n+1}{n+2}(DW^2 - DL^2)$$

$$= \left\{k + \frac{n+1}{n+2}(DW - DL)\right\} l$$

but $DW - DL = -2k$, for $DW = \frac{l}{2} - k$, $DL = \frac{l}{2} + k$

$$\therefore \quad a = k\left\{1 - 2\frac{n+1}{n+2}\right)$$

$$= k \cdot \frac{n}{n+2}$$

$$\therefore \quad k = \frac{n+2}{n} \cdot a$$

And therefore, if the principal section be placed at such a distance from the middle point of the load-line, the centre of gravity will be at the point F assigned to it.

If the curve of sections be one parabola both in the fore and after parts, but the sections be not perpendicular to the load-line, exactly the same reasoning will hold good.

The equations

$$\frac{n}{n+1} \cdot l \times \text{(area of principal section)} = D \quad . \; . \; . \quad (1)$$

$$k = \frac{n+2}{n} a \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

are the foundation of the parabolic system of naval construction. This is a system invented by Chapman for the sake of convenience in laying down the lines of vessels. It has the advantage of other methods in not altogether excluding, by its conditions, all rules found by theory or experience to be advantageous. It is not, I mean, of such a nature as to permit only one form of vessel to be thereby constructed. And yet, on the other hand, it does cramp the architect unless he does away, in some degree, with the very advantage which this was invented to obtain; he must either take for better for worse, the form which he deduces according to the rules hereafter given, or he must alter and re-alter the form of his vessel, after it has been drawn out, until it embraces all the excellencies which he has proposed to himself. But yet, again, the form deduced from the exponential expression is not so accurately defined as to allow of no latitude in construction; the area of each section is given, but the relation of breadth to depth is undefined, so this relation is only hampered by the requisites for fairness in the lines of the body.

We proceed to make some remarks upon this method of construction. When the values of some of the terms in the above equations are given, the others can be determined. Thus we will suppose the distance of the centre of gravity from the middle point of the load-line to be a given quantity; then the distance of the principal section from the same point is known in terms of the exponent $(k=\frac{n+2}{n}\cdot\alpha)$. If the displacement, length of load-water-line, and area of the principal section are given, the exponent is determined $(n=\frac{D}{lM-D}$, if M be the area of the principal section). But if the displacement is not given, and the exponent is assumed, then the displacement is determined.

Thus let $\alpha=o$ (or the centre of gravity is in the middle), then $k=o$ (or the principal section is in the middle), then if $n=2$, and l, and M be given, we have:

$$D=\frac{2}{3}lMB.$$

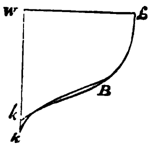
And the areas of the sections follow the law prescribed by

$$y^2=mx$$

To find m, we observe that when $x=\frac{M}{D}$, $y=\frac{l}{2}$.

$$\therefore \quad m=\frac{l^2B}{4 \,.\, M}$$

The quantity, m, for the after-body, will be different from the parameter m, in the fore-body, if we have not $a=o$, and $k=o$.



This method is similarly applied to the other elements of a ship. Thus let KWL be the immersed part of a midship section. Draw a straight line kB, so that the area $WkBL=WKBL$ as nearly as can be guessed by eye.

Now,

$$WL=\frac{1}{2}B\text{; and let } Wk=h\text{; area } WkBL=\frac{1}{2}M$$

And let n' be the exponent of a parabola on the lines WL, Wk as abscissa and ordinate, and having an area $=\frac{1}{2}M$

$$\therefore \quad \frac{1}{2}M=\frac{n'}{n'+1}\cdot\frac{1}{2}Bh$$

and
$$n'=\frac{M}{Bh-M} \quad \text{. . . . . (3)}$$

This quantity, n', is called the *exponent of midship section.*

Similarly we may find the exponent for a water-line.

Let the required exponent be n''. The length of the middle line $=L$; the area of the *whole* water-line $=w$

$$\therefore \quad \frac{n''}{n''+1}\frac{B}{2}\cdot L=\frac{w}{2}$$

$$n''=\frac{w}{BL-w} \quad \text{. . . . . (4)}$$

Again, suppose that the areas of all the water-lines at equal distances below each other, are as the abscissæ of a parabola. Let the exponent be n''', $Wk=h$ as above.

$$\therefore \quad D=\frac{n'''}{n'''+1}\cdot wh$$

$$n''' = \frac{D}{wh - D} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

n''' is called the exponent of the displacement.

These various exponents have been calculated for various good ships, and it was found that, in the Swedish navy,

	For ships of the line.	For smaller vessels.
n	varies from 2·5 to 2·7	varies from 2·3 to 2·1
n'	. . . 5·0 „ 3·8	. . . 3·0 „ 1·9
n''	. . . 6·6 „ 5·9	. . . 5·2 „ 3·25
n'''	. . . 2·2 „ 1·8	. . . 1·6 „ 1·25

Thus we see that small vessels have larger exponents in proportion to their displacement than larger ones.

Each of the four exponents shows the degree of fulness in a different direction. But they may be combined, so as to show at once the longitudinal and transversal fulness.

From equations (1) and (3) we have

$$\frac{n}{n+1} \cdot \frac{n'}{n'+1} Blh = D \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

From equations (4) and (5)

$$\frac{n''}{n''+1} \cdot \frac{n'''}{n'''+1} = LBh = D \quad . \quad . \quad . \quad . \quad . \quad (7)$$

In these two equations the quantities lBh, LBh represent two equal parallelopipeds (for in the load-line $L=l$) and the factors $\frac{nn'}{(n+1)(n'+1)}$, $\frac{n''n'''}{(n''+1)(n'''+1)}$ express the volume of the ship relatively to these parallelopipeds.

By substitution, close approximations to the depth of the centre of gravity of the displacement, the height of the metacentre, &c., may be arrived at; and the requisite alterations in these essentials may be effected before a line is drawn in the plan.

Perhaps the most convenient way of employing the exponential method of construction is as follows:

Let the ratio of the length to the breadth $=\mu$
" " breadth to the depth $=\nu$

By substitution in (6) we get

$$\frac{nn'}{(n+1)(n'+1)}\mu\nu B^3 = D$$

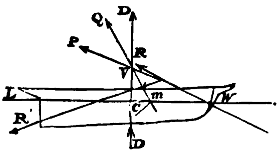
n, n' are known by experience, and by assigning certain values to μ and ν, then B is found by approximations being made to the quantity D.

When B, l, h, are found, then calculate the weight of the hull exactly, and add the other weights in the ship, and if the result differs from D, as found by the above equation, then we must again determine new values for the breadth, length, and depth of the ship, until the two values of D thus found, become equal. This done, the next thing to settle is the position of the principal section, and of the centre of gravity; afterwards the parameters of the fore and after-body, and the area of the midship section.

CHAPTER VIII.

ON THE DISPOSITION AND EXTENT OF CANVASS.

Let C be the centre of gravity of the displacement at which the pressure D is supposed to act in a direction vertically upwards.



Let R be the resultant of the increase of resistance, due to the motion of the vessel, which is exerted against the bows; R' the resultant of the suction to the stern; let P be the resultant of R and R'; Q the resultant of P and D; which may be supposed to act at the point V in the direction of D. Then V is the point velique. From C draw Cm perpendicular to the direction of Q. And let angle $VCm = \eta$.

Now V is the point at which the centre of effort of the sails must be, and if F be the force of the wind on the whole extent of sail, we must have

$$F . CV = Q . Cm$$

Now (1) if the wind act at a point below V, the resultant Q and the wind will form a couple, which will tend to lift the bows by turning the vessel round her centre of gravity, so that the stern will be depressed. If, on the contrary, the wind act at a point above V, the stern will be raised and the bows depressed.

And (2) when the wind increases in strength, Q will be augmented, and its direction will form a smaller angle with P; therefore Cm will be increased. But if the force F be increased so as to become nF, then Q will become nQ (but the velocity only becomes multiplied by $\sqrt{n}$).

So that we have

$$nF . CV = nQ . (Cm \times f) \quad \text{suppose,}$$

and if S be the surface of sail, so that $F = W . S$; and since $Cm = CV . \cos \eta$ where $\sin \eta = \frac{D}{Q}$ so that

$$Cm . f = CV . \sqrt{1 - \frac{D^2}{n^2 Q^2}})$$

then we have

$$F.CV = Q.CV\sqrt{1-\frac{D^2}{n^2Q^2}}) \ .$$

$$W.S = Q\sqrt{1-\frac{D^2}{n^2Q^2}}$$

$$= \sqrt{Q^2-\frac{D^2}{n^2}}$$

and $$S = \frac{\sqrt{Q^2-\frac{D^2}{n^2}})}{W}$$

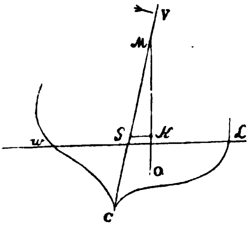
if the sails are inclined at an angle θ to the wind, then S becomes $S \, . \sin^2 \theta$, and

$$S \, . \sin^2 \theta = \frac{\sqrt{Q^2-\frac{D^2}{n^2}})}{W}$$

but in this case, the resistance to the two sides of the vessel is not the same; and hence Q does not meet the direction of D.

It will be observed that the less the angle which the direction of P (constant for each ship) makes with the water, the lower the point velique will be; and the centre of effort being lower, the vessel may have a larger surface of sail. Hence the floor at the bow should be very sharp; and the projections of the dividing-lines in the half-breadth plan should be full, in the sheer-plan sharp, in the bows.

The value of S above found is only with reference to the length of the vessel, without any regard to her stability; it is only such a relation that neither bows nor stern shall be depressed. But



now, let LCW represent the body of a ship inclined at an angle θ to the horizon. G the centre of gravity of the ship; V the centre of effort of the sails, $GV=f$; O the cen-
of displacement; draw OM perpendicular to WL meeting GV in M.

Then if W be the force of the wind, we have

$W \cos\theta$ acting perpendicular to GV

$W \sin\theta$ „ parallel to it.

Now the ship rotates round G.

$$\therefore \text{ moment of sails} = S \,.\, f \,.\, W \cos^2\theta$$

and the moment of the ship to resist this force is

$$= D \,.\, GK - SW \sin{}^2\theta \times f \,.\, \sin\theta$$

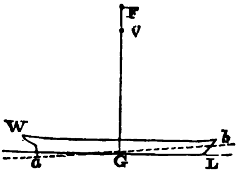
$$= D \,.\, GK - SWf \,.\, \sin^3\theta$$

$$\therefore SWf(\cos^2\theta + \sin^3\theta) = D \,.\, GK$$

or
$$SWf(1+\sin\theta)=D\,.\,GK$$

$$S=\frac{D\,.\,GK}{Wf(1+\sin\theta)}$$

so that if to θ we assign the angle of utmost inclination, then by assigning different values to W, we can find the proper surface of sail for each force of wind; f of course must remain constant, in order to fulfil the condition in the former page.



Let WL be the water-line when the centre of effort of the sails is at the point velique V. Then let more sail be added, and let the new centre of effort be at F. Let s be the amount of sail which is added; and let ab be the new water-line.

Then the moment to turn the ship round the centre of gravity in the first case is

$$=WS\,.\,VG$$

In the second it is $=W(S+s)\,.\,FG$

But the horizontal resistance of the water must equal the horizontal propelling force when the velocity is constant; and therefore in the first case it is

$$=WS$$

In the second it is $=W(S+s)$

But as the centre of effort is too high, there is no equilibrium until the bows are depressed; and the force exerted in depressing the bows is

$$W(S+s)\,GF - WS\,.\,GV = W(S\,.\,FV + s\,.\,GF)$$

and the bows must be depressed until F becomes the point velique.

Then bGF will be the angle of the ship's square-sails with the horizon. Let it $=\frac{\pi}{2}-X$.

$\therefore$ the part of the force of the wind which propels the vessel in her course

$$= W(S+s)\cos^2 X$$

while $W(S+s)\sin^2 X$ acts vertically downwards, like an additional weight in the ship. But when the centre of effort is at V, the force propelling the ship is $W\,.\,S$.

Now the amount of force lost by the malposition of the centre of effort is $W(S+s)\sin^2 X$; and unless

$$W(S+s)\cos^2 X > WS$$

or

$$s\,.\cos^2 X > WS\,.\sin^2 X$$

then the vessel will actually go slower.

Moreover, the area of resistance is considerably increased by the downward pressure of the wind, which has not been taken into account.

In the above consideration, we have supposed the plane of the sails, when the vessel is at her proper load-line, to be vertical. If the masts were raked, there would not be the downward pressure of the wind.

If the centre of effort were too low, the stern would be depressed, and then the part of the wind resolved vertically, would tend to lift the vessel instead of acting as an additional weight. When the bows are depressed, the ardency is increased, when the stern settles the ardency is diminished.

A very broad stern enables the builder to put the centre of effort a little lower than the point velique; so that the addition of the extraordinary topsails brings it right. For the breadth of the stern makes the depression to be very slight. A broad stern increases also the stability.

The commander of a yacht should be provided with a pendulum, that he might immediately be made aware of any alteration in the water-line of his vessel. It may then be rectified by a different disposition of the weights in the vessel.

To determine the proper amount of sail for a vessel, is by no means an easy matter. In the first place, it is easily seen how that two vessels may have the same length, breadth, depth, tonnage and stability, and yet, from a difference in form, require the centre of effort at a different height, and be obliged to carry a very different area of canvass. But hereupon no standard can be set up by theory; the average amount of sail proper for a vessel must be determined by experience alone. The 'America' has about 56 square feet of canvass (exclusive of jib) for every square foot in her midship section; while our yachts usually have only 42 feet. Chapman says, that the area of canvass should vary as the stability to the power of $\frac{2}{3}$. It is clear that it must vary with the stability, and the proper ratio can only be found by experiment.

For three famous American schooners, I have calculated the moment of the sails round the middle line of the ship at the height of the load-line (that is, the area of sail multiplied by the height of the centre of effort), and also I have determined the value of the expression $\int l^2 d\lambda$ for each of them.

Name.	$\int l^2 d\lambda$.	Moment of two try-sails, fore-sail and jib.	Moment of all sails.	Tonnage.
Baltimore clipper	5062·75	21816·7	25707·0	65
'America' . .	23726·67	125975·66 (no jib)		171
'Mary Taylor' .	8175·7	85492·32	146562·9	83

Thus the ratio of $\int l^2 d\lambda$ to the moment of the lower sails is respectively as

$$1 : 4{\cdot}2$$
$$1 : 5{\cdot}2$$
$$1 : 10{\cdot}4$$

CHAPTER IX.

RIGGING AND MANAGEMENT OF YACHTS.

Every rig has its own peculiar advantages; some suiting best in some places, others being better adapted to other seas. For small craft, a dipping-lugsail gets more out of the boat than any other rig; there is little weight aloft, and it is a very lifting sail. A standing lug does better for short tacks, but is not so lifting a sail. It is more handy than the other kind of lug, but is not equally good on both tacks; for, on one tack, the part before the mast becomes a backsail. An improvement in this kind of sail was suggested by my father; it consists in having *only* the bolt-rope at the luff, in order to make the sail stand; but there is no canvass before the mast, and the weather-leech has hoops round the mast as in a trysail. This would do admirably for vessels larger than mere boats. Small schooners

would be improved, by
sails instead of a gaff, fo
less weight aloft; and t
the way of the other s
deal peaked up. A sp
for small boats, and
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necessity be a kind of play. It is differently produced in different rigs, but it must always be carefully preserved, whatever alteration may be made in the rigging. In the cutter, the weight of the great mainsail and boom hangs on the mast; and the jib is sweated up very taut, so that the play is in the spring of the bowsprit, and the rising and falling of the boom. It is evident that, when the most is required of a cutter, the bobstay should not be taut. In a schooner it is the switching of the masts which produces the play. If the masts were upright, they would drive the vessel's bows into the seas at each switch forward, or perhaps themselves go by the board. When they are raked, the switch is upwards. The Americans once had a spiral spring to the top of the jibstay, in order not to lessen the elasticity. For the same reason, the only proper mainstay for a schooner extends from the mainmast head to the foremast head; that is, "a jumper-stay."

When the mainstay is brought down to the deck, as in our schooners, the play of the mainmast is destroyed. A large fish schooner, off this coast, was originally rigged with two mainstays down to the deck; but it was soon found necessary, in our heavy seas, to substitute a jumper-stay, although this caused great inconvenience with her fore-gaff-topsail in going about.

In a lug the play is from the tack up to the yard, and also in the yard, as in a latteen-sail.

The play in all these rigs is produced in a different manner, according to circumstances; but there is a play in all of them. It is for want of knowing this that people often imitate something of one rig in another, and, by not applying it rightly to the altered state of the case, they lose the advantage which, by cleverness of invention they had hoped to attain. And for the same reason it is, that good cutter-sailors are not found to succeed so well in luggers or schooners. A ship has no play in her rig: but, being larger, she has a great momentum, which suffices instead of the play.*

The rationale of the advantage obtained by a play in the rig, is the same as that of the benefit which results from a spring in the ballast, under which head it will be explained with more ease and simplicity than could be attained in the case of the rig. It is for a similar reason, also, that a slight elasticity in the hull has been found to be an advantage; in these circumstances the bow and stern can each subside, or rise an inch or two without affecting the other. This is one of the greatest advantages in Sir William Symond's system of diagonal planking in small boats. When the ballast is all stowed round

* For the above remarks I am indebted to my father.

the centre of gravity, the bows and stern can be pressed up a little by the force of the water, and will fall as soon as that support is diminished. For this reason it is that vessels, when chased in the war, have escaped by knocking out all bulkheads, and sawing down the sides at the midship section for a few feet.

MASTS.

The lateral strength of two cylinders of the same matter, and of equal weight and length; but one of them bored longitudinally, and the other solid, are to each other as the diameters of their ends.

Let the length of the cylinders be l, the diameter of the one to be bored $=2a$.

Then the area of the end is $=2\pi a^2$
and its solid contents $=2\pi la^2$

Now let a hole of diameter a be bored from end to end;

$$\text{the solid contents thus removed} = 2\pi l\frac{a^2}{4}$$

$$\text{and the remainder} = 2\pi l\frac{3}{4}a^2$$

Hence this hollow cylinder is of the same weight and consequently of the same strength as a cylinder of the same length, and of a diameter $= a \cdot \sqrt{3}$. So that the strength before and after boring is as

$$1 : \frac{\sqrt{3}}{2} = 1 : 0.866$$

and the weight before and after boring is as

$$1 : \frac{3}{4}$$

so that a hole bored in a cylinder of a diameter equal to half that of the cylinder, would, in theory, reduce the weight $\frac{1}{4}$th, and the strength by $\frac{1}{10}$th. But as the pith and central wood is not so firm as that outside, the strength would be reduced perhaps less; the stick also will be better dried, and so would weigh less. But the elasticity would be slightly impaired.

On the above principle, masts and spars are frequently bored in America.

The masts should be stepped where there are good bearings; this is necessary for safety, both when the vessel rolls, and when under bare poles.

The average length of the lower mast of a cutter is $\frac{3}{4}$ths of the length, breadth, and depth, and it is usually stepped $\frac{5}{12}$ths from forward.

The following rules for masting schooners is extracted from Griffiths' "Marine and Naval Architecture."

Main. 3, or $3\frac{1}{2}$ times the extreme breadth.	1 inch thick for every 4 feet in length.
Foremast. $\frac{8}{9}$ or $\frac{9}{10}$ of the main.	

Mast-heads. $\frac{1}{8}$ or $\frac{1}{9}$ of the length.

Bowsprit outboard. $\frac{1}{2}$ or $\frac{2}{3}$ of the extreme breadth. Same diameter as the foremast.

Jib-boom (outboard of bowsprit). $\frac{3}{4}$ of beam. Diameter, 1 inch for every 5 feet of the whole length.

Main boom over the stern $\frac{1}{3}$ of the distance from the mainmast to the stern. Diameter 1 inch to 5 feet.

Gaff. $\frac{2}{3}$ or $\frac{3}{4}$ of boom. Diameter, 1 inch for 4 feet.

Fore gaff. 4 to 6 feet shorter than the main.

Main-topmast. 2 or 3 feet longer than half the mainmast.

Fore-topmast. $\frac{8}{9}$ or $\frac{9}{10}$ of the main.

Hoist of trysails. 2 or $2\frac{2}{3}$ times the beam.

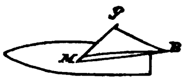
To step the masts, divide the deck into 756 parts; at 192 from forward place the foremast; 258 from fore to main; 336 parts for the foot of the foresail; 408 for the foot of mainsail; 204 for the head of each; 348 for the foot of the jib.

The rake of the masts varies from $\frac{3}{4}$ to $1\frac{1}{2}$ inches per foot.

SAILS.

The sails of the 'America' were made of cotton duck; for they are lighter, easier worked, and hold the wind better than common canvass. The only advantage of heavy canvass is that it lies flatter; for this reason the Bermudians use it for the mainsails of their boats. But I am told that in the 'America' they soaped or greased their sails for the race, to make them hold the wind, and kept them flat with battens.

But the sails in this country are not so cut as to



lie flat; and this is the reason for the practice: If *M* be the mast, and *MB* the boom, then the gaff will be in some direction *MG*. Now, if the angle *MG* be the best angle for the sail to form with the wind, then the lower part of the sail near the boom would be nearly aback, or at least forming a very bad angle; but if *MB* be at the best angle, the sail up aloft would be lifting; and for this reason they make the sail with a great belly, and bring the boom to too small an angle with the wind, so that the belly may be at the right angle. This evil may be obviated by having the gaff much more peaked up, and having the mainsheet nearer to the mast. For, as the vertical height of the boom from the deck is the same (to all intents) but the length of the sheet is increased the further it is from the mast; therefore the power of the sheet to keep the sail flat bears a greater proportion to its power in keeping the boom in when the sheet is placed nearer the mast than when it it is further off. The advantage of a horse is that it keeps the sail flatter, the disadvantage is a want of play. This plan would attain the advantage of each kind. There are two other advantages in having the gaff much peaked: one is that the play of the gaff is upwards, instead of tending to drive the vessel's head into every sea, and the other is that the head of the sail is smaller, and so the sail is more reduced in size, with less trouble, when reefing. When the sail is very flat, you can afford to lace the foot of the sail to the boom, as the Americans do; if the sail is not very flat, but the gaff goes off at a different angle to the keel from the boom, then this lacing would cause a backsail. In a schooner, if the sails are not flat, the wind from the jib acts against the foresail, and the eddy from the foresail against the main; which in each case, tends to retard the vessel's progress.

There might be made some improvements in the rig of our cutter. The mast should be more aft, (the beam also, of course, in a corresponding position), and there should be less head sail. The mainsail should be *the* sail of a cutter; and the foot should be much longer in comparison to the head. Also, the present heavy gaff and boom being nearly horizontal, do not switch up and down when the vessel pitches; they drive her bodily into the seas. They should be peaked up more, and the boom kept much lower; the jaws of the boom should be down almost in the cabin. The gaff should form an angle of 45° with the mast.* The bowsprit should be shorter, stouter, and without a bobstay. There should be no foresail (which is a very pressing sail), but only a large jib. And it will be necessary, therefore, in order to work with ease in going about, that the mast should be stayed forward by two forestays to catheads out of the bows, instead of one stay to the stem-head. She should have no topmast; but her gafftopsail should be run up with a yard, which should stand up and down the mast, as in American schooners. It is not, I am aware, quite a new thing to omit the foresail; but I do not think my plan of the forestays out to catheads has ever been tried.

It would be a good plan, in schooners, to have a boom for the foretrysail, with a jigger and a snotter round the mast, instead of jaws; so that it could be brought in when the vessel is in stays, and bowsed out again as soon as she is on the other

* The above remark, as far as relates to the peaking up of the boom and the gaff, is from my father.

tack. It would give more play to that sail, and make it stand better. The 'America' had a boom (with jaws) which extended only to the mainmast.

No racing vessel should have a gunwale of more than a few inches; for it only serves to catch the wind, and send her to leeward. Neither should there be any cabins or bulk-heads below. A piece of painted canvass stretched across the vessel amidships would be quite sufficient.

BALLASTING.

When a vessel is raised in the forepart by a wave; and when the wave has passed the forepart and the bows fall; then, if she with difficulty raises herself upon the succeeding wave, she is said to pitch; if she does a similar thing abaft, it is called 'scending. Both pitching and 'scending impede a vessel's way and endanger the masts; but they may, in a great degree, be corrected by a proper stowage of the ballast. When the wave is amidships, the bow, being imperfectly supported, drops with a momentum which is the product of the weights of the forepart multiplied by their distance from the centre of gravity (which is the centre of rotation). Hence, as much of these weights as possible should be brought from fore and aft and stowed about the centre of gravity; then, although the rapidity of the pitching will be somewhat increased (the pendulum being shorter) yet the violence of it will be greatly diminished; the vessel will be more lively, and her way not stopped so much. A similar rule applies as to the depth of the ballast below the surface of the water, as affecting the rolling.

But wherever the ballast is stowed, it should, above all things, be placed upon springs; in order to make it "a live," and not "a dead weight." Why, in a chase, do they sometimes put a shot in each hammock, and make every man hold a shot in his hand? To make the ballast a live weight. At Malta there was a race between little sailing-boats; one boy slung his ballast under the thwart of his boat; there was a slight tumble on the sea; the boat jobbled up and down, but forged away from all the rest and won the race. Why was that? "The true-blooded Yankee," a famous cruiser, was one of our 10-gun brigs; but her ballast had been taken out and stowed upon broom-stuff (which gave it a spring), and light tops were substituted for our heavy ones. Instances might be multiplied to shew the advantages of a live weight; but it were useless, as the matter is pretty well acknowledged. The reason of the advantage accruing from the above practice is this: when a vessel is one solid mass, a wave, on striking the bow, must at once overcome the inertia both of the whole ship and of the ballast, before the ship will rise over it. Or, in other words, the wave must rise up about the bow until the buoyancy which is generated, is greater than the inertia of the vessel and ballast. But when the ballast is on springs, the ship will rise over the sea, when much less buoyancy is generated—when much less of the bow is immersed—because only so much additional buoyant power is necessary as shall overcome the inertia of the vessel alone. And the inertia of the ballast, as the springs recover themselves, is overcome by a subsequent effort of the water. So also on plunging down again, when the wave reaches the stern, a vessel in which the ballast is not stowed on springs, will plunge much deeper into the water, because the momentum of both ship and ballast together must be overcome at one effort. But when the ballast is on springs, then, at the instant when the momentum of the ship is overcome, the ballast still plunges down on its springs, till its momentum is overcome by a subsequent effort. The advantage of a play in the masts is exactly similar to that of the play of the ballast. But if the play is to be in the masts, they must rake in order not to drive the bows down. If any one would like to convince himself of these facts by an analogy, let him procure a carriage and a cart of the same weight, and drive them at a moderate pace on a rough road. He will soon see that the carriage is the lightest in draught. He will also see the wheel of the cart frequently hopping off the ground, while those of the carriage do not show light beneath them; or let him try to cut a branch, which has a considerable spring in it, with a mallet and chisel.

To find the best position of the sail to the wind, in order to stand on a given course; the direction of the wind with reference to the course being given.

Let the angle of the wind and course $= a$

" " and sail $= \theta$

then the impulse of the wind

$$= WS . \sin^2\theta$$

and the resolved part along the keel

$$= WS . \sin.^2\theta \sin(\alpha - \theta)$$

which is to be a maximum.

$$\therefore \{2 \sin\theta \cos\theta \sin(\alpha-\theta) - \sin^2\theta \cos(\alpha-\theta)\} d\theta = o$$

and $$\tan(a - \theta) = 2 \tan\theta.$$

TABLES.

I.

THE FOLLOWING TABLE SHOWS THE PROPER ANGLE OF THE SAIL FOR VARIOUS ANGLES BETWEEN THE APPARENT DIRECTION OF THE WIND AND THE COURSE.

α	$(\alpha - \theta)$	θ
103°·53	42°·30	61°·23
99 ·13	40	59 ·13
94 ·25	37 ·30	56 ·55
89 ·28	35	54 ·28
84 ·23	32 ·30	51 ·53
79 ·06	30	49 ·06
73 ·39	27 ·30	46 ·09
68 ·	25	43 ·
62 ·	22 ·30	40

To assist the commander in working to windward, it would be well to have a mark on the taffrail, over which the boom must be when the vessel is close-hauled, in order that the sail may form the best angle with the wind.

II.

WEIGHT OF VESSELS* (AVERAGE).

Class.	Tons burthen.	Weight of hull.	Weight at sea.
Cutter	160	83	160
10 guns	235	157	283
18 „	382	214	456
28 „	500	414	784
46 „	1063	795	1466
52 „	1468	1042	2110
74 „	1741	1617	2976

* From Edye.

III.

TABLE OF THE SPECIFIC GRAVITY AND STRENGTH TO RESIST A TRANSVERSE STRAIN.

Oak	·625	1308
Beech	·690	2031
Ash	·811	2430
Elm	·544	1620
Teak	·744	2151
Willow	·405	1095
Riga fir	·480	1590
Norway fir	·639	2376
American pine (Weymouth)	·460	1974
Danzic oak	·756	1457
Red pine	·657	1341

IV.

Name of wood.	Specific gravity.	Weight of cubic feet in lbs.	Comparative strength.	Stiffness.	Cohesion of square inch in pounds.
Ash	0· 76	47·5	0· 23	0· 089	15784
Beech	0·696	45·3	0· 15	0· 073	17709
Elm	0·544	34	0· 21	0· 073	13489
Red or yellow fir	0·557	34· 8	0· 3	0·1154	
White fir	0· 47	29· 3	0· 23	0· 1	
Larch	0· 56	35	0·136	0· 058	10224
English oak	0· 83	52	0· 25	0· 093	11880
Dantzic oak	......	36			
American yellow pine	0· 40	26·75	0· 25	0· 087	
African teak	......	60· 6	......	} 0·1084	} 15000
Malabar teak	......	53	......		
Rangoon teak	......	26·2	......		
Cedar	......	28·2			
Brass	8· 37	523	0·435	0· 49	17968
Gun-metal	8·153	509·5	0· 65	1· 535	36368
Copper	8· 75	549	......	......	20272
Cast iron	7·207	450	1	1	17565
Malleable ditto	7· 6	475	1· 12	1· 36	62079
Lead	11·352	709·5	0·096	0·0385	

V.

TABLE OF WINDS.

Weight of a column of water in the tube, in inches.	Force in lbs. on square ft.	
0·05	0·26	A pleasant breeze.
0· 1	0·52	Fresh breeze.
0· 5	2·60	Brisk breeze.
1	5·21	A high wind.
2	10·42	A very high wind.
3	15·62	A storm.
4	20·83	A great storm.
5	26·04	Very violent storm.
6	31·75	Hurricane.

VI.

OF CHAIN CABLES.

lbs. per fathom.	Inches diameter of iron.	Substitute for a rope of circumference in inches.	Proof in tons.	Supposed tonnage.	Weight of rope substituted, per fathom.
8	⅜	4	2		4·32
10½	7/16	4¾	3		
13½	½	5¼	4	20	
17	9/16	6	5	35	9·72
24	⅝	6½	6	50	
27	11/16	7	8	70	13·23
30	¾	7½	9¾	90	
36	13/16	8	11¼	110	17·28
42	⅞	9	13	130	21·87
50	15/16	9½	15	150	
56	1	10½	18	170	
60	1 1/16	11	21½	200	32·67
86	1¼	13¼	38½	320	
125	1½	16	43	500	

On every subject many detached pieces of information are scattered among the various members of society. Some facts, of great intrinsic value, may be known to but few, and there may be no convenient medium through which to communicate them to the world. Also the numerous pieces of information, although singly of no great moment, may, when brought together, help to evolve a theory, or determine a much vexed question. Those who possess such information will greatly favour the author of this little work if they deem him worthy of sharing their knowledge. He may then be enabled to form a valuable appendix with the contributions of those who are anxious to advance the science of naval architecture.

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