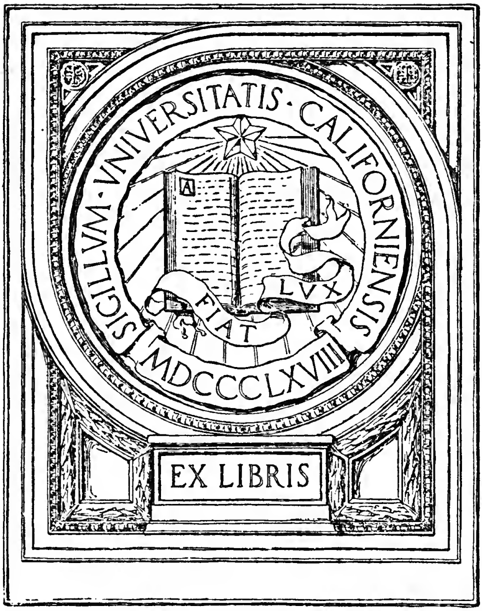
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AVIATION

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A remarkable snap-shot of a 60-h.p. Deperdussin monoplane flying within three yards of the camera. The staff photographer of *Flight* secured this picture by standing on No. 1 pylone at the Hendon aerodrome while a race was in progress. The pilot on the aeroplane is N. Slack, and the passenger's seat in front of the pilot is empty. The pilot is in the act of turning the control wheel for warping the wings in order to level up from the banked turn.

AVIATION

AN INTRODUCTION TO THE ELEMENTS OF FLIGHT

BY
ALGERNON E. BERRIMAN
TECHNICAL EDITOR OF "FLIGHT" AND THE "AUTO"
ASSOCIATE FELLOW OF THE AERONAUTICAL SOCIETY
MEMBER OF THE INSTITUTION OF AUTOMOBILE ENGINEERS

WITH THIRTY PLATES AND MANY DIAGRAMS

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PREFACE

THERE is an ever-increasing number of people who desire to appreciate the main issues of technical subjects unconnected with their own professions: to such, primarily, I address this Introduction to the study of flight.

There is no evading the fundamental technology of any real subject, whether commercial, scientific, or political by nature; the reader must ever provide the interest if he would receive any return whatsoever for his purchase of the author's capital. In this case, as the capital is so small, the initial interest on the reader's part must be all the greater.

The scope of the book is indicated by the arrangement and character of the chapters. I have divided the treatment of the subject into four main parts. The first part relates to the fundamental principles of flight; the second part is concerned with practical accomplishment; it refers in detail to the work of certain notable pioneers like Lilienthal and the Wrights, and also has chapters on modern development, as demonstrated, for example, at the military aeroplane trials of 1912. The third part is mainly historical, and is placed in this order so that the significance of the "milestones" may more readily be appreciated.

The fourth part is a collection of appendices that have no exact sequence or proper place in the body of the book.

Among these I have included several simple numerical examples that may be of some assistance to the student. In any case, there is nothing like a few specific questions and answers as an assistance to fixing ideas on a strange subject.

As far as possible, I have drawn upon the admirable Technical Report of the Advisory Committee for the results of experimental research. It is the source to which all students should first turn for data of this character.

The pictures in this book are a few of the many hundreds that are prepared in the usual course by the staff of *Flight*, and are typical of the illustrations that appear in that journal every week. It is, of course, on the periodical that the reader who would remain *au fait* with current developments must necessarily rely for immediate information, and if this book succeeds in assisting those who read it to follow the later steps of this new movement with greater interest and appreciation of detail, it will have served its purpose well.

A. E. B.

London, *September*, 1913

CONTENTS

PART I

CHAPTER V

Direction of pressure and direction of weight—The cause and the cure of lateral disturbances—Steadiness and large span—Speed and safety—Wing warping: its object and its effects—Cause and effect of sideslip—Fins as stabilizers—Upturned wing tips as fins—Stability against gusts—Negative wing tips and lateral stability.

CHAPTER VI

The true purpose of a rudder—Its manner of action—How a ship answers the helm—The balance of power—Instability and the importance of the rudder—Banking for the turn—The centrifugal couple—The differential negative warp.

CHAPTER VII

The ballasted flat plate and wing of single camber—The fore-and-aft dihedral as a speed regulator—Stalled—The dive—An experiment by Orville Wright—The reversed camber wing—The Fales section.

CHAPTER VIII

Propeller in front *v.* propeller behind—Two screws *v.* one—Military requirements—Size and efficiency—Size and speed of flight—Rankine's theory—Wing *v.* propeller—Aeroplane *v.* helicopter—Aero engines.

CHAPTER IX

Wing resistance and body resistance—Streamline flow—Relative importance of the head and the tail of a body—Fair-shaped struts—The gain in lift due to reduction or resistance—Surface friction.

CHAPTER X

Lilienthal's research—The cambered wing compared with the flat plate—The tangential—Advantages of uneven distribution of pressure.

PART II

CHAPTER XI

Bird flight as the basis of aviation—The invention of gliding—Experiments at Rhinow—The artificial hill—Researches on the cambered plane—Lilienthal's tangential.

CHAPTER XII

CHAPTER XIII

CHAPTER XIV

CHAPTER XV

CHAPTER XVI

CHAPTER XVII

PART III

CHAPTER XVIII

PART IV

APPENDICES

LIST OF PLATES

LIST OF DIAGRAMS

AVIATION

PART I

INTRODUCTION

INTRODUCTION

THE CHARM OF FLYING

An early flight meeting in France—When aeroplanes become commonplace—The Great Unflown—The first time up—High speed in the air—Sensations in the glide.

THE great charm of flying lies in the extraordinary fascination of the problem of flight, which has innumerable aspects and every one of them interesting. There are tricks to every trade, but where will you find an occupation so replete with important issues as is the field of aviation to-day? It is not alone to the pilot that this privilege belongs; the engineer who builds the aeroplane, and the student who studies the science, are alike under the same great thrall.

It is the intensity of the interest that tells in flight. No matter which way you turn, there is always some new point to whet the intellect and to hold the mind absorbed. Everyone feels it, once he knows how an aeroplane flies; but how few, relatively speaking, do know, when by knowing is meant the full understanding of what you can see any day that it pleases you to go to Hendon, or to Brooklands, or to any other centre of aviation, where the aeroplane is daily in the air?

Curiosity was the impulse that formerly took the Frenchmen by their thousands to see those early efforts at Juvisy on the outskirts of Paris; but it is the interest born of understanding that to-day holds still more thousands of believers firm-rooted in their conviction as to the future of flight.

How well I remember one of those Juvisy meetings! It was a Sunday, and all Paris, with the better half of France, was there already when my tardy train drew up at the quiet little station beyond the environs of the metropolis. In the roads and in the fields were motor-cars and vehicles of every description, some abandoned, some still occupied by irate sightseers who had no more chance of getting nearer to the show than they had of flying. The time-worn metaphor still applied, but how soon it was to lose its meaning.

Above the green that day men were already in flight. Big Voisin biplanes loped heavily through the air, while lighter monoplanes hopped a sprightly measure on the grass. Fanfares from ceaseless trumpeters kept up a weird music on the ear, and the dense crowd surged with the restless motion of the sea, watching and cheering, running to the palings and standing on chairs, and anon subsiding for a moment to seek refreshment in a cup of coffee and a sandwich, for which, if I remember rightly, the *restaurateur* disdained to give change for five francs.

It was all truly wonderful ; but how glad I was that I left early, and suffered myself to be carried by struggling humanity into a compartment of the last train that returned to Paris. Three hours we occupied on that journey, but we did reach Paris, which was more than could be said of those who tried to get home later in the evening. Some people who left Paris by rail that afternoon never even reached Juvisy ; for the story went that an over-excited crowd, unable to find accommodation, amiably invaded the line by way of passive resistance, to prevent outward-bound trains from disgorging still more passengers whose only thought then was how to get home again. Certain it is, at any rate, that many people had the memory of their first experience in aviation firmly implanted in their minds by the unexpected necessity of spending a night under the open sky.

To-day, flying has become more commonplace, but it has not become less wonderful. When you see the modern aeroplane start away so easily, and gradually disappear in the distance without so much as a flutter from its straight course, it seems almost uncanny that so much should have been accomplished in such a short time, and with machines that have, *au fond*, been so much alike all through. In a few more years the general public will not even stop to think that it does not really know how an aeroplane flies—it will just take it for granted, as it takes its telephone and its tube and its taxis.

But for the man and the woman who realize that a new thing is worth knowing, and who take a serious interest in the subject now that it is in its infancy, and, therefore, seems more easily to be understood, there should be no such apathy of mind. They will be keen to follow every phase of the game, and the bare news of a short press paragraph will unfold its own story without further words: the milestones of aviation's history will have more than the mere romance of triumph to make them interesting to those who trouble to study the subject now.

To-day, the great unflown is divided into two camps. There are those who say with keen anticipated ecstasy, " I should love to go up " ; there are also those who pessimistically pronounce, " Not I, at any price." But both can take an interest in flight, and both can have a real appreciation of the progress of the art. It is not necessary that you should fly yourself in order to be really interested in flying : that is the great advantage of a subject that presents so many aspects to the mental view. It might even be that you would feel disappointed in your first experience aloft—passengers often do, and in any case the first time up is not calculated to give anyone a full perception of the joy of riding the air.

Well do I remember my own first ride with Cody on his great " Cathedral,"[1] the man and his machine alike unique.

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[1] It is, I think, generally supposed that this nickname was due to the comparatively large size of the Cody biplane. As a matter of fact, how-

There was an iron seat behind the pilot, of the kind that is used on threshing machines and agricultural instruments of the vehicular kind generally. It was comfortable enough to sit on, but when we got going over the roughnesses of Laffan's Plain it was extraordinary how seldom the seat would hit me in the right place. How Cody himself remained secure with both hands on the control, when it was all I could do to remain in the machine by clinging with both hands on to the framework, exercised my mind even then to the comparative exclusion of the one other thought of how awkward it would be for both of us if I should happen to fall out.

Once in the air, and how different it was !—the extraordinary smoothness of motion and yet withal the feeling of firmness in this aerial support. I was engaged wholly with my own sensations, and I think they still predominated when Cody motioned me that I was to observe how responsive was his big machine, which he thereupon proceeded to sway about in the air. On the whole, I must honestly confess that the real sense of enjoyment came afterwards on that occasion.

I thought then, and I have thought since, how like an aeroplane is to the magic carpet of our childhood's days ; only on some machines one does not perhaps altogether relish sitting so very near the edge.

In flight, the sense of motion is not in the least what you would expect from a prior knowledge of the speed attained. It is the proximity of stationary objects that gives one the impression of velocity. On an aeroplane, the ground is so very far away and so very expansive that it is almost an effort of will to keep the eye on an earth-bound

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ever, it was due to a *bon mot* by F. W. Lanchester, the well-known author of *Aerial Flight.* The principle of the upward dihedral angle (wings sloping upwards from shoulder to tip) was under discussion, and Cody was explaining how his planes, so far from displaying this feature, were, in fact, slightly arched. " Ah, yes, I see," said Lanchester, " you've got a kat(Gr. down)hedral."

object for sufficient length of time to appreciate that one is moving relatively to it at all. The speed through the air is, of course, enormous, and directly behind the propeller the relative wind is so terrific that it is difficult to see without goggles. The very flesh of one's face seems to drag at its foundations, it sags and quivers in this astounding draught, which drives the very breath backwards down your throat until you become accustomed to the art of breathing under these strange conditions.

There is, indeed, often a curious feeling of standing up against a solid wall of wind that is trying to blow you backwards, but never have I experienced quite the same sensation of rushing through the air that one gets on a fast car, where the draught is merely an accessory to the fundamental impression of speed resulting from the motion over the road, which is always directly in the line of sight.

It is one of the phenomena peculiar to the process of getting aloft in an aeroplane that the country, which lies very naturally ahead when you start off on the preliminary run over the ground, in some mysterious way seems suddenly to spread itself out beneath your view like a vast carpet. The transition takes place almost mysteriously : you are looking ahead, and then, without realizing that anything definite has happened, you find yourself looking *down*.

These impressions do not necessarily come to mind during the first flight, but after a while you begin to notice such details. Little peculiarities catch the attention : you are struck, for example, with the dignified way in which the machine seems to stride up into the higher levels step by step, as the elevator is tilted and eased off under the control of the pilot. Soon you get accustomed to noting the lie of the land, to watching for the gusts in the hollows and over the spinneys, where aerial disturbances are sure to be found whenever the wind is blowing. Perhaps the machine will sink a little, like a small boat in a lop, and then climb out over the crest of some invisible wave, which you feel is there, even though you cannot see it. Or there may be an indescribable impression of flying through an aerial shoal, especially when edging round into the wind for the landing.

At the end of the flight comes the glide, most exhilarating of all its episodes, when the aeroplane turns into a toboggan and you slide down full tilt towards the ground. There is nothing quite like it for the real joy of an unalloyed sensation. Mother Earth spreads her green quilt invitingly, and you slither down an invisible stairway with the confident abandon with which you fling yourself over the balusters in a dream. How smoothly the wings cleave the air, how gently the engine ticks round at its ease after its strong work aloft ! It is the dignity of repose in motion. Of the same kind is the suppressed energy of a loco's rolling stride as it enters the terminus, or the liner's majestic approach up the fairway to the dock.

Of the same kind, yes ; but how different in detail ! Where is the pompous boiler bursting with steam, where is the irresistible mass of the gigantic hull, in the fairy-like grace of a monoplane descending to earth ? And the little finale : can you not see the flutter of the bird's wing as it steadies its flight to alight on the bough, in the br-r-r of the motor as the pilot switches on at the last moment and cocks up the tail flap to flatten out ere touching the ground ? It is the consummation, this smooth flattening out, of that delightful impression of softness that is presented by the typical green field towards which you have rushed downwards through space, like a god descending from some higher plane. In cold blood you know the impression is false, for even the football ground, on which you first gained an early preference for falling on grass, must have disillusioned you from the first on that score. Besides, it is only necessary to see one aeroplane smash, where half a ton of timber and steel has tried conclusions with the earth's surface, to realize how terribly hard is the hand lying hid in that velvet glove.

But if you let such thoughts as these deter you, you would be chained to your bed for life, and then live in fear of fire and earthquake. You would never cross the street, never travel in tubes and motors, never go abroad in mammoth liners, and, in fact, never do any of the hundred and one things that occupy your normal existence and are cheerfully accepted as part and parcel of life because you have confidence that, being adopted of the people, they are above reproach.

The ever-regrettable loss of the *Titanic* tore the heartstrings of humanity because of the sorrow that came in its wake, but just as severe in its way was the public's painful surprise when it realized that such a thing could be. Modern civilization has so enfenced our daily existence with protective legislation that the first principle of public service is not only that it shall be safe, but that it shall also be fool-proof. According to our idea of things to-day, it should not be possible for a man to come to grief through his own carelessness in misusing conveniences that are provided by the civilization of which he forms part.

Men rail against the insistency of progress, but their resistance is of no more avail than would be the holding of the hands of the clock in an attempt to place a check upon time. Progress and time are, in fact, synonymous : time is, and progress continues. Neither the one nor the other can rest, yet the master of both is for ever at peace with himself and the world, and he alone is happy. A novelty offends you—study it. Think well upon it, and consider whether or no it is a link in the great chain, or whether merely an appanage that comes to-day and to-morrow is gone—a bit of seaweed held up against some ship's side by the tide. Is the aeroplane but a passing fad, do you think, when men have searched through the ages for the solution to flight ? Whoever says so has never seen a flight with the full understanding of his mind, has never grasped what it means to pass over hill and dale, to cross river and road, to stride forests and lakes as if they were not.

How terribly cold these things seem in print! But see them happen with your own eyes, and you will understand. Condescend for a moment to stand as a simple child before the wonders that man has worked with Nature's laws. Forget the telephone and the tube and electricity and all the things you know so well, but understand so little, and just think of the physical fact of flight. A man and a machine, solid material both of them, go up into the air without visible means of support and fly for miles. Is it less wonderful than the Indian juggler who climbs the mysterious rope, and vanishes? It is more interesting, anyway, for we do know something of how it is done, and although the knowledge is small it adds immensely to the value of the performance.

The study of aviation is a real science, and the business of aeroplane construction is sound engineering: both are worthy of the professional interest of men who have already laid the necessary foundation of technical knowledge. The former, the scientific side, has perhaps the wider scope of influence, for it might well be numbered among the pages made interesting by Sir Edwin Ray Lankester in his *Science from an Easy Chair*. Aviation is, in fact, an excellent introduction to science, because of the breadth and of the intensity of its interest to those who have never professed to be scientific. It puts science in a pleasing light, for, starting in mystery, it ends in simplicity, and yet leaves the student respect for the wonderful.

More important, in many ways, than any reason yet mentioned for being interested in flight is its national significance. The aeroplane and the airship have become armaments of first-class importance, and have been developed as such by France and Germany to an extent that has placed those countries in possession of large aerial fleets. British policy has, unfortunately, been to await the march of events elsewhere, and, in consequence, our aerial force is woefully small. Lacking the spontaneous enthusiasm so characteristic of nations farther south, people in England have been comparatively apathetic towards a movement that they do not understand and which makes, to the majority of them, no personal appeal. Living on an island as we do, however, superiority in the air is as necessary to our safe defence as is the command of the sea, and for that reason alone every thinking Englishman should so far study the subject of flight as to arouse in himself an interest sufficient to ensure his support of the principle of British aerial supremacy.

AVIATION

PART I

CHAPTER I

WHAT AN AEROPLANE IS

Getting under way—What the wings do in flight—Relative motion—A railway carriage experiment—The effect of the angle—Why aeroplanes are like yachts—How birds soar—Why power is necessary to flight—Nature flaps a wing—Man revolves a propeller—What happens when the engine stops—Gliding on an aerial toboggan—Kites flying in the wind—Pros and cons of the cambered wing—Natural stability—The need for a tail—Advantages of flying high.

EVERYONE, nowadays, is familiar with the appearance of an aeroplane, but many there are, nevertheless, who do not know what, scientifically speaking, an aeroplane is. They see the machine on the ground: they observe someone giving frantic tugs at something that moves in jerks; they hear a roar, which they know must come from an engine, although why it makes such a noise they doubtless fail to understand; they perceive that, in starting, the machine runs for a while along the ground before rising gently, as if lifted by some invisible moving stairway, into the air; but, still, they do not know why the aeroplane flies.

It has something to do with the wings, of course, but how? That is the question at which the average lay mind stops short, not for lack of ability to understand the problem, but, generally, for lack of some appropriate explanation that will bring what is, fundamentally, a very simple phenomenon out of its proper sphere of aeronautical science into the realm of everyday things that are comprehended by common sense.

There is an elusive aspect of the general view, and only one, that is apt to hide itself from the uninitiated unless brought prominently into the full light of the mind in the very first instance, and that is the significance of a simple scientific expression much used in aviation, namely, " relative motion."

If the man in the street saw an aeroplane apparently standing still in the air, it would not occur to him to think that the machine must be flying through the wind at its full speed, and that its relative motion in the air is quite unaffected by its motion relatively to the ground on which he is standing. Yet the same man knows very well that if he starts running on a calm day he will feel a slight breeze in his face, which is solely the result of his own relative motion through the air. He is also aware that if he puts his head out of an express railway train he will encounter half a gale of wind, notwithstanding that the leaves of the trees may show not so much as a tremor.

If, instead of putting his head out of the window, he were to take a sheet of stiff cardboard and put that outside, he would have a still more practical demonstration of the force of the relative wind, which supports the aeroplane in its flight.

The first sheet, having been put out at random, will, probably, be broken even if it is not wrenched out of his hands. This will set his mind reasoning that he must be careful to hold the cardboard edge-on if he wishes it to remain outside in safety. A second attempt, on these lines, will give rise to still more astonishing results. If the train is moving really fast, the cardboard will exhibit a violent tendency to flap upwards or downwards with the least variation from its truly edge-on horizontal position.

It is at this point that the embryo scientist begins to think really hard. His mind perceives an unsuspected fact that he senses to be of great importance. He has observed that by slightly raising the front edge of the piece of cardboard so that it (the cardboard) is at a slight angle to its line of motion, instead of being truly edge-on, an extremely strong lifting force acts on the cardboard, although its

"Flight" Copyright Photo

SCENE AT THE HENDON AERODROME IN 1912

A Bleriot monoplane descending and a Farman type biplane ascending. The biplane is flying away from the camera and the monoplane is approaching from above.

resistance to motion through the air is but little more than it was when the cardboard was edge-on.

So pronounced is the preponderating value of the lifting effort over the resistance at very small angles, that anyone making this experiment would at once conclude that if he wished the wind to support a weight he would certainly arrange some sort of surface beneath it, like a table, but tilted so as to have only a slight angle of inclination to the line of its flight through the air.

It is improbable that our railway carriage scientist would get further than this of his own accord, and particularly so under the limitations of his environment, but he has served his purpose in introducing us to an important principle in a way that lends itself to repetition by the curious. The speed of a fast railway train has the merit of demonstrating the various phases of the phenomenon on a realistic scale, and if the restrictions of space reflect themselves in the diminutive dimensions of the object that it is convenient to handle in this way, there should, nevertheless, be no excuse for the experiment failing to engender a firm-rooted appreciation and respect for the nature of the lift that a relative wind will exert on the surface of a properly arranged aeroplane.

The inclined flat plate exerts a lifting force[1] because it deflects *downwards* a stratum of air in its flight. If it deflected the air upwards, the reaction on the plate instead of being a lifting force would be downwards. When the plate is set upright, facing the wind, the deflection takes place in every direction as the wind swirls round it, and the reaction is neither upwards nor downwards, but just a straightforward pressure, acting in the line of the wind. In any event, it will be noticed, the force is always perpendicular to the face of the plate. When the plate is slightly inclined it is a lifting force, when the plate is upright it is a resistance. When the plate is edge-on, the resistance is mostly due to the friction of the air against the surface of the plate.

An aeroplane has its table-like supporting surfaces so

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[1] See Appendix on Newton's *Laws of Motion.*

arranged as to get the best lifting effect for the least effort, having regard, of course, to the conditions under which the machine is designed to fly. It is clear, merely from a glance at a number of different aeroplanes, that they are not all exactly alike in this respect, but it will be noticed that they all have one point in common, which is that the surface, instead of being flat, is cambered or slightly bellied like a sail of a yacht.

This is an important analogy, because a yacht is one of those commonplace objects that are so familiar that the man on the quay never stops to ask himself whether or no he understands how it sails. It will be the same with the aeroplane in a few years' time, which is why it is worth while troubling to appreciate an explanation now, in order that one really may be informed as to the essential facts by the time aviation, in common with so many other interesting things, becomes veiled under the ever-spreading pall of public indifference.

A yacht is propelled by the wind into which it sails, but an aeroplane is pushed forward by its propeller, which, like the screw of a motor-boat, is driven by an engine. A real wind needs must blow for the yacht to move ; moreover, the wind must blow obliquely against the sail, notwithstanding that a good boat, well handled, can sail within a few points of the very eye of the wind.

The sail of a yacht is an aeroplane in principle, but its use differs materially from the purpose of the wing of an aeroplane. When the wind blows obliquely on the sail of a yacht, the pressure that it exerts is mostly directed towards capsizing the boat, but owing to the set and camber of the sail the force is also directed slightly forward towards the bows, and the amount of this component is sufficient to propel the boat.

If a real wind were to blow obliquely from beneath on to the sail of an aeroplane, the same propelling effect would be produced, and the main force that tends to capsize the yacht would be turned to the useful purpose of supporting the weight of the machine, which would continue to fly without using its engine so long as the conditions remained appropriate.

The phenomenon of flight without any development of power in the object that is flying is a common occurrence among many kinds of birds, which may be observed to "soar" above cliffs, promontories and other physical obstructions to the horizontal motion of the wind, which tend to give to the wind an obliquely upward course.

In a steady horizontal wind, soaring flight is impossible; likewise is it impossible in a dead calm—the support of which statement by Lord Rayleigh notwithstanding—there are often to be seen in print suppositions that imply the contrary.

Soaring is an art that has been but little practised by man. The late Wilbur Wright and his brother Orville have been almost the only exponents up to the present time. It may be regarded in the nature of superflying, when practised with machines as now built, for although the evidence afforded by soaring birds opens up a fascinating realm of thought, there are many considerations that, for the time being, keep this kind of flying outside the boundary of immediate practical possibility. The object of discussing it here is to emphasize the significance of the relative wind in flight; to show that, under suitable circumstances, a real wind will maintain flight, and to argue therefrom that the purpose of the engine on an aeroplane is primarily to maintain a state of relative motion between the machine and the air, so that practical flying can take place in a calm or any other sort of weather.

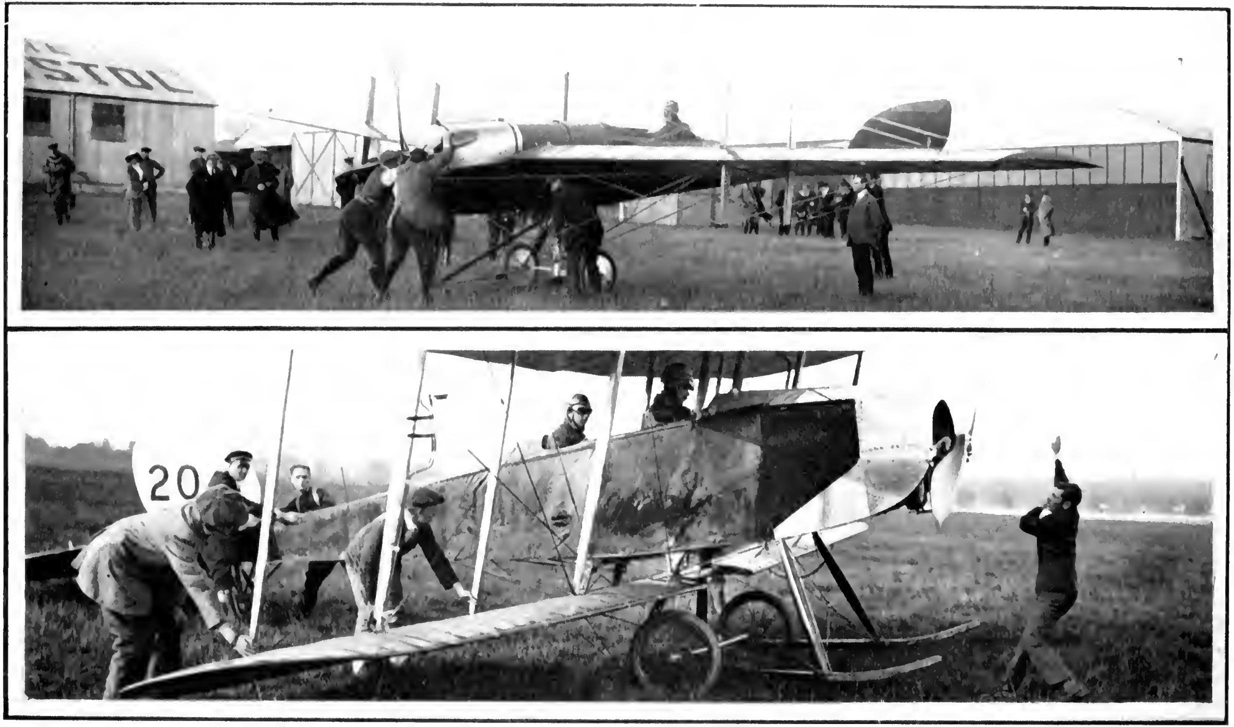
At this point let us become thoroughly familiar with the idea of power in connection with flying. What has been said above about soaring may have given the notion that flight was possible without any manifestation of energy, but nothing is further from the truth. When the wind blows it often possesses enormous power, and when it blows suitably against a windmill, or the sail of a yacht, or the wing of a bird, it may transfer some of its energy into mechanical movement as grinding, sailing, and flying respectively in the three instances cited.

When the air itself does not move, or does not move in a suitable way to enable the transformation of its energy into soaring flight, the power necessary to the continuance of flying must be supplied by the object that flies. The bird flaps its wings, the aeroplane starts its engine. Ordinarily, a head wind is merely an added resistance to flight ; only from winds that blow upwards or pulsate in a certain manner is it even theoretically possible to extract power for soaring flight.

To the uninitiated there may be little resemblance between the action of a bird's wing and that of the propeller which is driven by the engine of an aeroplane. Scientifically, there is a close analogy between them. Nature builds on a plan and with materials that man cannot slavishly copy. One of her masterpieces is the perfect articulation of the joints of an anatomy that permits of such a smooth-acting to-and-fro movement as is manifested by the legs of an animal when walking and of a bird's wing when in flapping flight. The material of the moving members has to be nourished by arteries that must pass across the joint and so nature is limited to this sort of action.

Reciprocating motion is anathema to engineering, but the engineer finds a great compensation in the principle of rotation, and wherever it is possible to do so the mechanism of mechanical power is confined to the continuously revolving shaft. Thus, on an aeroplane, you find an engine, which generates the power, a revolving shaft, which transmits the power, and a propeller on the shaft, which transforms the power into thrust and so pushes the machine as a whole through the air. Generally, the presence of a shaft is not visible externally, because the propeller is attached close up to the engine ; often, too, the engine itself revolves with the propeller, but these are details that it would be a digression further to discuss in the present place.

Power is essential to flight truly, but when the engine stops in mid-air, the aeroplane does not fall to the ground, nor is the pilot in any need of a balloon, or of a parachute, or of any other life-saving apparatus in order to reach the earth safely. The popular idea that some such precaution



"Flight" Copyright Photos

STARTING UP

The above photographs show the method of starting the engine by turning the propeller. The upper illustration is a photograph of the Martin-Handasyde monoplane; the mechanics are just about to swing the propeller. In the lower photograph, which shows one of the Royal Aircraft Factory's biplanes, the mechanic has just released the propeller and is getting clear of its rotation.

as this would be a safeguard against accidents, does but proclaim its own ignorance of the basic principles of flight, for the aeroplane itself, when properly designed and flown, possesses an inherent quality that is far better than any artifice, and without which, indeed, flying by aeroplane would be quite out of the question.

A machine that is already in mid-air can always continue to fly for a considerable distance, even if the engine does stop accidentally, provided that the direction of the flight is obliquely towards the ground. Roughly speaking, a modern aeroplane can glide in this manner for a distance equal to six times its height above the ground : for example, if it is at one thousand feet up in the air when the engine stops, the pilot has his choice of landing more or less anywhere within a radius of a mile. He must, of course, immediately make up his mind, from the lie of the land and the direction of the wind, which spot within sight should best serve as a landing-ground. The downward path begins directly the engine stops and there is no means of checking the descent for a fresh observation.

The speed of gliding is somewhat slower than the normal fast-flying speed; otherwise, the conditions of gliding are the same as flying and the machine is equally under control. A slope of 1 in 6 is not steep and, except that a landing is essential and that the pilot has no alternative than to make the best of a bad ground, if he finds, at the last moment, that he is mistaken in his choice, the danger of alighting under necessity is no greater than that of returning to earth in the ordinary way. A normal descent is in any case accomplished by a glide, but the engine is ordinarily kept slowly rotating so as to be in readiness for instant action if needed.

Let us now make a brief résumé of the foregoing points, which have followed perhaps some slight inconsequence in their order of presentation. In the first place, there is the readily demonstrated fact that a suitably arranged surface in the form of a flat plate, which technically is commonly called a plane, will support a considerable weight when slightly tilted to the wind. Secondly, there is the fundamental theory, which is equally easily proved to be fact, that this phenomenon depends only on relative motion between the plane and the air and does not demand that a wind should blow that can be felt by anyone standing on the ground. It makes no difference whether the air blows under a stationary plane, as in the case of a kite flying in the wind, or whether an aeroplane flies through a calm atmosphere, the supporting effect of the aerodynamic reaction between the plane and the air, which is set up by their relative motion, is identical in principle and similar in degree for both cases so long as the same relative velocities prevail and other things are equal.

Further, we have established the very important principle that power is as essential to flight as to any other form of motion, and that, under suitable conditions, which, as yet, do not prevail for modern aeroplanes, the energy of the wind is available for this purpose. Continuous flying by the aid of the wind alone is called soaring. In the absence of a suitable wind and proper means for utilizing its energy, an engine is, therefore, essential to the maintenance of mechanical flight and all aeroplanes are fitted with them.

It has been explained, however, that should the engine fail in mid-air, the aeroplane can still continue to fly for a considerable, although strictly limited, distance, by gliding towards the earth, and that in its inherent ability to play the aerial toboggan lies the natural safety of this form of machine.

Arising out of the discussion on soaring, or flight by the aid of the wind, an analogy was drawn between the action of the sail of a yacht and that of the wing of an aeroplane, an important detail being indicated in the cambering of the surfaces. It is significant, too, that birds' wings are invariably cambered, which fact was observed and commented upon, as a feature that ought to characterize the design of aeroplane wings, by Sir George Cayley as long ago as 1809.

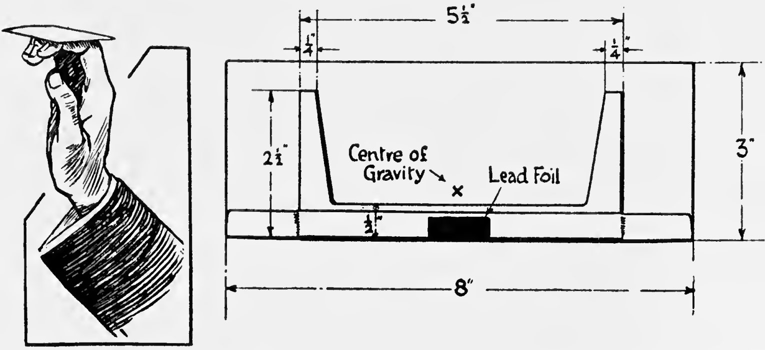
Of the various qualities that make a cambered wing superior to a flat plate more will be said later; here it needs only to be pointed out that it will support more weight and be the cause of less resistance to motion at any given speed. Thus, it enables the engine to perform a greater amount of useful work in a given time for the same expenditure of power, either by carrying a heavier load, or by transporting the machine at a higher rate of travel through the air. It does not follow that there is any especial virtue in an excessive amount of camber : the contrary may, in fact, be the case. The amount of camber and other peculiarities of wing-form are technical questions, the discussion of which must be deferred, as they cannot readily be dealt with in general terms. There is, however, one aspect of the principle of cambering that it may be interesting to consider forthwith and that is its influence on " natural stability."

CHAPTER II

THE INSTRUCTIVENESS OF PAPER MODELS

Natural stability in a simple form—Flat *v.* cambered wings—Why aeroplanes are broader than they are long—The " T " test—Why an arrow flies straight—The Centre of Pressure and the Centre of Gravity—The purpose of the tail.

NATURAL stability is a much-abused term, being far too commonly employed without a qualifying explanation, and having in itself no very definite meaning. It is, however, a fact, easily demonstrated by simple models, that certain forms of surface exhibit in flight an inherent tendency to recover their equilibrium if disturbed, whereas others exaggerate their initial loss of balance to a point at which they capsize.



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Sketches giving suitable dimensions for a simple paper glider, and showing how to launch it. Plasticine may be used instead of lead foil for the weight. A post-card cut to shape will serve to stiffen the paper as shown.

Thus a perfectly flat plate, such as, for example, may be made from a half-sheet of stiff note-paper cut in two lengthways, will demonstrate a high degree of natural stability if loaded with a small weight like a split shot in the

"Flight" Copyright Photo

The Cody biplane arriving at the Hendon Aerodrome from Farnborough.

very centre of its front edge, and launched broadside-on into the air. By taking a little care in adjusting the weight and choosing the paper, it may be made to glide in a surprisingly steady manner across the full length of a room, and even when dropped vertically will recover itself and glide off in an almost horizontal direction, provided that there is sufficient room for it to make the initial fall before touching the ground.

This matter of the necessity for sufficient height in which to fall, has, by the way, a very practical and a very serious aspect in real flying, where altitudes in the order of 1000 feet have long been recognized as realms of comparative safety for this very reason. During its vertical descent the paper model gains the velocity required to establish the relative motion between itself and the air, which alone will support it in flight. When a real aeroplane has for any reason lost headway in mid-air, the pilot's only safe course is immediately to point the nose of the machine earthwards, and to dive downwards until he recovers his proper flight-speed.

Much more can be learned from the use of paper models than can be described here, but it is not without interest to refer to another simple experiment that teaches a useful lesson. Having observed the natural stability of the loaded flat plate, it is instructive to see the inherent instability of the same surface when it is cambered. The cambering may be accomplished, for example, by stretching a silk thread between the leading and the trailing edges, so that the paper is bent like a bow.

Launch this modified design with what care you may, it will inevitably capsize before it has gone far, and in this simple yet very convincing manner will bring you face to face with a most interesting phenomenon, which, technically, is referred to as the travel of the "centre of pressure." More will have to be said about this matter when we have progressed further into our subject.

It is difficult to overrate the advantage of studying the fundamental principles of aviation by the aid of elementary models such as may so easily be made from the simplest sort of material. Half a sheet of stiff note-paper, casually dropped from the hand, pursues a zigzag course that is instructive. No movement takes place without some guiding force at the back of it, and the persistent repetition of a recognizable action is a sure sign of some governing principle being at work, even when the performance as a whole is apparently so erratic as is the fluttering of a piece of paper while it is falling to the ground.

Cut the same piece of paper into the form of the letter T, and then repeat the experiment by dropping it head first, and again tail first. If the model has been made from suitable paper, it will always reverse in the air when it is dropped head first, and will come to earth stem first. At first sight, the significance of this result may not be apparent; actually, however, it affords a very simple and very direct proof of the advantage of flying aeroplanes broadside-on instead of end-on.

The end-on aspect, or that position in which the plane flies with one of its narrow edges leading, would probably suggest itself to most people as the common-sense way of arranging the planes on a machine instead of placing them, as they are at present, broadside-on to the line of flight. Undoubtedly, the end-on aspect would be a more convenient position in many respects, but unfortunately it is by no means so useful in flight. In this connection it is interesting to observe that the wings of birds always have a greater dimension in span than they have in the line of flight.

The difference in effect between these two methods of arranging a similar surface is clearly demonstrated by the result of the above-described T test, which was, I believe, first devised for this purpose by Mr. F. W. Lanchester. If the T piece be so cut that the stem and the cross-bar are of equal size, then we have two similar planes flying under identical conditions, except that one is broadside-on and the other end-on to the line of flight. Were they equally effective, there would be no reason for the phenomenon that accompanies the experiment. The fact that the cross-piece of the T which is flying broadside-on invariably lifts itself into the uppermost position when dropped head first, shows that the pressure upon it is greater than is manifested on the stem of the T, which is of the same area, but is flying end-on. Clearly, therefore, the most effective way of using a given amount of surface for the purpose of supporting a weight, is to arrange it so that it flies broadside-on, and it is for this reason that the wings of aeroplanes fly in this aspect.

Another illustration of the same principle is afforded by the flight of an arrow. Without feathers, an arrow-shaft would have no stability of direction, and would in many cases finish its journey through the air tail first. The feathers themselves are in end-on aspect, but regarding a pair of them in respect to the very narrow shaft, they constitute a tiny aeroplane flying broadside-on like the cross-bar of the T. The air pressure upon them is always greater than the pressure upon the shaft, consequently any disturbing influence on the shaft, tending to swerve it from its course, is counteracted by a superior force on the feathers, which maintains the direction of motion unchanged. For the same reason, the steering of dirigibles on a *straight* course is much facilitated by the presence of fin surfaces well aft.

It may be desirable to explain in respect to these tests with paper models that even an apparent calm is full of disturbances, which prevent light objects, such as a sheet of paper, from pursuing a truly edge-on motion for any considerable distance. You may drop a flat sheet of stiff paper, edge-on, with great precision, but it will certainly be disturbed before it has fallen more than a foot or two. Directly the paper ceases to follow a perfectly edge-on course, it assumes an inclination to its line of motion, and becomes an aeroplane in full flight.

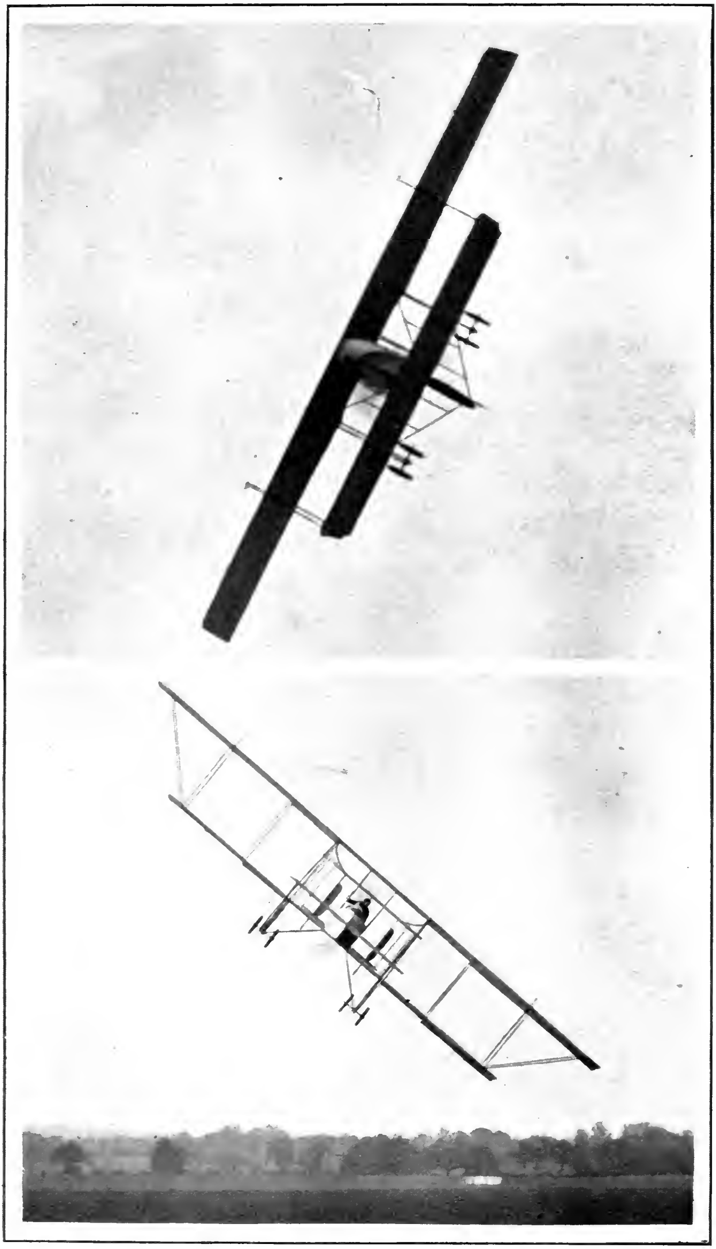
There is a very important phenomenon associated with the air pressure on an inclined plate, to which it may be as well to direct attention at once. This is that the centre of pressure, or spot where the lifting force of the air seems to be concentrated, lies close to the front edge of the plate when the angle of inclination to the line of flight is very small. When, for any reason, the plate becomes more tilted, so that its angle of inclination to the line of flight is coarse instead of fine, then the centre of pressure travels backwards towards the centre of the plate. If the plate were held vertically upright facing its relative wind, the centre of pressure would coincide with the centre of figure.

If the location of the centre of pressure (often written C.P. for short) is near the leading edge of a plate that is falling edge-on vertically through the air, it is evident that the lifting force will tend to turn the plate into a horizontal position. This is precisely what happens when the sheet of note-paper makes its first flutter into its zigzag path. The energy of its motion acquired during the fall expends itself on a brief horizontal flight, during which the plate loses headway, and ultimately falls backwards. The repetition of these phenomena in definite sequence is the simplest explanation of an apparently erratic performance.

If the plate carries a little weight on its front edge, such as a pellet of buck-shot, a piece of plasticine, or even an ordinary pin if the model is very small, a coincidence may be established between the centre of pressure and the centre of gravity (the point where the weight seems to be concentrated) so that the levelling of the plate towards a horizontal position is checked at a critical angle. Under these conditions the plane will proceed to glide in a beautifully smooth manner, and will, in fact, have become an elementary aeroplane under the automatic control of its own inherent stability. The success of the experiment depends on the selection of a weight proper to the size of the plate, and demands considerable care and patience.

The nature of the inherent stability of the loaded flat plane is now easy to see, for it evidently depends on the variable leverage that is exercised about the fixed centre of gravity by the movable centre of pressure as it travels to and fro under the influence of the changing angle or attitude of the plane in flight.

It has been explained how a change in the angle is initially due to some slight disturbance in the air, and how, at very small angles, the centre of pressure is quite near the leading edge of the plane. At first, therefore, the centre of pressure will be in front of the centre of gravity, which never changes its position, but as the front edge of the plane is



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BANKING

The top photograph shows Chevillard executing a banked turn with the Henry Farman biplane over the Brooklands Aerodrome, 1913. The lower photograph is of Verrier on the Maurice Farman turning at a comparatively low altitude. The foreground in the lower view gives an accurate horizon from which to judge the angle of the machine, but the upper photograph was also taken by the same staff photographer of *Flight*, and the attitude is in no way an exaggeration of the position that Chevillard frequently assumed.

tilted upwards, the centre of pressure will travel backwards until it coincides with the centre of gravity, and so temporarily establishes a condition of equilibrium. This state, however, is only momentary, for as the plane has already commenced to swing upwards, it is certain to swing beyond the neutral position of balance, and so the centre of pressure will be caused to travel still further towards the rear, until the upward swing of the front edge has stopped.

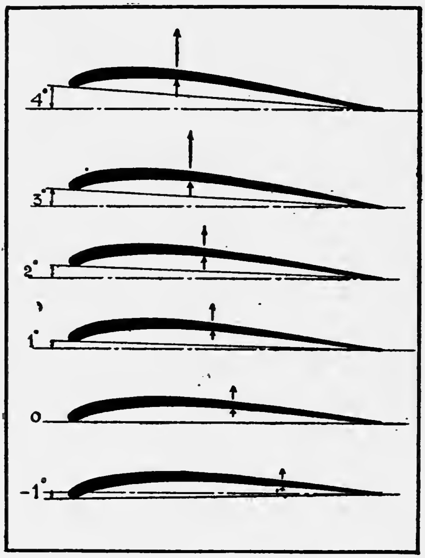

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Diagram illustrating a wing section in a series of different attitudes, showing, by the position of the arrow, the retrogression of the centre of pressure as the angle of incidence becomes finer.

The centre of pressure is now well behind the centre of gravity, and the plane has lost headway, so that it tends once more to fall headlong in order to regain its velocity. This process is repeated as an undulating motion during the first portion of the flight of the model, but by degrees the undulations damp themselves out, and the attitude of the plane remains steadily in one position, slight disturbances being immediately counteracted by slight movements of the centre of pressure as above described.

When this experiment is tried with a cambered plane of single curvature it results in failure every time, because the centre of pressure plays a trick that totally destroys its former good effect. Within the range of angles commonly used in flight, the centre of pressure travels *backwards* as the angle of incidence decreases. This is diametrically opposite to the phenomenon that occurs with a flat plate, consequently any disturbance of a cambered wing in flight is accompanied by a movement of the centre of pressure that itself augments the disturbance. Instead of being like the flat plate, inherently stable, the cambered wing is inherently unstable, for an augmented disturbance must ultimately culminate in capsizing the model.

The above applies to all wings at present used on aeroplanes ; it does not follow that it is impossible to find a wing section without this characteristic. More, however, is said upon this subject in another chapter. For the moment it is all-important to recognize the prevailing principle, and to realize that there is only one way in which to correct this unfortunate tendency, and that is to provide the cambered plane with a tail, or with the equivalent of a tail, and this brings us to the consideration of the principal parts of a real aeroplane, which is the subject-matter down for discussion in the next chapter.

CHAPTER III

SOME CONSTRUCTIONAL FEATURES OF THE MODERN AEROPLANE

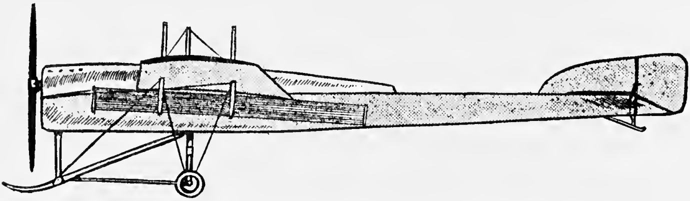
Aeroplanes compared with birds—Monoplanes and biplanes—Difficulties about length—Span, chord, and gap—Why the centre of pressure does not stay still—When flight was impossible—What Sir George Cayley knew—How an aeroplane is steered—What the elevator is for—Characteristic features of design.

LIKE birds, aeroplanes possess bodies, wings, and tails; they also have undercarriages that serve the purpose of legs when alighting. The class of machine that most closely approximates to the bird type is the typical monoplane of the present day; biplanes often having no resemblance whatever, in appearance, to Nature's best flyers.

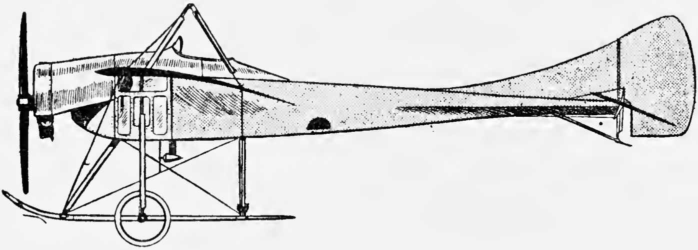
The technical difference between a monoplane and a biplane, however, is merely that a monoplane, in common with the bird, possesses only one pair of wings, while the biplane is provided with two main supporting surfaces, one situated above the other.

The main supporting surfaces of a machine, which in a monoplane are commonly called wings and in a biplane are more usually called planes, are always readily identified because they are by far the largest and most prominent objects visible to the eye at a casual glance. This is not surprising when one realizes that the span or measurement of the wings from tip to tip is seldom less than 30 ft., while some measure over 60 ft. across.

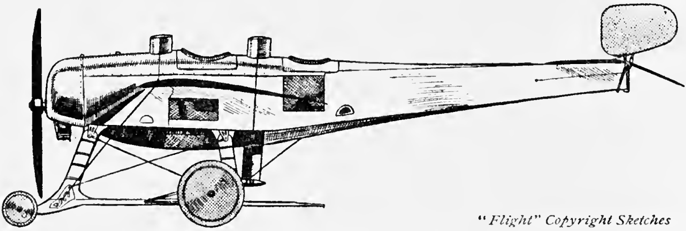
There is apt to be considerable confusion about the use of the term "length" when applied to aeroplanes, owing to the already mentioned fact that the wings fly through the air broadside-on. It is natural, when speaking of the wings alone, to refer to their longest dimension as their length, as one would do when speaking of any other object ; but, when the machine is in flight, one might equally well remark how short is the length of the wings compared with that of the machine as a whole, meaning thereby the measurement of the wing from its leading edge to its trailing edge. For this reason, it has become customary to apply the terms "span" and "chord" in this connection, and having an obvious derivation they justify their existence as technical words and are deserving of general use. One speaks of the span of a bridge and of the chord of the arc of a circle :



The Martin-Handasyde monoplane at the 1913 Aero Show.



The Vickers monoplane at the 1913 Aero Show.



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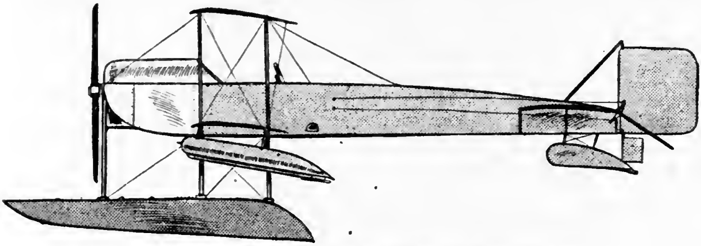
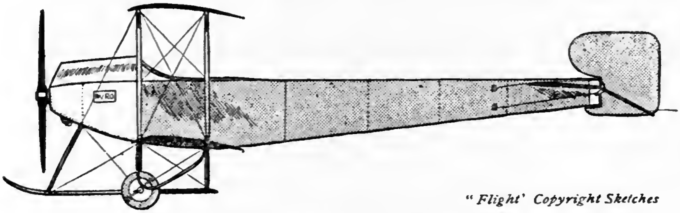
The Bristol monoplane at the 1913 Aero Show.

both expressions have an analogous significance in reference to the aeroplane.

Thus, the wings, which are the supporting members of the machine, form a kind of bridge that spans the air in order to hold aloft the weight; the wings themselves, as has already been mentioned, are cambered so that a string stretched between the leading edge and the trailing edge would occupy the position of the chord to the arc that is formed by the wing surface. This arc, by the way, is not circular, but is of such contour as is found best by experiment on models that are tested in an artificial wind. The highest point of the curvature of any wing section is always nearer the front edge than it is to the trailing edge of the wing.



The Short hydro-aeroplane at the 1913 Aero Show.



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The Avro biplane at the 1913 Aero Show.

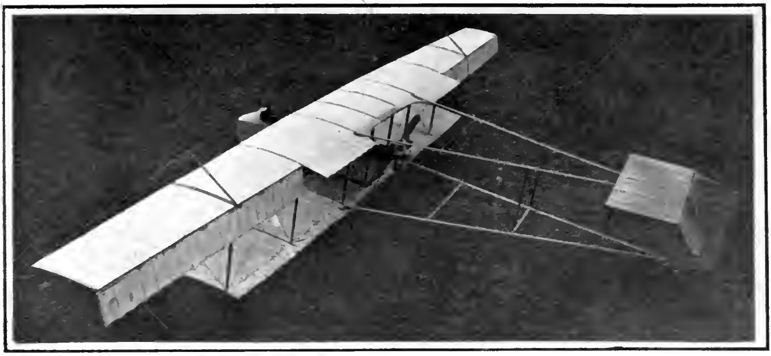
It has been pointed out that the cambered wing was recognized as a possibly better form of supporting surface than a flat plate by Sir George Cayley more than a hundred years ago, and his conception of other proper features for an aeroplane was singularly prophetic of the modern machine. He included as two of its most important accessory features an elevator and a rudder. Cayley, having satisfied himself that an aeroplane was a reasonable conception, imagined it in a reasonable and simple form. He argued that since it would sail in instead of on the aerial ocean, it must be equipped with two sorts of rudder, one for steering to the right and to the left in the ordinary way and another for steering up or down. This latter we now call an elevator in order to avoid confusion of terms; actually it is merely a pivoted plane just like a rudder, but arranged horizontally instead of vertically.

In a monoplane, the rudder and the elevator form part of the tail of the machine. The term "tail" applies to a group of organs of which the two just mentioned are hinged and movable to perform directional functions under the pilot's control. A third plane, horizontally arranged like the elevator, but rigidly fixed, is commonly added in order to confer some degree of natural "longitudinal stability" in flight.

In those aeroplanes that have long boat-like bodies extending the full length of the machine, this fixed tail plane is often a mere fin-like excrescence. On other types, however, the rigid portion of the tail is a much larger affair; in either case, it commonly carries the elevator as an extension in the form of a hinged flap. The purpose of the fixed tail-piece has already been indicated; it will be remembered that, when discussing the natural instability of the cambered plane, mention was made of the fact that the missing quality could be incorporated by equipping the plane with a suitably arranged tail member.

One principle involved in a suitable arrangement is that the effective angle of the fixed tail must be less than the effective angle of the main wing. This is to say that if the two were extended they would make an angle with one another; the angle is so slight, however, as to be invisible to the eye, but the principle is there and it is commonly referred to as the fore-and-aft "dihedral." Its object is, as has been mentioned, to confer stability in flight, but for the further discussion of this aspect of the subject it will be desirable to refer to another chapter.

As this book is written to be as far as possible an in-



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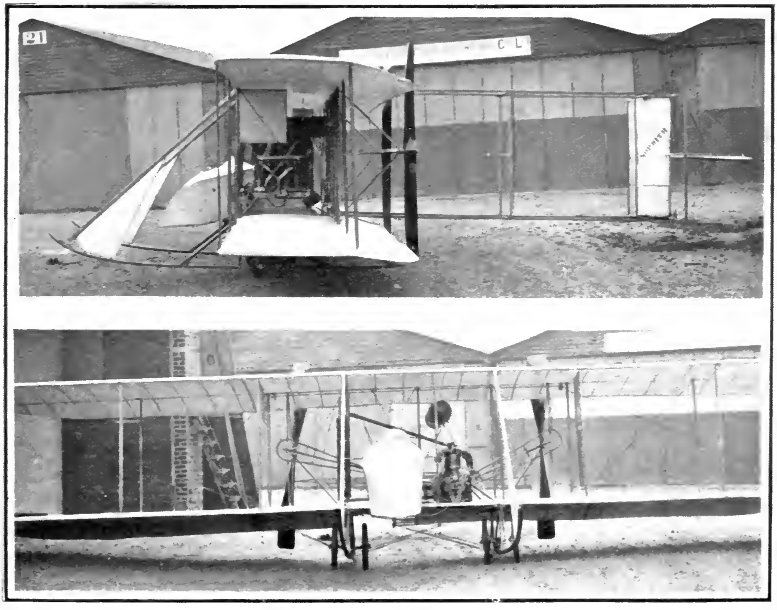
View of the Henry Farman biplane showing the balancing flaps on the upper plane. The upper plane has a much greater span than the lower plane. The particular machine illustrated was one much flown by Grahame-White during 1912.



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Two views of a Wright biplane, built originally by Burgess in America, but reconstructed later by Sopwith at the Brooklands Aerodrome.

troduction to the subject, it has been necessary to assume that the reader is unaware of the purpose of many outstanding characteristics of modern aeroplanes, which must, nevertheless, in fact, be familiar by sight. At this stage of the description it would be as well, therefore, if some particular attention were paid to the illustrations. They have been chosen especially for the purpose of making clear the more important distinctions between machines and also to show some of the chief phases of flight to which reference is made in other chapters.

The presence of the two main planes as the distinguishing feature of biplanes is apparent at a mere glance and any confusion as to type should, therefore, be impossible to anyone who has once appreciated the simple distinction that exists between biplane and monoplane. The appropriateness of the term "wings," when applied to the supporting members of monoplanes, should also be sufficiently self-evident from the pictures to call for no further comment. Moreover, after previous explanations it should be unnecessary to remark that the wings do not flap.

Instead of flapping its wings, to do which would involve constructional difficulty, the machine carries a propeller. This is usually a two-bladed object built of timber, and it measures about 8 ft. 6 in. or more in diameter. Owing to its high speed of rotation, which commonly is between 900 and 1200 revolutions per minute, the propeller is invisible in some of the machines that are photographed in flight.

It is common practice to put the propeller in front and to mount it upon the engine crankshaft. A general study of the designs of the machines makes it very clear that the forward position—or "tractor screw" as the propeller in front is often called—is structurally convenient.

Monoplanes were from the first designed with long girder-like bodies, which necessitates a single air screw being placed either in front of the wings or behind the tail. When this form of the body became more common on biplanes the tractor screw accompanied it, and in most of the machines illustrated the propeller will be seen in front.

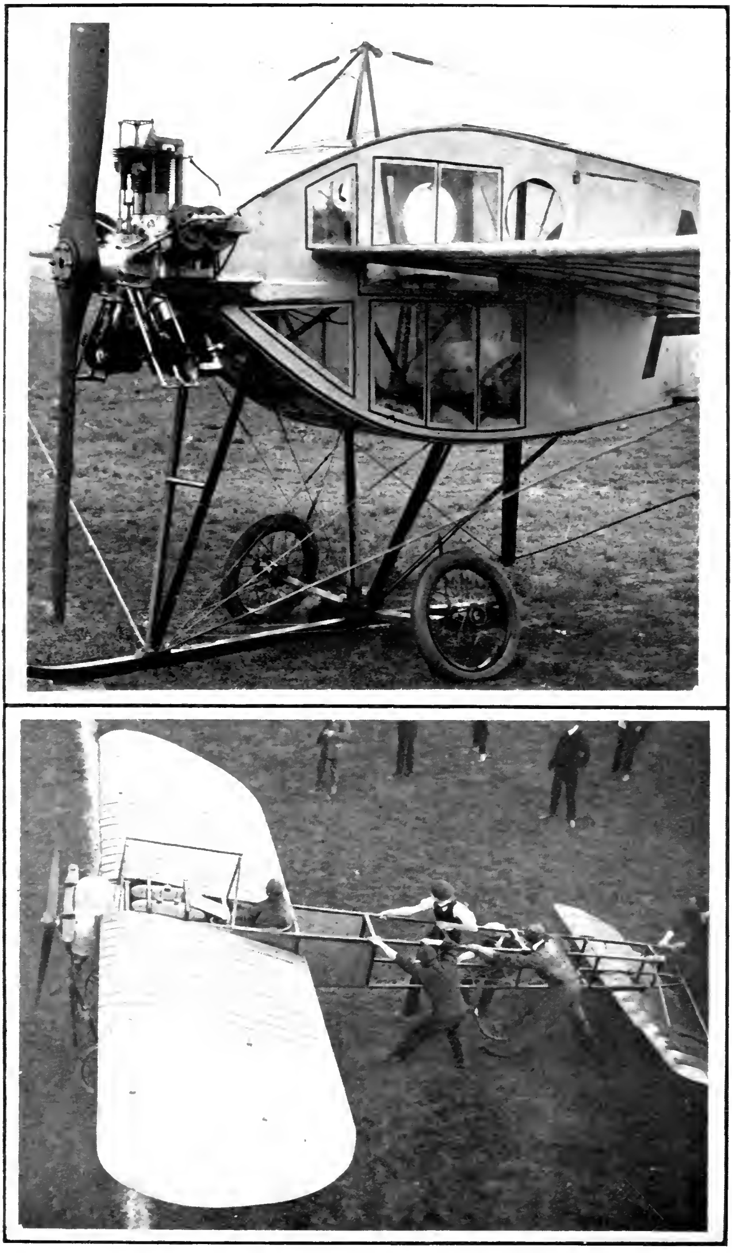
Those that are exceptions include the Farman biplane, in which the propeller is situated between the main planes and the tail. Its presence in this position draws attention to the dimensions of the outrigger framework supporting the tail, which has to be large enough to clear the propeller on all sides. Yet another interesting thought that arises from a consideration of the propeller being in this position is that its draught blows only on the tail. When the propeller stops in mid-air, therefore, the tail suffers an immediate reduction in relative speed, which may cause it to sag and so tilt the machine nose upwards into a position that is called *cabré.*

With the propeller in front the draught affects both wings and tail, and although not necessarily to an equal extent its cessation would in this case cause a less marked difference of the effect on the two members.

The only machine illustrated having two propellers is the Wright biplane, which has been thus characterized from its original design. In another chapter some attempt is made to explain the action of propellers in an elementary way, and it is there shown that large diameters tend towards higher efficiency, especially in low-speed flight. The Wright biplane is designed for comparatively slow speed, and the makers thereof have always been strongly in favour of using the largest propellers that it is possible to fit to the machine. From the pictures it is evident that the builders have incorporated the idea to the fullest limits of practical possibility, for not only are there two propellers, but each has a diameter as large as the ground clearance will permit.

Chains are used to drive these propellers, and a chain is also used to drive the very large single propeller on the Cody biplane.

Timber, as has been mentioned, is used exclusively for propellers at the present time and in most instances there are only two blades. Some exceptions to this will, however, be noted among the various machines illustrated, the Royal Aircraft Factory's biplane, B.E. 2, for instance, having a four-bladed propeller of a design that has ap-



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THE PILOT'S SEAT

In the lower illustration the pilot is seen seated in a Bleriot monoplane, which is about to start. The mechanics are holding on to the fuselage against the pull of the propeller. The upper photograph shows a totally enclosed Avro monoplane, the pilot being completely surrounded by the body. These machines were in use in 1912.

parently been very successful in use. In the construction of wooden propellers several layers of timber are carefully glued together so as to form a laminated block out of which the propeller is carved to its proper form.

Of the engines used to drive the propellers, the Gnome very properly deserves first mention owing to the undoubted stimulus that its properties gave to the development of aviation during the period when it was exceedingly difficult to obtain any other motor of a sufficiently light weight for its actual power. Its peculiarity is that the engine itself revolves instead of the shaft: the propeller is, of course, fastened to a sleeve that is integral with the engine casing. Its cylinders, of which there are either seven or fourteen according to the power, are machined from solid pieces of steel and are set radially about the steel crank chamber.

This is, however, not the only type of radial engine, nor are all those that have their cylinders so arranged of the rotary kind. The Anzani on the Avro, illustrated opposite page 22, is a stationary engine; that is to say, its cylinders are fixed to the body of the machine, while its shaft, which carries the propeller, revolves.

Light weight is essential to successful aeroplane construction and the primary reason underlying the design of radial engines, as such, is the fact that cylinders so arranged are compact and, therefore, economical of material.

Stationary engines, that is to say those in which it is the shaft that revolves, are, for aviation work, often made with their cylinders arranged in V formation. The Renault engine on the Maurice Farman and on the B.E. 2, is a popular example of the V type. Among the stationary upright engines with vertical cylinders all in line, the Austro Daimler on the Cody and the Green on the Dunne monoplane are illustrated in the photographs.

The names of the engines, it will be noticed, differ from those of the aeroplanes on which they are used. The business of engine building is, very naturally, an undertaking demanding specialization, so it originated as and still remains a separate branch of the industry.

The engine, being the heaviest object carried by the aeroplane, determines by its position the arrangement of some other parts of the machine. The propeller, too, needs considerable space in which to revolve and so determines the height of the undercarriage necessary to provide adequate clearance between the propeller tips and the ground. Nor can this height be greatly curtailed by raising the propeller-shaft, for the axis of the propeller represents the line of its thrust, which cannot usefully be raised indefinitely above the other principal objects of the machine.

In monoplanes the propeller-shaft is ordinarily on a level with the middle of the body, in biplanes it occupies a position about midway in the gap between the planes. It is very clearly indicated in this position in one of the pictures of the Cody biplane in flight, for on the Cody the propeller-shaft is separate from the engine, and its elevated position causes it to become a very prominent object in a side view of the machine. The shaft in this case is, as has been mentioned, driven by a chain.

In the picture of the biplane B.E. 2, it will be observed that the propeller-shaft is raised above the centre of the body so as to be more nearly in the centre of the gap. Alternatively, it will be noticed in the photograph of the Dunne monoplane how the shaft lies below the level of the wings because in that machine the heavier objects, including the pilot, are also beneath the wings.

When the machine is flying level, the chord line of the wings ordinarily makes a slight positive angle with the horizon, and according to the angle, the shape of the wings and the speed so does the lift vary per unit of wing area. It is from data connecting these three factors that the size of the wings is calculated. If pictures showing various machines in side view are compared one with another, some idea of the angle of incidence of the wing will establish itself in the mind.

The angle of incidence is the angle made by the chord of the wings with the line of flight, which in most cases may be assumed to be represented by the propeller-shaft.

It has been explained that the chord is the line joining the leading edge of the wing with the trailing edge, and it will be observed that the under side of the wing surface is cambered so as to be concave to the chord.

Owing to the presence of the wing framework between the surfaces, the upper face of the wing is more cambered than the lower face. It is the upper side that contributes most to the lifting effort of the wing in flight.

Another picture of interest to which it is necessary to draw attention is that of the Breguet biplane, which is seen standing on the ground in the photograph facing page 26. Most machines when at rest occupy positions that differ considerably from their flying attitudes owing to variations in the height of the support under the tail. The tail-skid is comparatively an insignificant member of the design: provided it serves its purpose as a protection, the precise position in which it causes the machine to stand is a matter of small consequence. It is necessary, therefore, to be cautious about judging the angle of incidence by the general attitude of the wing as the machine stands at rest.

In the case of the Breguet biplane, moreover, there is need to remember that the wings themselves are attached to their spars by springs. These springs " give " under the air pressure in flight and so cause the wings automatically to change their angle of incidence. From the picture of the machine on the ground it might be thought that the angle of incidence was abnormally large, for the wings, when not supporting the weight of the machine, do assume a very steep pitch.

A peculiarity of this machine is that it has only one spar to each wing. This spar is a steel tube. Ordinarily, as at present constructed, the wings of aeroplanes, whether monoplanes or biplanes, contain two spars each and they are usually made of timber.

Wing surfaces, as at present used, invariably consist of varnished fabric, which is tightly stretched over and fastened to the wing framework. This framework ordinarily consists of the two spars already mentioned and a series of curved ribs joining them at intervals. These ribs produce the camber of the wing: the interior structure is, or should be, properly braced by steel wire; otherwise, special stresses are thrown upon the fabric and its fastenings.

It has been explained that the angle of incidence of the wing and its camber determine its lifting effort per square foot of surface at any particular speed. The speed is limited by the resistance in relationship to the engine power; the resistance is ordinarily expressed as a fraction of the weight. Owing to the variation of lift with speed being such as to provide a much greater effort at high speeds than at low speeds, less wing surface will suffice for machines that are designed solely to fly very fast. The relationship between the lift per unit of surface and the speed is, with ordinary wing-forms, such that if the speed is doubled the lift per unit of surface rises to four times its original value for the same angle of incidence.

For machines intended to be able to fly slowly with ease, large surfaces are essential. When the weight to be carried in flight is also heavy, the total wing area reaches an amount that is preferably constructed in two units. These being superimposed, cause the machine to be called a biplane.

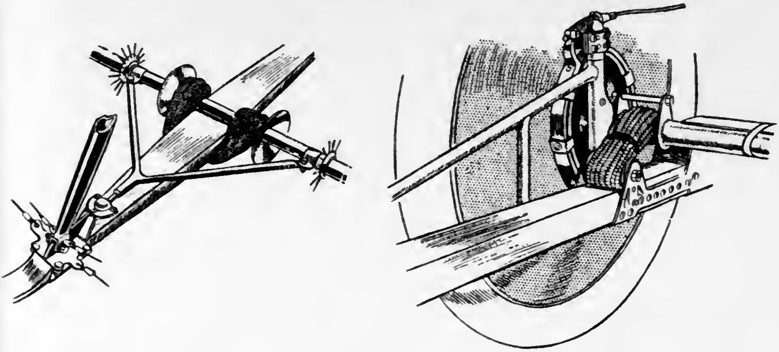
Reverting to the subject of undercarriages, it is interesting to study the various designs, and to observe the prevalence of those that combine wheels with skids. This type of landing chassis was originally evolved by Henry Farman, and various modifications as well as the original form are in extensive use.

As fitted to the Farman biplanes, each skid carries a pair of wheels, which are joined by a short axle that is lashed to the skid by elastic. A steel radius rod hinged to the axle and the skid serves to limit the stretch of the elastic to its proper range of action. If the elastic were to break under the strain of a very rough landing, the skids and the undercarriage struts still remain as a protection to the machine. In several cases the breaking up of these undercarriages has absorbed the shock of a faulty landing sufficiently to save both pilot and the machine from what otherwise might have been very serious consequences.

On the Bleriot monoplanes an altogether different type of undercarriage is employed. It has no skids, and the wheels

"Flight" Copyright Photos

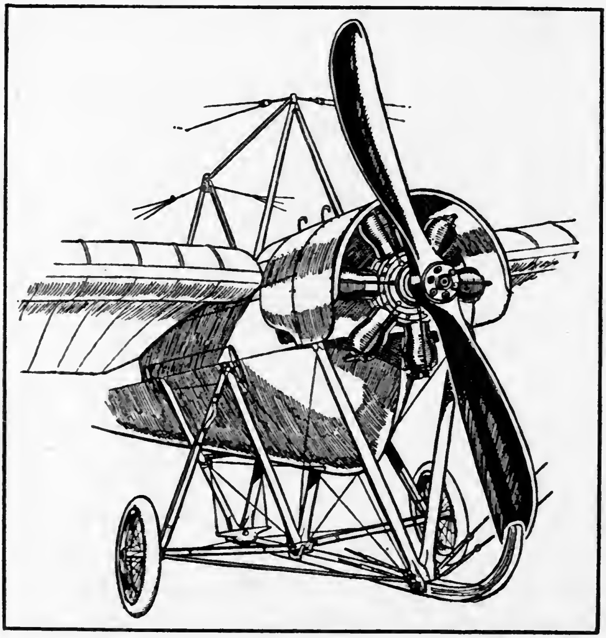
1. The Breguet biplane.
2. The "B.E. 2" alighting on ploughed land.
3. The Deperdussin monoplane starting on ploughed land in the Military Aeroplane Trials.



A. B. *"Flight" Copyright Sketches*

(A.) Sketch illustrating the method of attaching the axle by rubber cord to the skid of a Henry Farman biplane.

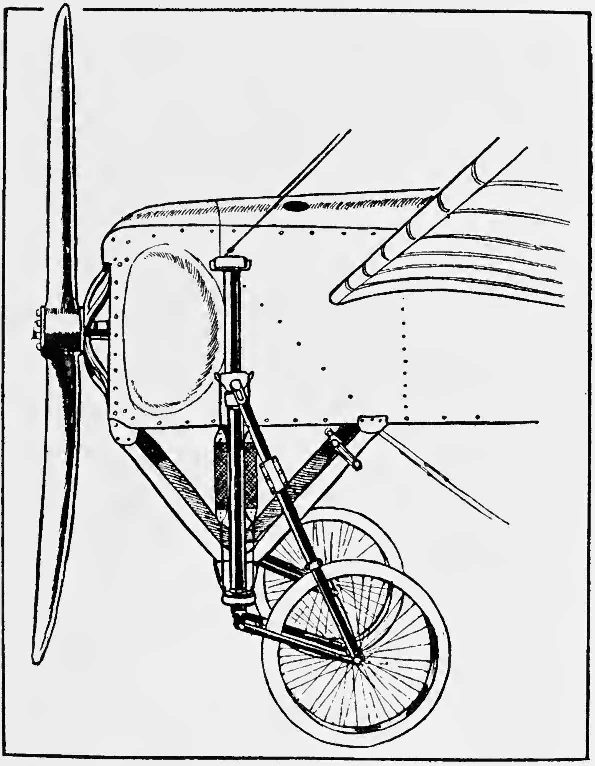
(B.) Sketch illustrating the elastic suspension on the Bristol aeroplane exhibited at Olympia, 1913. A brake drum is fitted to the wheel for pulling-up on the ground.



"Flight" Copyright Sketch

A typical central skid undercarriage, as exemplified on the Handley Page monoplane.

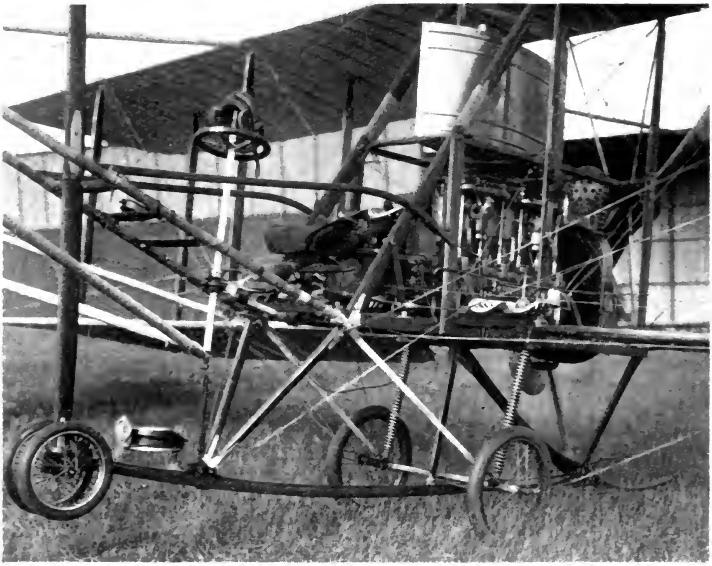
have a great range of movement against the action of strong elastic springs placed just outside the supporting columns by which the wheel brackets are attached to the body of the machine. While the softness of such a suspension has, of course, many advantages, it is necessary to effect a skilful landing in order to avoid bouncing.



"*Flight*' *Copyright Sketch*

The Bleriot undercarriage.

For the support of the Cody biplane, steel springs are used in conjunction with one pair of wheels and a strong central skid. At the rear, this skid joins a member somewhat resembling a kangaroo's tail, which scrapes along the ground to serve as a brake when the machine is coming to rest. Ordinarily, no special mechanical device is provided



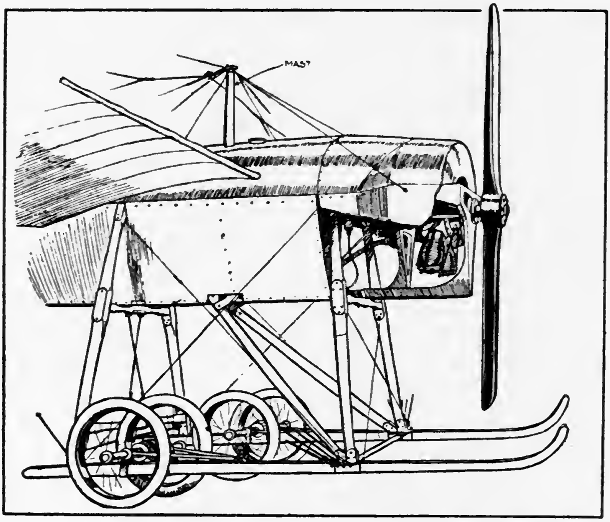
"*Flight*" *Copyright Photos*

UNDERCARRIAGES

The upper photograph shows the central portion of the undercarriage of the Cody biplane as used in 1912. The lower photograph illustrates a Bleriot monoplane of the same date.

on an aeroplane for the purpose of checking its ground speed after alighting.

Regarded as an appanage of the machine in the air, the undercarriage is merely a nuisance, for it adds weight and resistance. For the beginner, a substantial landing chassis is a safeguard of some importance, but on machines built for skilled pilots the undercarriage might often be less conspicuous, were it not for the presence of the propeller. Wheels are, of course, essential in order to enable the machine to run over the ground when starting, but it is interesting to recall that the early Wright biplanes were designed without wheels in order that they might carry as little unnecessary weight into the air as possible.



"Flight" Copyright Sketch

A double skid undercarriage used on the Blackburn monoplane.

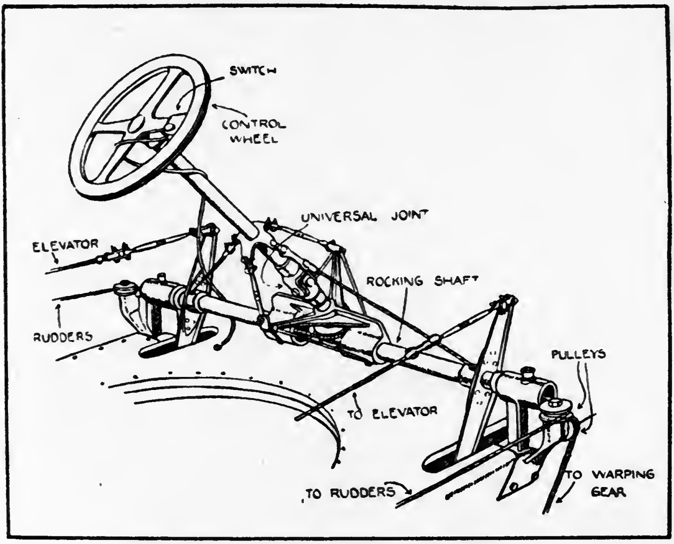
Originally, a temporary track was laid on the ground for starting purposes in connection with the Wright biplane. It consisted of a series of planks standing on edge, and set end to end. A thin steel rail protected the edge of the plank, and in contact with this ran a trolley supporting the machine. In order to facilitate initial acceleration, the trolley was connected by a cord to a weight, which was released from the top of a portable tower when the pilot was ready to start. The falling weight pulled steadily on the machine, and ensured that it should acquire sufficient velocity before coming to the end of the rail. It will be understood, of course, that it is essential to accelerate to flying speed by running over the ground before it is possible to rise permanently into the air.

It was not for some time afterwards that the Wright biplanes were built with wheels on their landing carriages, but the tower was abandoned by most of those who learned to fly these machines, as it was found possible to obtain the necessary acceleration from the propeller thrust. The engine was started and accelerated to its proper speed in advance, while the machine was held back by a catch that the pilot could release from his seat.

Several of the illustrations have also been chosen for the manner in which they bring the tail organs into prominence, and it is instructive to compare them one with another. Those machines that have boat-like bodies also exhibit a general similarity about their tails. The fixed plane is sometimes cambered so as to carry weight, as in the Deperdussin above mentioned, and sometimes is a flat plate, as in the Hanriot monoplane illustrated on page 52. When it is of this kind, the tail plane does not contribute to the support of the weight. It is there merely in order to confer longitudinal equilibrium and steadiness on the machine in flight.

The elevator usually forms a hinged extension of the tail plane, and is often divided to make room for the rudder in the manner that is clearly illustrated in the picture of the Hanriot. The Breguet tail, which will be seen on page 26, is peculiar in having no fixed plane. Its horizontal member is entirely elevator, and the vertical member is entirely a rudder. They are supported upon a pivot, and move together; when the rudder is moved the elevator also moves in its own neutral level.

Another modification of great interest appears in the Cody biplane, on which the tail element consists of two rudders, each of them carrying a small fixed horizontal fin. These fins, which correspond to the fixed tail planes of the other machines, are of comparatively small area. They are only just visible in the photograph on page 10. The very large elevator in front is, however, a prominent feature. It is supported on an outrigger framework of bamboo, and is divided into two portions, which move in sympathy with the warp.



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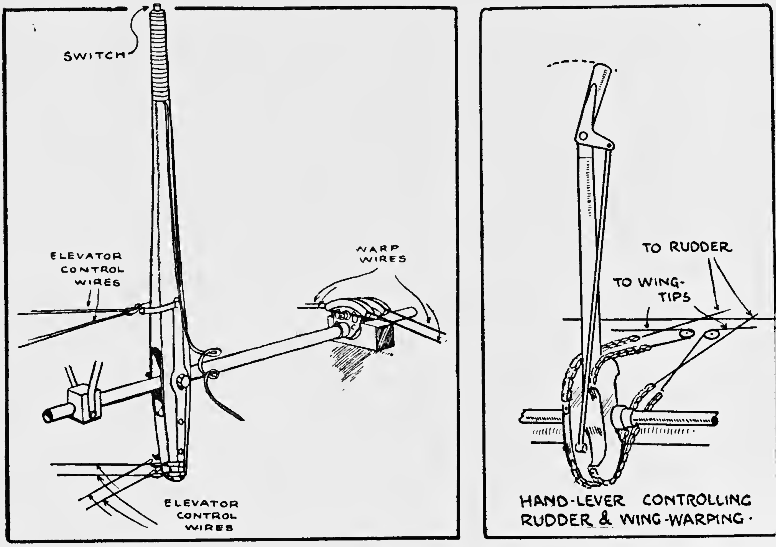
Sketch illustrating the control used on the Blackburn aeroplanes. Turning the control wheel on its own axis operates the rudder through the agency of pulleys and cables. Pushing the wheel to and fro controls the elevator through the agency of the rocking shaft and the levers which are attached to cables. Moving the wheel bodily sideways actuates the warp through the direct attachment of cables to the control column.

It will be understood, of course, that the elevator and the rudder are both organs under the direct control of the pilot. In some machines, the rudder is operated by wires from a pivoted bar under the pilot's seat ; in others it is connected by a steel cable to a drum attached to a hand wheel arranged in much the same way as it often is on motor-boats. There are many modifications of detail in the systems of control in present use, and in due course there will doubtless be some attempt to encourage uniformity in such an important matter. For the moment it is of greater importance to allow the various systems every opportunity to prove their practical value in flight.

When the rudder is operated by hand, it is usual for the column supporting the wheel to be pivoted at its base so as to be movable as a lever in any direction. A to-and-fro motion of the head of the lever is employed to operate the elevator and a sideways motion controls the warp.



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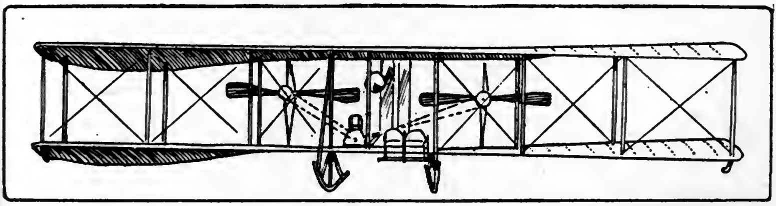
On the left, a simple pivoted lever control used on the Caudron aeroplane. Moving the lever to and fro operates the elevator through the direct attachment of cables to the lever. Moving the lever sideways actuates the warp through the agency of a rocking shaft. The rudder is independently controlled by a pivoted bar under the pilot's feet. On the right is the control employed on the Wright biplane. The handle of the lever is pivoted so that it can be independently moved at right angles to the motion of the lever as a whole. This independent motion of the handle operates the rudder. The movement of the lever as a whole to and fro actuates the warp. A separate lever is employed to control the elevator.

In a photograph on page 42 can be seen the control of the Bleriot monoplane, but the pivoted rudder bar is only just visible. Although a hand wheel is fitted to the top of the lever that normally stands upright between the pilot's knees, this is only for convenience of manipulation. It is not a wheel in the sense that a wheel implies rotation on its own axis ; it is rigid with the lever proper and the control movements are made by moving it bodily. In order to work the elevator, the motion is either forwards or backwards, and in order to operate the warp the motion is either to the left or to the right of the neutral point.

A full understanding of the action of the warp necessitates knowing something of the construction of the wings. They consist of an exterior surface of fabric stretched tightly over an interior framework of wood. The framework of each wing of a monoplane consists firstly of two main spars projecting from the side of the body of the machine and extending to the wing tips.

Each spar is supported at intervals by wires that run overhead to a mast or *cabane* above the pilot's seat, and beneath either to another mast, or, more usually, to a point on the chassis. Those wires that support the front spar are fixed both to the overhead mast and to the chassis, but those that belong to the rear spar pass over a pulley or its equivalent on the upper side, and are attached to an operating mechanism below the body.

The rear spar itself is hinged to the body of the machine, and when the pilot moves sideways the lever that ordinarily stands vertically between his knees, the wires leading to the real spars are operated in such a manner as to cause the end of one spar to be raised while the end of the other spar is depressed by an equal amount.



"Flight" Copyright Drawing

Sketch from a photograph showing a Wright biplane with its planes warped.

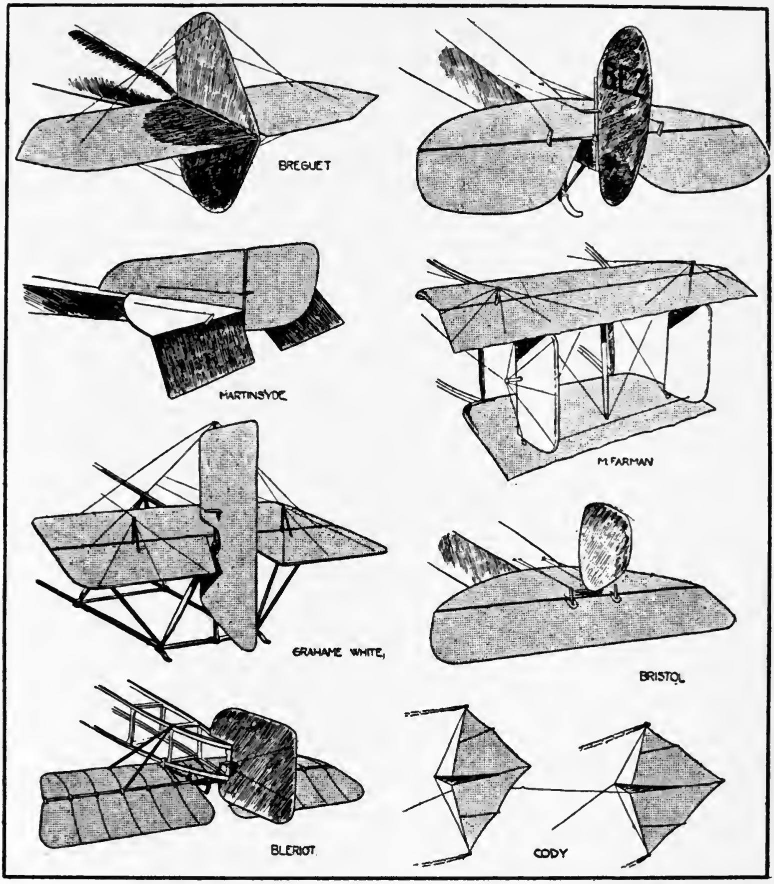
Between the spars, at intervals of 12 inches or so, are curved ribs of wood. It is to these ribs that the fabric is fastened, and it is from their shape that the wing obtains its camber. When the rear spars are moved in the manner thus described, the effect is to alter the angle of incidence progressively from shoulder to tip. The angle of incidence of the wing in which the rear spar is lowered is increased, particularly towards the tip, while in the other wing, in which the rear spar is raised, the angle is correspondingly diminished.

Instead of warping the wings, some machines are fitted with flaps in the trailing edges of their planes near the extremities. An excellent illustration of this system may be seen in the photograph of the Farman biplane on page 21. When at rest, the flaps hang down of their own accord ; in flight they fly out in the wind, and are level with the wing surfaces. A sideways movement of the control lever causes one or other of the flaps to be drawn down against the wind pressure,while the wire to the opposite flap is correspondingly slackened.

Roughly stated, the rudder is for steering in the same sense that a boat is steered ; the warp is for keeping the wings level and for control against rolling in general ; the elevator is for keeping the machine on an even keel and for control against pitching in general. The indirect effects of the use of these controls and the need for combined actions under various circumstances are somewhat complicated, and in order properly to understand this side of the subject, it is necessary to discuss at some length the general problem of the balancing and control of aeroplanes in mid-air.

Although the balance of an aeroplane in flight may be maintained by human control of the various organs thus described as characteristic of the design of modern machines, the conditions of present-day flying are frequently so disturbing as to render any craft extremely dangerous, even for the expert pilot, unless possessed of some inherent steadiness as a mere result of its proper design.

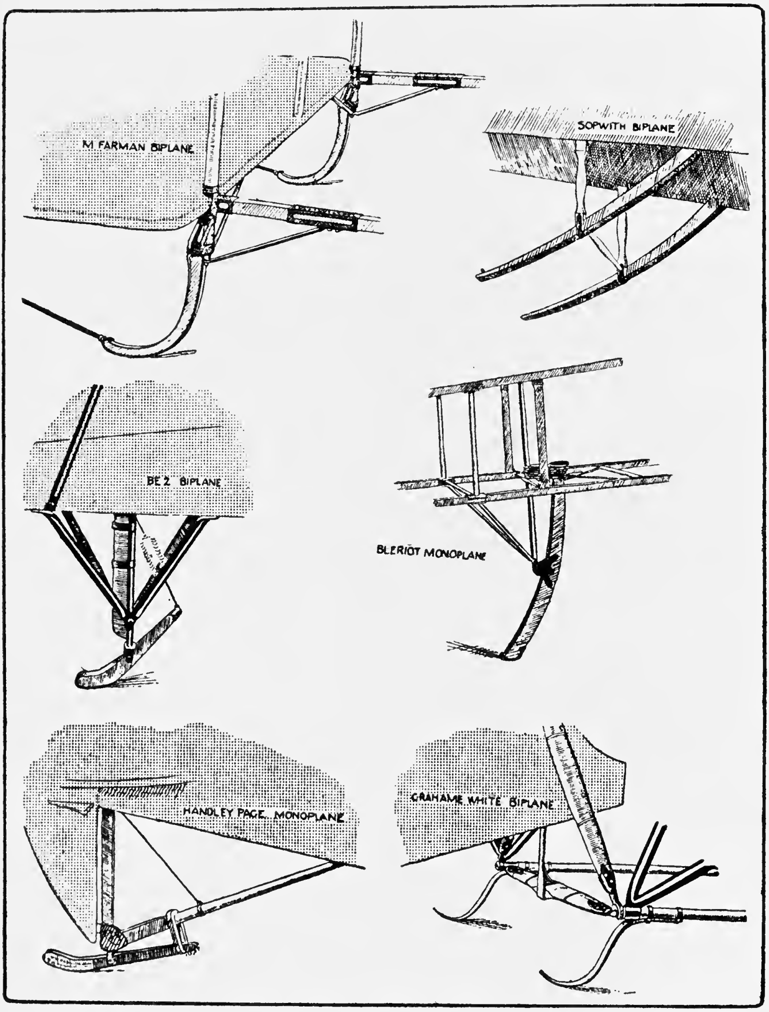
In order to arrive at reasonable conclusions regarding this matter, it is clearly necessary to be careful to consider in the first instance only those features of design that are most obviously possessed in common by a variety of different types that are known to fly well. If a number of well-known standard makes of biplanes and monoplanes were to be considered collectively, it would be observed in the first place that every one of them is of considerable length, notwithstanding the fact that the wings themselves are short from front to rear, and that the pilot and the engine seem to need but little more room than is afforded by this same dimension.



"Flight" Copyright Sketches

Sketches of tails as shown on machines exhibited at the 1913 Aero Show. The Breguet tail is particularly notable inasmuch as it has no fixed plane. The elevator and the rudder together form one unit, having a motion in two separate directions according as it is controlled for steering or elevation.

It will further be noticed that the engine and the pilot are in all cases fairly close together, and that the undercarriage is likewise compactly arranged when compared with the immense span of the wings. In fine, the massing of the objects that weigh most about a common centre in the middle of the wings will be one of the first characteristics to be noted as common to all machines.



"Flight" Copyright Sketches

Sketches of tail skids to be seen at the Olympic Aero Show of 1913.

In the case of biplanes the bulk of the weight so carried is located between the planes, and in some cases it will be observed that the engine and the pilot's seat are raised somewhat above the lower plane, in order to bring them more nearly into the centre of a high gap. For obvious reasons the undercarriage must lie below the rest of the machine, but it is none the less evident that the designers' endeavour is to keep it as short and as light as possible.

This concentration of the larger masses about a common centre, which thus becomes the centre of gravity of the machine, serves to emphasize the significance of the extreme length of the machine. Merely judging the distance by eye, it is evident that from front to rear most aeroplanes measure about 30 ft. or more. With equal facility it may be estimated that the span of the wings is even greater.

At the rear of the machine there is always a tail, which has already been described as a group of organs ordinarily comprising a fixed horizontal plane with a flap extension called the elevator and a vertical plane that serves as a rudder. The elevator and the rudder are under the pilot's control, the tail plane proper does not move. The tail portion of the machine is supported by a light skid when on the ground.

Although not necessarily obvious to the eye, it is important to mention as a fact that the tail plane is invariably set at a lesser effective angle of incidence than the main wings. This arrangement is commonly described as the fore-and-aft dihedral. If both tail and wings consisted of flat plates, and sometimes the tail is a flat plate, the arrangement would roughly represent the letter V, dismembered, opened out, and turned on its side, thus —. . . . ./, but still recognizable as a dihedral angle when speaking of planes. The same feature, but far more pronounced, sometimes characterizes the arrangement of the wings relative to each other, in which case the principle is described as the transverse dihedral, and may be represented thus \./

CHAPTER IV

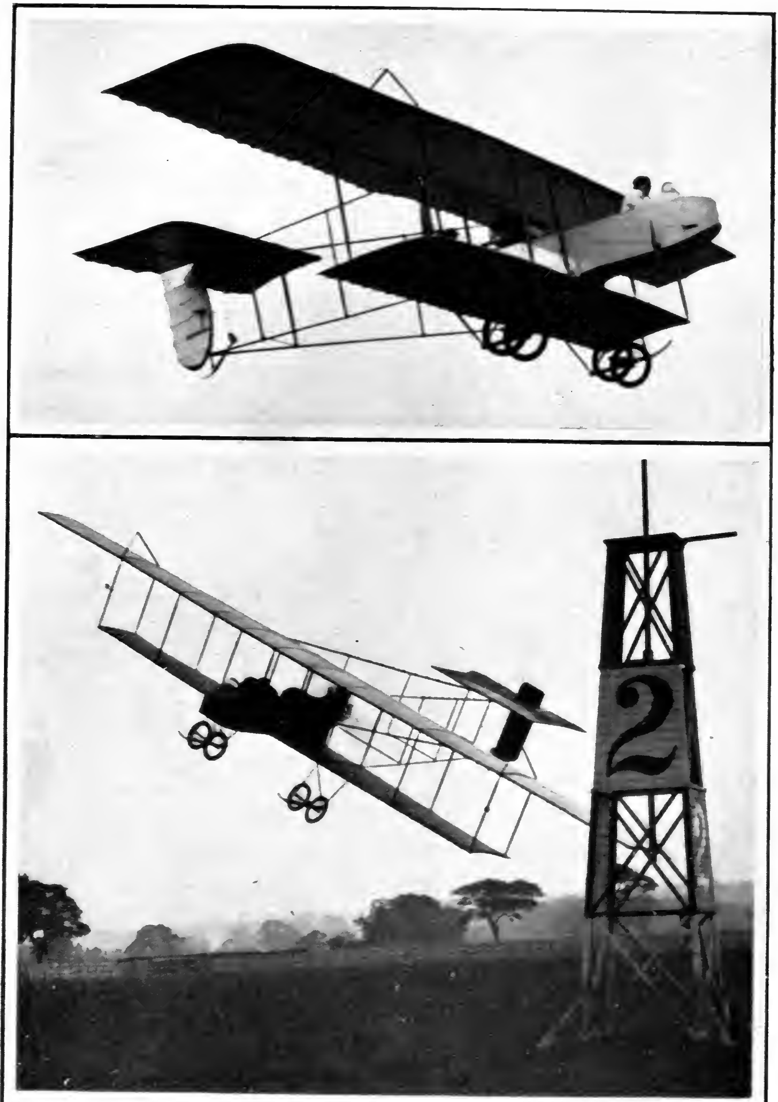
EQUILIBRIUM IN THE AIR

Equilibrium and stability—Pitching, yawing, and rolling—Recovery of balance—The importance of practice—Steadiness in flight.

IT has been the object of preceding chapters to present side by side a picture of the aeroplane as a visible machine and some conception of the invisible function that is performed by the chief of its organs. In flight, the weight of the aeroplane is supported by the reaction between the wings and the relative wind created by their motion through the air. So long as the proper relative motion continues, the wings perform their function of maintaining an upward pressure, but it depends on a variety of circumstances whether that pressure continues to be applied in exactly the correct way.

Some previous use has been made of two important technical terms, the centre of gravity (C.G.) and the centre of pressure (C.P.). It will be as well that the reader should become thoroughly familiar with their meaning, for they are as important to a proper understanding of how an aeroplane is balanced as is a full conception of the idea of relative motion to the realization of the fundamental principles of its support.

The centre of gravity is the point where the weight of the machine seems to be concentrated, and the centre of pressure is the point at which the lift of the wings seems to be focussed. Any object that is supported exactly at its centre of gravity is always balanced in any position in which it may be set. When it is not so supported, it tends to fall into such a position as will bring the point of support vertically in line with the centre of gravity.



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The upper view shows a Henry Farman biplane, of the later 1912 pattern, climbing; the lower picture illustrates a similar machine banking while turning about one of the pylones at the Hendon Aerodrome.

A perfectly symmetrical wheel on an axle is in balance irrespective of which spoke is uppermost, but the mere presence of the valve on a bicycle wheel is sufficient to displace the C.G. from the axis of the hub, and the wheel turns round of its own accord until the valve is the lowest point. The centre of support is the axis of the hub, and the C.G. then lies vertically beneath it. Another position of equilibrium exists when the wheel is turned so that the valve is uppermost, but there is a distinct difference between the stability of the two extreme positions. The slightest movement of the wheel in the latter case (when the valve is uppermost) is sufficient to capsize the arrangement ; on the contrary, if the wheel is turned when the valve is the lowest point, the original conditions automatically re-establish themselves when the disturbance ceases.

Both positions, it should be observed, represent states of equilibrium : but only one of them is stable. The criterion of stability in such a system is whether the C.G. is raised or lowered by the disturbance. If, as in the case where the valve is undermost, the C.G. of the system is raised by turning the wheel slightly, then the system is stable because the C.G. naturally falls back again to its original position.

An ordinary table is stable for this reason : when tilted, the C.G. is raised ; when released, it falls back into position. A tall stand on a narrow base is less stable than a low table with its legs wide apart, because the C.G. rises less when tilted and may more readily be pushed beyond the limit.

It is necessary to refer to these elementary facts relating to ordinary objects in order that the use of the terms " equilibrium " and " stability " in reference to aeroplanes may more adequately be appreciated. No word, perhaps, has been more misused or is less clearly defined as to an accepted meaning, than is the expression " stability " in the terminology of aviation.

Like ships, aeroplanes are potentially liable to pitching, rolling and yawing, and it is essential from the beginning to recognize that some of these acts may at times be essential to the guidance of the machine from one point to another through space. If, for example, an aeroplane were incapable of being made to swerve at will, it could not be steered; on the other hand, a tendency to make erratic changes of direction of its own accord would be described as directional instability. It is, then, evidently necessary clearly to fix in the mind what qualities it is desirable that an aeroplane should exhibit when in flight: not less is it essential to consider what characteristics may reasonably be expected of a machine situated as is an aeroplane in the air.

In the first place, it is important to bear in mind that the air does not provide a fixed platform as does the floor in the case of the table just mentioned as an illustration of stable equilibrium. When an aeroplane is canted, so that one wing is lower than the other, the C.G. of the machine has not necessarily been disturbed; nor, even if it had been raised, would it necessarily have cause to fall back again to its former level.

Although by no means an accurate analogy, the difficulty of balancing a marble exactly in the centre of a plate gives a somewhat better idea of the situation than is to be obtained from any point of view originating from a conception of what ordinarily is understood by stability on land. There is also a very ingenious sideshow, often to be found at large exhibitions, that may assist the imagination in grasping the breadth of the subject. It consists of a flexible track that ceaselessly undulates in supposed representation of the waves of the sea. The usual sixpence admission gains for the enthusiast the right to try to pilot a raft-like trolley round the course, and serves incidentally as a very good object-lesson in two forms of stability. The machines in question are stable in the ordinary sense to the degree of absolute security, for they cannot conceivably capsize by any accident that might befall them *en route*. On the contrary, the instability of their direction is, so to speak, the very basis of the success of the show. They scarcely move three yards without making sudden swerves into one barrier or the other, yet those who practise the art of steering them can negotiate the circuit without collision, or would be able to do so were other pilots equally expert with themselves.

When an aeroplane is canted, the forces brought into play correspond with those that make the trolley run into the barrier, and their effect is equally to tend to make the aeroplane slip down sideways through the air. This motion will be noticed as a characteristic of the flight of the paper models described in a previous chapter, and it is important to realize that it is solely because the models are free to slide that they recover their equilibrium. When the initial cant is due to a draught, the model slips rapidly down an oblique path to leeward, and will probably bring its flight to a premature conclusion on the floor unless there happens to be sufficient height for the manœuvre of recovery.

Inasmuch as the obliquely sideways motion does tend to restore the lateral balance, features of design that help to emphasize the effect are frequently described as principles of inherent stability. The most common of these is the use of dihedral wings, that is to say, wings sloping upwards from shoulder to tip. A very marked example of dihedral wings is to be seen in the photograph of the Blackburn monoplane facing page 52.

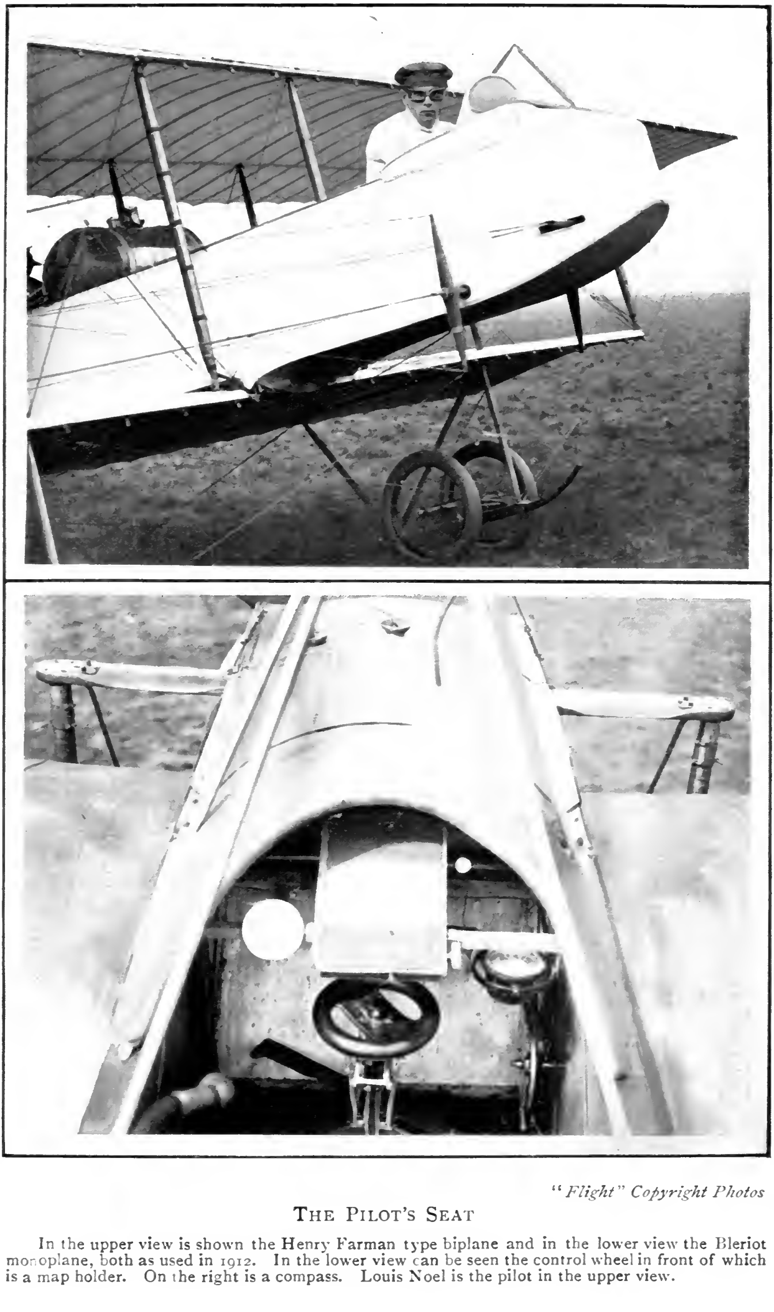
Again reverting to the paper model, another characteristic phase of its flight is an undulating motion during the earlier stages. When the motion dies out of its own accord, the model is said to be longitudinally stable. With cambered planes of single curvature, it will be found necessary to fit a horizontal tail and to set this tail at a lesser effective angle than the main wings in order to secure inherent longitudinal stability of this order. It is important to observe that although the pitching of an aeroplane may cure itself while the machine pursues its general course unchanged, the wings themselves possess no such power of inherent recovery from rolling. It is essential, in order to cure a canted position without personal control, that there should be a sideways component of motion.

It is also very important to bear in mind what has above been mentioned, because some confusion of thought on the subject is at present rather prevalent. Principles such as the transverse dihedral are sometimes described as having the power to re-establish equilibrium of their own accord while the machine pursues an axial course. But, as the pressure on each wing is always at right angles to the wing spar, the pressure on one wing is also balanced by the pressure on the other wing, irrespective of their relative positions. Consequently, there is no couple capable of turning the machine about its longitudinal axis, which is essential if the wings are to be put level again. It is when the machine slides sideways, which it does as soon as it is canted, that the pressure under one wing exceeds that of the other and so brings into existence a restoring force.

All these movements would naturally seem to a spectator on the ground to be evidence of instability rather than otherwise, which points to the necessity of differentiating between what I generally describe as weathercock stability and stability in the absolute sense. A wind vane, which may move all over the place, remains stable in its attitude to the relative motion of the air in its vicinity: when the wind veers or backs, the weathercock moves in sympathy.

Of this order is the longitudinal stability of the paper model above described. It rocks of its own accord about its transverse axis and so tends to preserve a constant angle of incidence to the relative wind. When sliding obliquely sideways, it displays what I call "compass" directional stability inasmuch as its longitudinal axis remains parallel to its original position, like the needle of a magnetic compass that is moved from one place to another. If the model is fitted with a vertical tail plane so as to give it weathercock stability of direction to the relative wind, it will lose its power of recovering its lateral equilibrium. Immediately it begins to slide sideways, the tail fin acts like a rudder and steers the plane so as to face along its new line of motion. The oblique position, which is essential to recovery from a canted position, is rendered impossible, and the model speedily capsizes in a head-first dive.

This draws attention to a consideration of evident im-



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THE PILOT'S SEAT

In the upper view is shown the Henry Farman type biplane and in the lower view the Bleriot monoplane, both as used in 1912. In the lower view can be seen the control wheel in front of which is a map holder. On the right is a compass. Louis Noel is the pilot in the upper view.

portance, namely, that the possession of one form of stability may prevent the simultaneous existence of stability of some other kind. It is evidently a question, therefore, of ascertaining what combinations are possible and of choosing those best suited to the purpose of practical flight. The early gliding experiments of the Wrights described on page 128 have an especial interest in connection with this aspect of the subject.

The whole problem of stability in air is a vast subject that has as yet been but little investigated. There is reason to hope, however, now that much of the more fundamental laboratory research has been completed, that it will not be long before a systematic series of experiments puts the matter on a more satisfactory basis.

To those who have read thus far, the difficulties of the subject should in some measure be apparent. But, to some of the earlier pioneers who were unable to realize their dreams of flight, the very existence of the problem itself seems to have been unsuspected.

A German named Lilienthal, whose work is referred to later, was perhaps the first to appreciate the situation in all its bearings, to realize that even a few minutes' actual experience aloft would do more to advance aviation than could possibly be accomplished by a whole lifetime of thought. Whether he was the first to realize it or not, however, is of small moment compared with the unquestionable fact that he was the first to put his belief systematically into practice, to perceive that brief flights were already possible in spite of the absence of an engine and to build for himself a little gliding machine, which he proceeded to use as an aerial toboggan by flying down the side of a hill. Perseverance, not priority, was his real merit.

It was real flying and Lilienthal soon had very good reason to understand, as others have done since, that his ideas as to the primary importance of the problem of balancing were only too certainly correct. He realized that the air pressure supporting an aeroplane is virtually centred at a point and that as the machine has, so to speak, no other leg to stand on, there might well be difficulty in keeping it properly balanced under the varying conditions of flight. Lilienthal, however, was thinking more particularly of the pilot's control of the machine than of the machine's control of itself. The human element is, of course, the determining factor in the situation in respect to any form of vehicle, and more so in an aeroplane than in most. It is essential, therefore, to introduce the subject of personal control, and to realize the purpose and possibilities of the various organs with which modern machines are provided.

In this connection, too, there is a factor that is perhaps of more importance than any other in the modern machine, and that is the steadying as distinct from stabilizing influence of certain characteristics of the design. By a steadying influence is meant the quality of checking the oscillations in the sense of putting on the brake: it does not imply the power of recovery. Moving the hand about under water gives rise to more resistance than do similar movements in air. If the hand is held edge-on under water while one is travelling in a fast motor-boat, the resistance to lateral movement is noticeably exaggerated as compared with the conditions obtaining when the boat itself is at rest.

The keel of a yacht, for instance, is far more potent to resist a puff of wind on a sail when the boat is moving quickly through the water than when it is at rest. The resistance, however, is only maintained during the application of the pressure, and as the result of the lateral displacement of the keel: of itself, it is incapable of entirely preventing the disturbance and it is impotent to restore the initial conditions.

It seems conceivable that the wings themselves may thus damp the tendency of an aeroplane to roll, but more will need to be said upon this point in another place. Other things need to be considered in design, as affecting the control and steadiness in flight, quite apart from the subject of stability pure and simple.

It should be useful, therefore, to recapitulate the various divisions of the subject in order that it may arrange itself more systematically in the mind. Firstly, there is the human control of the balance as performed by the manipulation of various organs. Secondly, there is the need to consider how far certain characteristic features of the design may tend to steady the machine, although not possessed in themselves of any inherent power to restore balance. Thirdly, there are the principles of stability that restore balance as the result of the motion of the machine. Fourthly, there remains to be investigated whether the aeroplane may be made stable to the point of being undisturbed by a real wind. Such stability might appropriately be termed "platform" stability, in order to imply steadiness and to distinguish the quality from the power of recovery inherent in "rolling" stability.

In each section it is necessary to consider separately the question of pitching, rolling and yawing; then to consider how one movement may affect another, and, finally, to bear in mind the possible need for being able to promote such movements at will for the purposes of directing the path of the machine in flight.

In the broader use of the term, what ordinarily is called longitudinal stability has to do with the prevention and cure of pitching. Lateral stability is similarly related to rolling, and directional stability to yawing from the course. Of these three divisions, sufficient has been said already to emphasize the especial significance of lateral stability owing to the fact that any lack of balance involves a sideways sliding of the machine from its proper course. It will, therefore, perhaps be advisable to devote some further space to a consideration of lateral equilibrium in a separate chapter.

CHAPTER V

LATERAL BALANCE

Direction of pressure and direction of weight—The cause and the cure of lateral disturbances—Steadiness and large span—Speed and safety—Wing warping: its object and its effects—Cause and effect of sideslip—Fins as stabilizers—Upturned wing tips as fins—Stability against gusts—Negative wing tips and lateral stability.

WHEN an aeroplane is seen advancing from directly in front, the upward pressure or lift of its wings may always be assumed to be acting in a direction perpendicular to the spars. The downward force of the weight acts always vertically towards the earth. If, therefore, the wings are canted, their pressure is no longer precisely in line with the weight, and there is, necessarily, a sideways component tending to make the machine swerve off its former course.

On the assumption that the machine ascends into the air with its wings level, it is necessary to account for the disturbance of the balance by the introduction of some extraneous force. This, however, is readily supplied by supposing that the machine is struck by a gust. A gust, for present purposes, is assumed to be a sudden veering or backing of the relative wind.[1]

It is not necessary that the machine should be possessed of vertical fin surfaces, against which the oblique wind

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[1] Special attention is drawn to this hypothesis because, while it is fundamental to much of the argument that follows, it is presented only as a personal line of thought and not as a generally accepted definition. I am, in fact, assuming that atmospheric disturbances, so far as they relate to the machine, cause angular oscillation of the vector representing the relative wind. Such oscillations may be in any plane, but I assume that the components of the movement in the horizontal and vertical planes may be considered separately. It is the component in the horizontal plane that is here referred to as a veering or backing of the relative wind.

may strike, in order to account for the tendency of a gust to cant an aeroplane. The characteristics of wing-forms as ordinarily employed suffice in themselves to explain the occurrence, for if a gust is a sudden veering of the wind, it is equivalent to a sudden spinning of the wings about their vertical axis, as a propeller might spin on a vertical shaft. Under such conditions there is an obvious tendency for one wing to lift more than the other, and so to upset the balance.

The consequence of canting the wings is immediately to bring into existence a force tending to make the machine slide obliquely sideways downhill to leeward.

As these are the conditions that tend to materialize on modern machines, it is first of importance to consider in what manner and to what extent they are actually cured in practical flight, before discussing possible means for their prevention. The subject, as has been explained, falls naturally under a series of separate heads.

Firstly, there is the outstanding fact that machines of many different types are flown with apparently equal security by reasonably expert pilots, and that there is, it would seem, some degree of inherent steadiness in them that is distinct from the human element. Such steadiness does not restore balance, but merely checks the severity of the disturbance.

Secondly, there is the pilot with the controls at his command.

Thirdly, there is the necessity of considering the effect of allowing the machine to slip downwards to leeward, and to inquire what principles, if any, are present that will tend to restore the wings to their proper balance.

Fourthly, it is a matter of interest and importance to discuss what means, if any, suggest themselves as possible systems of prevention, as distinct from cure.

Some of the natural transverse steadiness of the modern aeroplane is due, it has been suggested, to the fin-like action of the wings themselves, which conceivably resist displacement from their line of flight by dynamic reaction, just as the keel of a yacht resists a sudden gust on the sail. In this respect all well-designed aeroplanes should possess the basic quality in common, although doubtless in varying degree, and such would, in fact, appear to be the case in practice.

Arising out of this point of view, there is reason to direct particular attention to machines of relatively large wing area and span. If it is in the keel effect of the wings themselves that the inherent lateral steadiness of the machine is mainly centred, then one of the most direct methods of enhancing this quality would apparently be to increase the size and particularly the span of the wings.

This steadying effect of the wings is based on the fact that a plane that descends while moving horizontally is actually moving obliquely, and, therefore, makes an angle of incidence to its line of flight. Thus, when a machine rolls, the wing tip on one side has its angle virtually increased, and vice versa on the other side. Such an effect would tend to check the roll, but would have no power to restore balance.

To do this it is necessary to make an actual difference between the wing tip angles, and this is the purpose of the warp. The wings are constructed, as has been explained, so that they can have the angle of incidence at the wing tip altered by a movement of a lever. The effect is to establish a temporary difference in the lifting efforts of the two wings in such a way as to restore the balance of the machine.

It is, of course, the lower wing of a canted aeroplane that has its angle of incidence increased by the warp. The centre of pressure, therefore, tends to move on to the lower wing, and in so doing it brings about a restoration of balance.

There is need for considerable discretion in the use of the warp. The increase of lifting effort in a vertical direction may be accompanied by an increase in the horizontal resistance to motion. At large angles, the greater the lift the greater also is the resistance that the wing experiences to its flight through the air.

For very fine angles, the resistance may remain nearly constant or even slightly decrease with an increase of angle, but as the increase is continued the resistance ultimately increases also.

Let us then apply this reasoning to the case of the warped wings, and see how it may be expected to affect the machine in the air. On the one side, we have an increased lifting effort accompanied by an increased drag; on the other, a decreased lift, and, in consequence, less resistance to motion.

The engine as ordinarily installed on an aeroplane with a single propeller is pushing the machine forwards by a thrust applied at a point immediately between the wings. If, therefore, the resistance of one wing is made greater than that of the other, it follows that the machine as a whole must at once tend to spin about its own vertical axis in space. In fine, the first effect of wing warping is ordinarily to engender a " spin "; i.e. to make the aircraft yaw.

This is extremely important, not only from the navigator's point of view, but from its consequences in the aerodynamic sense. The lifting effect of a wing depends even more on its relative velocity than it does on its angle of incidence. If, therefore, the effect of the greater drag on one wing is to cause it to slow down in speed while the other begins to move faster than before—which it necessarily does if the machine begins to yaw—an immediate consequence of this relative difference in speed is to cause the lift of the slower wing to be diminished while the lift of the faster wing is increased.

If this happens, the faster wing rises and the slower wing falls. But it is the slower wing to which the warp was applied in such a way as to increase its angle in order that it might experience an increased lift thereby, and so be raised. We are thus faced with the situation that wing warping may do precisely the opposite of what was intended.

If we assume that the purpose of warping on some particular occasion is to restore the natural balance of a machine that has been canted, then there is no doubt as to the disadvantage of its yawing effect. If the machine tends to yaw while already canted, the balance will be still further disturbed.

Clearly, this effect of the warp needs the simultaneous use of the rudder as a counteracting couple. If, when the wings are warped, the rudder is employed at the same time, so as to tend to steer the machine in a sense contrary to the drag of the lower wing, the original course may be maintained, and the warp itself rendered effective in the manner described. It is evident, however, that the success of the operation depends on the skill with which the pilot handles his levers.

It has been remarked that the practice of wing warping originated with the Wrights, and it is equally interesting to observe that they made subject-matter for a master patent out of the necessity for the combined action of the warp and the rudder. A note on their legal position appears in the Appendix.

Although wing warping, or its equivalent, is universal today, the early Voisin biplanes used in France by Delagrange, Farman, and other pioneers, had no such means of lateral control. These large " box kites," as the larger biplanes are nicknamed, were fitted with elevators in front and rudders at the rear. The latter organ was partially enclosed inside a huge box-like tail. According to Hargrave, who invented the box kite in Australia, and recommended it as a principle of aeroplane construction long before it was actually so used, the system ought to possess strong powers of recovering its balance. In any case, the pilot could always assist recovery by steering outwards with the rudder. This, by increasing the relative speed of the lower wing, imparted to that side of the machine a greater lifting force, and thereby tended to restore equilibrium.

It is of the utmost importance to realize how intimately steering movements are associated with lateral balance.

Even when we pass on to consider the consequences of allowing an aeroplane to sideslip to leeward, the first point that it is of importance to observe is that the machine has changed its course.

An explanation of the force causing sideslip to leeward has already been given, namely, that it is due to the wing spars being canted and so tilting the direction of the wing pressure from the vertical.

This tilt introduces a horizontal force in addition to the vertical lift, and the machine commences to turn in a circle as if it had been purposely tilted for that purpose. At the same time, however, it slides downwards, for the tilting of the wings reduces the vertical component of the force to a value that is insufficient entirely to support the weight of the machine.

As, for the moment, we are considering only the initial disturbance and immediate recovery therefrom, it is convenient to ignore any reference to the circular path and to consider the downward slide as a simple lateral component of the motion taking place along the axis of the wing spar.

In order to understand the origin of the forces that restore balance, it suffices to consider this lateral component of the movement as a motion apart. Suppose the wings to be represented by the ballasted flat plate that serves so well as a basic experiment in aerodynamics. It is apparent that although the sideways motion is one in which the plate proceeds narrow edge first, it is none the less an aeroplane, and it will equally have its C.P. nearer to the leading edge than to the trailing edge. The C.G. being central, the leading edge will, therefore, tend to rise, and as the leading edge represents in this case the lower wing tip of the aeroplane, the action is one that restores lateral balance.

From a consideration of the fact that a gust may be of very brief duration, it would seem that in practice the majority of disturbances may be reduced to a mere flicker. But if the disturbance were such as to cause a severe loss of equilibrium, the distance that the machine might have to sideslip before righting itself would be so great as to be highly dangerous at all ordinary flying altitudes.

And while on this subject, attention may well be drawn to the necessity for keeping the lowermost wing well to the front during a sideslip. It is only by virtue of its relatively advanced position that it can hope to entice the

C.P. on to its surface. Steering inwards, that is to say towards the direction of the sideslip, would cause the lower wing to retreat and the upper wing to advance through the air. Such action would, therefore, tend to augment the loss of balance. Equally, an excessive amount of fixed vertical tail surface, such as would give weathercock directional stability, and tend, thereby, to make the machine swing into line with its relative motion, would be a disadvantage once such a sideslip had started.

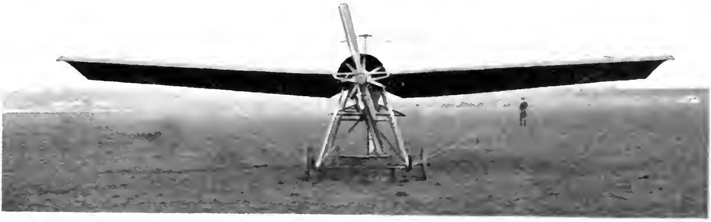
It is on its inherent absolute or compass-like directional stability, that the ballasted flat plate depends for its recovery of balance. In a system such as the aeroplane, which does not possess the same simplicity of form, it is apparent that some feature is needed to counteract the tendency of the rudder to promote a weathercock spin.

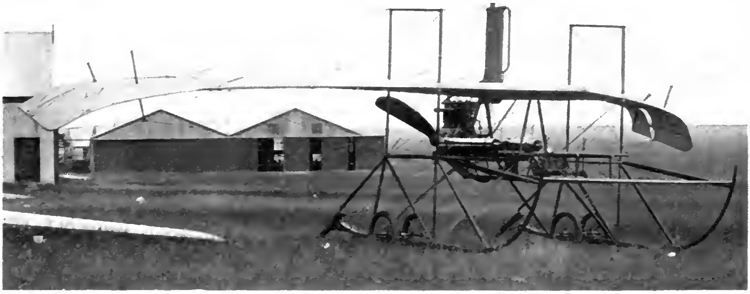
The use of a forward fin naturally suggests itself, but is also seen to be a possible structural difficulty in its elementary form, owing to the necessity of avoiding forward projections on certain types of aeroplanes.

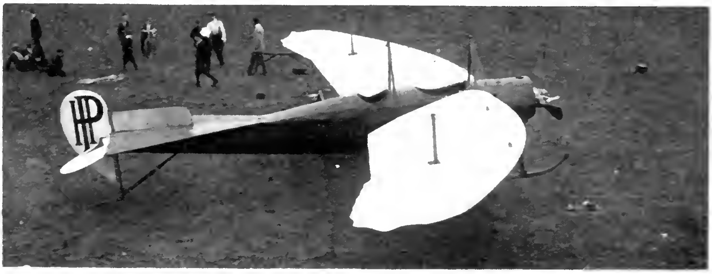
One way of acquiring a forward fin is to slope the wings upwards (the lateral dihedral) and to arrange the C.G. of the system slightly behind the C.P. on the wings. This involves carrying load on the tail or raising the axis of the propeller.

Another method is to turn up the wing tips only, and then swing the wings backwards slightly, which causes the upturned portion to face somewhat forwards, and so to project its virtual fin above and in front of the machine. Turning up the trailing corners of the wings is, in effect, doing the same thing.

In addition to looking after the compass directional stability, these virtual fins, being above the C.G., also enhance the quickness of recovery. Dihedral wings are notable in this respect owing to the fact that their virtual fin is well above the C.G. Upturned wing corners, on the other hand, tend rather to enhance the compass directional stability, by projecting their fins well in front of the C.G., and such machines might, therefore, be expected to have some inclination to roll.







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1. A Hanriot Monoplane of 1912.
2. An example of the dihedral angle in a front view of the Blackburn monoplane.
3. An example of negative wing tips on the Dunne monoplane.
4. View from above of the Handley Page monoplane, which has crescent-shaped wings with their tips slightly upturned at the trailing edge.

It is evident that the best position and size of such fins would be a matter for elaborate investigation. To the mathematical aspect of this phase of the subject, Professor Bryan and Mr. E. H. Harper, of the University of North Wales, have devoted considerable time and attention, and Professor Bryan's book should be studied by all who have mathematical minds. The importance of their work lies in the method that it lays down for the treatment of this phase of the subject: The "mathematical machine" provides results in accordance with the material supplied to it, and must not be blamed if inadequate data produce unpractical solutions. The science of the mathematician is essentially limited to remodelling the facts that constitute his hypothesis.

While the subject of stability in still air forms an important introductory field of research, practical flying takes place in winds, and any still-air stabilizing device, such as a fin, at once becomes a target against which a gust can strike to disturb the balance of the machine.

The absence of fins does not prevent the disturbance, for it has already been explained that the C.P. moves in sympathy with a veering wind. Nevertheless, if the fin augments still-air stability, that is good prima facie evidence why it should also increase the disturbing effect of a gust.

A ballasted flat plate of the kind described in a previous chapter, if flown in still air, manifests considerable steadiness of balance and direction. Should it enter a region of draught, however, it will cant and slide down obliquely sideways with great rapidity. If there is sufficient room, it will recover its balance, but from the heights at which such models are ordinarily launched, it will more often strike the floor.

This and other considerations seem to emphasize the fundamental importance of trying to prevent entirely the loss of lateral balance in windy weather, notwithstanding the fact that most well-designed machines appear to recover their balance with a mere flicker of movement, and are ordinarily extremely steady in the hands of expert pilots.

One system that has been tried may be described as the "automatic warp," in which the wing spars are so disposed as to make a gust tend to warp the wing of its own accord in such a way as to "spill the wind."

As this action is communicated to the pilot's hand, it is apparent that its popularity depends in a large measure on individual taste. Some expert pilots like the system very much, others are less favourably disposed towards it. It will be observed that it is a principle that tends to neutralize the efficacy of the dihedral angle, for the dihedral essentially depends on the wings being subjected to a *difference* of pressure, which it is the purpose of the automatic warp to prevent.

It may now be of interest to consider how far it would seem possible to make an aeroplane inherently laterally stable in the absolute sense; that is to say the prevention of the sympathetic travel of the C.P. with a veering wind on rigid wings.

Thus far a gust has been defined as a veering or a backing of the wind, and in the argument that follows, it is important to remember the limitations of this hypothesis. From the fundamental conception of relative motion, it is evident that a veering wind may be replaced in still air by a clockwise spin of the wings about a vertical axis passing between their shoulders.

If the vertical axis is assumed to be fixed in space, so as to facilitate a clearer mental picture of the process, the rotation of the wings thereon will resemble the rotation of a propeller on a vertical shaft. There is, however, the very important difference that while each blade of the propeller is properly inclined to its direction of motion, in the case of the aeroplane wings only one of the pair is in a correct attitude for either direction of rotation. The other wing makes, in fact, a negative angle of incidence to its path. It is thus very clear that the wing having the positive angle of incidence will lift while the other will tend to fall, in short, the wings will become canted.

In flight, the conditions may be mentally pictured by supposing the vertical axis to be advancing in an upright position and the rotation of the wings thereon to be taking place slowly at the same time. The wing that advances in the direction of motion will obviously tend to rise, while the wing that is retreating tends to lose its lift. It is this action that causes a boomerang to " bank " and so to steer itself back to the thrower.

From the above argument it seems evident that if a pair of wings rotating about a vertical axis in still air did not exert any lift at all, then neither would their balance tend to be disturbed by a veering wind.

The only form satisfying this condition is one in which the wing tips are permanently negative. When such wings rotate about a transverse axis, the negative tip of the advancing wing may neutralize the increasing lift of its positive part ; on the other side, the negative tip of the retreating wing will have become positive to its own direction of motion and will, therefore, tend to lift.

By suitably proportioning the angle from shoulder to tip, it seems possible that a pair of wings might be made laterally stable against veering and backing winds within useful limits.

When advancing in ordinary flight, the centre portion of the pair of wings would present a surface positively inclined to the direction of motion and to this would be due the support of the machine.

The negative tips would represent an added load to be carried, and to that extent the machine would be relatively uneconomical of power. Some lack of economy might, however, well be tolerated upon occasion for any real measure of inherent lateral security of balance.

Owing to the wing tips being furthest from the vertical axis, their relative velocity when turning about that axis is greater than that of parts nearer to the centre : it is feasible, therefore, that the extent of the negative surface should be less than the area set at a positive angle, for the relative effect will be in the ratio of the squares of their relative speeds.

When advancing together in flight, the relative speeds of all sections of the wings are the same, consequently the larger area of the positive part will predominate, and its surplus lift over and above that required to neutralize the load due to the negative tips will be available for the support of the machine.

The stablizing influence of negative wing tips has been discussed mathematically on the Bryan method by Mr. J. H. Hume-Rothery in an article in *Flight*, Vol. V, page 64.

A question of evident importance that arises in the mind after some little consideration of the foregoing argument is how such a machine may be steered. It has been shown to be fundamentally necessary that it should not cant when it turns on its own vertical axis, yet such a turning motion is precisely what a rudder effects, and it is ordinarily because the wings automatically make their own bank that the use of the rudder becomes an effective organ of steering control.

Steering possesses so many problems of interest, however, that it may be well treated separately in a chapter by itself.

CHAPTER VI

STEERING

The true purpose of a rudder—Its manner of action—How a ship answers the helm—The balance of power—Instability and the importance of the rudder—Banking for the turn—The centrifugal couple—The differential negative warp.

THERE is perhaps no object of a technical nature so universally familiar by name, appearance, and purpose as the rudder. Everyone knows that a rudder is used to steer the craft to which it is attached; few, comparatively speaking, clearly realize the precise means by which the rudder accomplishes its object.

Newton defined as the first law of motion that a mass moving in a straight line would not change its course unless a force were applied to it along the direction in which it is desired that it should accelerate. A rudder, owing to its usual position some considerable distance behind the centre of gravity of the craft to which it is attached, has no inherent ability to apply such a steering force, and its utility for the purpose for which it is intended depends wholly on the indirect consequences that attend its own direct action, which is of another kind.

The direct effect of a rudder relates to the control of movements about the vertical axis of the craft. Such movements may conveniently and appropriately be referred to under the general term "yaw." It is the tendency of the craft to yaw on its own vertical pivot that the rudder is used either to check or to initiate as the case may be.

When steering a straight course, the rudder is used to counteract disturbances that otherwise might give rise to yawing. Observe, for example, the behaviour of flotsam in a stream, how each little piece gyrates as it moves onwards.

Consider also how unstable would be an arrow without the steadying influence of its feathers, which form a neutral rudder, and the action of which is this sense has been referred to in a previous chapter.

In its initiative capacity, the rudder causes that to happen which formerly it helped to prevent. When the rudder is put over, the immediate and direct effect is that the craft begins to yaw ; the craft as a whole tends to continue its straight-line motion under the influence of its own momentum.

In the case of a ship, the consequence of a slight yaw is that one side is thereby presented obliquely to the direction of motion, and the reaction thereon is itself oblique, and so possesses a component force at right angles to the original course. This lateral component of the reaction acts through the C.G. of the system, and initiates acceleration at right angles to the original velocity ; their compounded effect produces a curved path of motion that persists so long as the helm is held over and an axial driving force is applied to maintain propulsion.

Incidentally, it is of interest to remark that according to the design of the boat so may the centre of the pressure reaction on the hull be in advance of or abaft of the C.G. When it is located forward of the C.G. it has the effect of augmenting the yawing, and thus of enabling the boat to be manœuvred more readily ; on the contrary, it makes the steering of a straight course more difficult. When the C.P. is behind the C.G. it opposes the rudder, and makes the ship less easy to put about, but such a boat will steer a straight course of its own accord, owing to the inherent weathercock directional stability of the system.

In the case of an aeroplane, which has no appreciable extent of vertical surface in the vicinity of the C.G., a slight yaw will of itself present nothing equivalent to the side of a ship against which the air can react in the above-described manner. But, when an aeroplane with positive wing tips is caused to yaw, one wing tip is thereby accelerated while the other is retarded, and so a bank is established thereby, which in turn tilts the direction of the air pressure on the wing.

It is this tilting of the air pressure by canting the wings that provides the steering force in the case of an aeroplane ; which being so, it is at once apparent that if other means than the rudder were available for tilting the wings the rudder itself might be dispensed with as a steering organ.

One alternative method of initiating a bank is to warp the wings. The manner in which the wings of aeroplanes are at present warped is such that the positive angle of one wing tip is increased while the positive angle of the other wing tip is diminished. With any aeroplane surface at a positive angle of inclination to the line of flight, the pressure reaction is obliquely upwards and backwards, and if the angle is increased, both these component forces will, ordinarily, also be increased. The wing tip that has its angle of incidence increased by the warp will thus usually tend to rise and to retreat ; a combination that is in opposition to the requirements of steering, as may readily be seen by reviewing the essential conditions that attend this manœuvre.

While travelling on a curved path it is evident that the inner wing tip must be flying at a slower speed than the outer wing tip. It is equally self-evident from their banked attitude that the inner wing tip must be the lower one of the pair. While banking, it is, therefore, clear that the tendency of the inner wing should be to descend and to decelerate, which is an effect that cannot, in general, directly be induced by the warping of a wing tip so as to increase the positive angle. When a positive angle is increased, the tendency to rise is mostly accompanied by a tendency to retreat ; if the rise is otherwise prevented, the retreat, representing a loss of velocity, may result in descent, but the descent is not a direct consequence of the force first brought into play by the warping of the wing.

In connection with these tendencies to retreat and to advance it is of fundamental importance to realize the significance of what may be termed the balance of power on the two wings.

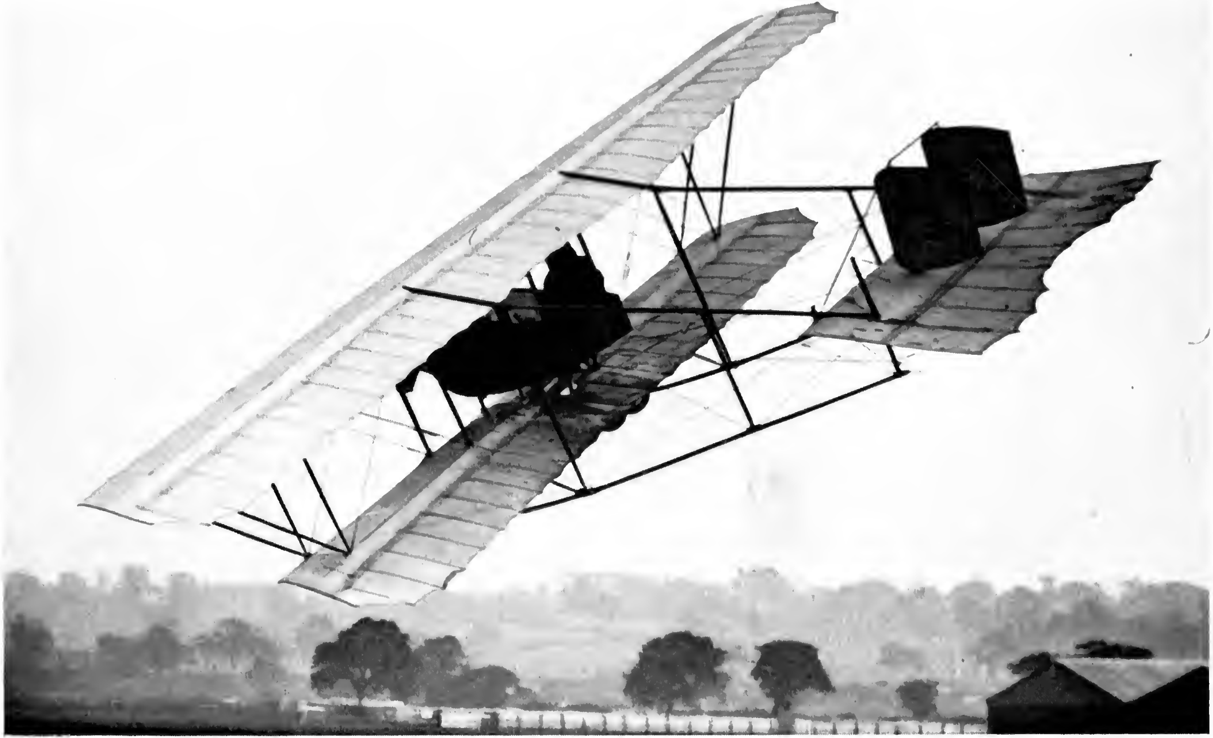
Suppose a flat-sided pencil is placed on the surface of a table, and an attempt is made to propel it broadside-on by pushing it with another pencil applied to the middle of its length ; the pencil so pushed will oscillate about its vertical axis with pronounced directional instability.

The causes that initiate the yaw on the part of the pencil so propelled are local irregularities in the surface of the table, which represent a variable resistance to motion. The power applied to the purposes of propulsion is divided equally between the halves of the pencil, and if the resistance experienced by one part exceeds that opposing the other, the balance of power will not permit of both parts travelling at the same speed. To assume that they did continue to travel equally fast would be to specify that one-half of the pencil was receiving more power than the other half, which would not be possible in the system of propulsion described ; such an assumption would thus be an evasion of the hypothesis.

This simple experiment is instructive inasmuch as it represents to some extent the relationship of the wings to the power plant of an aeroplane. It is not possible that a single engine and propeller situated on the longitudinal axis should supply unequal proportions of power to the two wings ; consequently any lack of equality in the resistances that they experience in flight must immediately be reflected in the commencement of yawing.

Directional stability in such a system as an aeroplane, which has its wings broadside-on and its power applied at a point midway along the transverse axis, does not depend primarily on the presence of a rudder at the rear end of the longitudinal axis, but upon the equality of the resistances opposing the broadside motion of each wing spar. Temporary disturbances that tend to engender yawing may, however, be damped by the inertia effect of the rudder plate, and indeed a rudder tends to assume a position of first-class importance as an organ of control in a system that lacks inherent lateral and directional stability in the wings themselves.

The intimate connection between lateral and directional stability has been emphasized in the preceding chapter, and it may be made more apparent here by considering the process of establishing a bank and steering a curved course.



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Sydney Pickles banking at the Hendon Aerodrome on a Caudron biplane

The warping of positive wing tips does not in itself directly serve the purpose of banking, because, as has been explained, the component forces engendered on opposite sides of the machine do not harmonize with the precise requirements. From a consideration of the problem from the point of view presented by the balance of power, it is apparent that the wing so warped as to have its angle increased will ordinarily retreat. On the other side, the wing will advance; but its diminished angle of incidence will require a higher relative velocity in order to support the same weight, and so its acceleration will not at first tend to make that wing rise.

Thus, it is evident that even if the machine is ultimately caused to bank by the acceleration of the outer wing, a disproportionate spin will have accompanied the manœuvre and this extra spin will in itself be evidence of instability. That this is so, may perhaps be more readily shown by the aid of a simple artifice that I find of some service when mentally picturing conditions of steering on a circular course.

Imagine the machine to be proceeding around a maypole on the top of which one is sitting. From this vantage point there is obtained a perfect plan view of the aeroplane, and it helps to fix ideas if it be supposed that there is a thread from the top of the pole to the button on the pilot's cap. Also let another thread be stretched from the inside wing tip to a point lower down the pole. The wing spar itself must be in line with this latter thread while the upper thread is at right angles thereto.

As the machine continues to fly on its circular course, both threads, which may be supposed to be attached to rings riding on the pole, make the same angular motion about the axis of the pole, and any stretching of either thread would thus be a sign of instability.

Such stretching of the threads might be caused by an alteration of the bank or by yawing, neither of which movements should be possible save under the pilot's control in an aeroplane that is regarded as inherently stable.

To assume, as was done just now, that the aeroplane initiates its circular course by a disproportionate spin is to break the lower thread at the very commencement of the manœuvre. Evidently, what is required when banking for a turn is to avoid such spin; with positive wing tips this is usually only possible by applying the Wrights' practice of simultaneously using the rudder and the warp. If the rudder is used alone, the bank is again due to the disproportionate spin, and the position is only an improvement on the warp alone in so far as the advancing wing possesses its natural angle, and so begins to rise at once.

By ruddering against the resistance of the warped wing, that is to say by increasing the angle of the wing that tends to be caused to advance by the effect of the rudder, a proper banking movement is accomplished. In this case, the wing with the greater angle rises; moreover, it continues to rise indefinitely, and will capsize the machine unless the rise is checked by a reversal of the warp so as to diminish the angle to an extent corresponding with the relative speed at which the wing has to fly on its circular path. As the relative speed depends on the radius, and as the radius depends on the bank and speed of flight, it is evident that the manœuvre of establishing and maintaining a circular course with positive wing tips is ordinarily one calling for considerable skill and experience.

Equally is it clear that in the proper use of the rudder by the pilot lies the safety of the situation; indeed, many pilots prefer not to use the warp at all if the machine will bank sufficiently under the action of the rudder alone.

In the original Wright biplane, the rudder and the warp were connected to a universally pivoted lever, so that one was operated by a to-and-fro motion, while the other was operated by a sideways motion of the lever. A diagonal movement of the lever thus operated both simultaneously. In a later design the handle was hinged to the warp lever so as to provide independent rudder control in a more convenient form. It is usual on other machines to operate the rudder by a pivoted foot rest, or by pedals, or by the rotation of a hand wheel.

That the steering of a closed circuit was early recognized as a crucial test of the pilot's ability to really fly, may be judged by the fact that the first Grand Prix d'Aviation of 50,000 francs was offered by M. Deutsch de la Muerthe and M. Archdeacon for the first one-kilometre circuit. This prize was won on 13 January, 1908, by Henry Farman on a Voisin biplane, and his feat undoubtedly marked the beginning of a new phase in the serious development of the art. That the Wrights in America had four years previously brought the mastery of their own machine to a state of far superior perfection was a fact either doubted or forgotten by the enthusiasts on the aerodromes of France, and it discounted neither the merit nor the encouraging effect of these later achievements.

If the manœuvring of a circuit was regarded as a test of the pilot's ability to take care of his machine, so, it seems to me, might the steering of a circular course with fixed controls be considered as a criterion of the aeroplane's ability to take care of itself; in fine, as a test for inherent stability.[1]

Reverting to the main problem of steering, it has been shown that none of the means now available is quite satisfactory for the initiation of the banked attitude that is proper to the condition of flying on a circular course. It will also have been apparent, as it was when considering the problem of balancing during straight flight, that it is the positive wing tips that are the seat of the trouble. In the previous chapter I endeavoured to show that negative wing tips potentially afford means for stabilizing the wings during straight-line flight; it remains now to consider if they equally seem able to remove the objections to positive tips when steering.

The reaction of the air pressure on a negative tip is downwards and backwards, and in straight-line flight these components would be in equilibrium about the horizontal and vertical axes of the machine, by warping the wings so as to increase the negative angle of one tip relatively to the other, the equilibrium is momentarily disturbed in such a way as to make the wing having the greater negative angle tend to descend and to go more slowly.

While in the act of descending, its negative angle is

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[1] See page 145.

virtually diminished. This tends to check the descent. By flying more slowly, the down pressure on the wing tip is reduced, which also tends to check the retardation, for there is always the balance of power available to maintain the speed of that wing at the highest value compatible with the load that it carries.

It would seem, therefore, that the effect of the differential negative warp should be dead beat, that is to say the machine should automatically assume a canted attitude appropriate to the new conditions established by the warp, and should be capable of staying thus without culminating in a dangerous position.

It has been explained that the differential positive warp either tends to destroy the bank or to culminate dangerously. If the lower wing has the lesser resistance, the balance of power tends to accelerate it, and so to increase its lift, which will ultimately destroy the bank. Alternatively, if the lower wing has the greater resistance, the tendency is for the outer wing to accelerate and to rise indefinitely.

With negative wing tips, the acceleration of the lower wing tip would increase the air load on it, and so maintain the bank, while in the other case either the acceleration or the rise of the outer wing tip would increase the top pressure, and prevent the continuation of the movement.

It appears to me, therefore, that the differential negative warp potentially affords a safe control, by which I mean that any possible movement of it, whether intentional or otherwise, causes the machine to perform a true steering manœuvre that will not culminate dangerously.

A rudder should, of course, be unnecessary on a machine controlled by the differential negative warp, for the action of a rudder, as has been explained, is merely to initiate or check a spinning or yawing of the machine, and neither action is required in the full realization of such a system.

Inasmuch as it is necessary to provide for the personal direction of any aeroplane, and in so far as the actual experience involves banking the machine—which is in itself potentially dangerous if there is inadequate power—it seems to me at present that a safe control as above defined is about as near as one may readily attain to the practical solution of the stability problem.

A safe control, I think, might very well satisfy the requirements of experienced pilots without any resource to permanent negative wing tips for the sake of endowing the machine with inherent stability at all times. Washed-out wing tips capable of being made negative at will would improve the speed and climbing qualities of the aeroplane, and provided that the pilot could not make a mistake in its control, there would not necessarily be any very serious objection to being liable to be caught by a gust.

In windy weather it would always be open to the pilot to stabilize his machine in straight flights by making both wing tips equally negative. The control mechanism would, of course, have to be re-designed, and preferably made so as to be capable of single-handed operation.

In connection with the subject of the negative warp, it is interesting to refer to the investigations of Dr. E. H. Hankin, who studied with the greatest care the soaring flight of birds in India. His observations were published in full in *Flight* during August, 1911, and from them the following quotations have been taken :

" I first obtained a clue to the nature of steering movements by observing the flights of the black vulture. . . . Occasionally the tip of one wing will be seen to be depressed downwards momentarily and then raised at once to its original position. . . . After the movement there is almost time to formulate in words which way the bird is going to turn before the commencement of the turn can be recognized. In my notes I originally described this movement as a dipping downwards of the wing tip. This phrase was soon abbreviated to dip, by which term I propose to refer to the movement in future.

" It is necessary to consider how the dip is brought about. The first possibility that suggested itself to me was that it was caused by some intrinsic muscles of the wing. But on examining the wing of a dead bird, it appeared to me that the range of possible movement at the carpal-joint was less than my observations had led me to expect. It then occurred to me that perhaps what really happened was that the whole of the wing was rotated until the air pressed on its upper surface instead of on its under surface. . . . In order to decide between these two possibilities I dissected the wing of a black vulture and found that neither of the above suggested explanations is an adequate statement of the facts of the case.

" None of the intrinsic muscles of the wing have any power of making a dip movement by any direct action. But, on the other side of the ulna, I found three muscles that have the power of rotating the front edge of the outer part of the wing. Supposing the wing is extended horizontally, then if these three muscles come into action, the front edge of the wing tip becomes depressed. That is to say, the wing tip is rotated round the axis of the wing. The rotation is in such a direction that the air ceases to press on the underside of the wing tip feathers. Instead, it presses or tends to press on their upper surfaces. Hence the tips of these feathers are bent downwards, producing the appearance of the dip movement. From the dorsal aspect of the wing, two muscles may be seen that have the power of rotating the front edge of the wing tip in the opposite direction. These muscles come into action to return the wing tip to its original position. I have also found these muscles in the wings of the common vulture, the adjutant, and the sarus."

In Chapter XIV will be found some brief account of the Dunne aeroplane, which actually possesses negative wing tips and makes use of a differential negative warp control without a rudder.

CHAPTER VII

LONGITUDINAL STABILITY

The ballasted flat plate and wing of single camber—The fore-and-aft dihedral as a speed regulator—Stalled—The dive—An experiment by Orville Wright—The reflexed wing—The Fales section.

LONGITUDINAL stability, it has been explained in a preceding chapter, is concerned with the pitching of the aeroplane in the air. Such motion takes place in the form of a partial rotation about the transverse axis, which, for the sake of argument, may be supposed to be coincident with one of the wing spars of a monoplane.

In the absolute sense, longitudinal stability would imply that the fore-and-aft axis of the machine was never disturbed from an attitude parallel to the horizon ; and if such were the case, all movement, including that of ascent and descent, would necessarily be accomplished on a level keel. Instead of the modern glide with the head of the machine pointing towards the earth and the tail towards the sky, the aeroplane would merely subside obliquely downwards through the atmosphere as the result of switching off the power.

Such absolute stability as is hereby implied, would involve a system of planes in which the C.P. never moves from its coincidence with the C.G. for any angle of incidence within the limits needed to cover the conditions of practical flight.

A flat plate slightly inclined to the direction of its relative motion has its C.P. situated towards the leading edge. When the angle is increased, the C.P. retreats, and vice versa. It follows, therefore, that the ballasted flat plate would not satisfy the conditions implied by longitudinal stability in the absolute sense. It has, nevertheless, a form of stability of the weathercock kind that may very well be suited to the purpose of practical flight.

Indeed, preceding descriptions of elementary experiments with this simple model have sufficed to show that as a system its power of recovering balance is excellent. Moreover, in the remarks in a former chapter relating to absolute lateral stability by means of negative wing tips, the existence of weathercock longitudinal stability was laid down as part of the hypothesis. It is, therefore, to a consideration of the qualities of modern aeroplanes in relation to this principle that the present chapter is devoted.

In the first place, modern aeroplanes use wings of single camber, that is to say, wings in which the surface is wholly concave to the chord, and the phenomena associated therewith are diametrically opposite to the qualities displayed by the ballasted flat plate. For instance, when the angle is very fine indeed, the C.P. may be nearer to the trailing edge than to the leading edge. As the angle is increased the C.P. moves forward, but when a certain critical angle is reached, the C.P. begins to retreat. Finally it coincides with the centre of the surface when the wing stands upright against the wind.

In flight, it is only with the finer angles, those below the critical angle, that the aeroplane designer is concerned; and the essential point of importance that needs constantly to be borne in mind is that the cambered wing of single curvature is inherently unstable longitudinally.

Thus, if the C.P. moves forwards from the position in which the aeroplane is in equilibrium, the tendency is to tilt the head upwards, which will, of course, cause an increase in the angle of incidence to the line of motion. But, with a cambered wing of single curvature, an advance in the C.P. can only be itself brought about by a preliminary increase in the angle of incidence. Consequently, the nature of the movement is such as to augment the initial disturbance.

With a flat plate, on the contrary, a disturbance tending to increase the angle of incidence would tend to cause the

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A BLERIOT MONOPLANE ABOUT TO ALIGHT

C.P. to retreat, which would be a movement in opposition to the disturbance and so one making for stability.

By fitting the cambered wing of single curvature with a tail carrying a lighter load per square foot, the system as a whole may be made to possess the characteristics of a flat plate in respect to the travel of the C.P. with changes of angle.

A tail set at a lesser angle of incidence than the main planes introduces what is known as the longitudinal dihedral angle, which may be illustrated diagrammatically thus___.../ The tail member, if a flat plate, is normally neutral. When it rises, the wind strikes its top surface and blows it back again; vice versa when it tends to fall. The principle presents, in short, an example of weathercock stability.

On some machines, the tail planes are cambered like the wings and help to support the weight in flight. The angle of incidence of the tail is less than that of the wings, however, and the principle above described applies equally to such cases.

The practical realization of the principle of the fore-and-aft dihedral depends on the leading plane of an aeroplane having a heavier loading (pounds per square foot) than the tail plane. In the case of a tail-first type of machine, the main planes occupy the position of a tail and must be less heavily loaded than the stabilizing plane in front. In the case of an ordinary aeroplane, the main planes being in front, must be more heavily loaded than the tail.

The distribution of the weight of the machine is such that the aeroplane is balanced fore and aft in its normal flying attitude. If the attitude of the machine changes by a small amount, so that the angle between its axis and the relative wind is, say, two degrees less than formerly, then both the main planes and the tail plane will have suffered an equal diminution in their angles of incidence.

Assuming that the effect of this diminution is an equal absolute loss of lift per square foot on both planes, then the *proportionate* loss is less on the leading plane, because it has the higher initial loading. For example, if its initial loading is 5 lb. per sq. ft. and it loses 1 lb. per sq. ft., the reduction is 20%; if the tail plane initially carried 3 lb. per sq. ft. the loss is $33\frac{1}{3}\%$. The consequence of this difference is the creation of a couple tending to restore the normal attitude in flight.

When the main planes are very lightly loaded, there is greater latitude for the design of a stabilizing plane that is to go in front. Here it must be more heavily loaded than in the rear, where it would be less heavily loaded than the main planes. This argument is sometimes advanced in favour of the tail-first type of aeroplane. In principle, its stabilizing action is, as has been shown, of the same weathercock kind in both cases.

Weathercock stability results in the maintenance of equilibrium in respect to the trend of the relative wind: that is to say, longitudinal stability of the weathercock order tends to maintain a constant angle of incidence under all conditions. Inasmuch as a constant angle of incidence requires a constant relative speed, the longitudinal dihedral may be regarded as an automatic speed regulator. As such, it draws attention to the significance of speed as a factor in maintaining longitudinal stability.

If a real wind gives to the relative wind an upward trend, weathercock longitudinal stability tends to make the machine raise its tail until it is again neutral to the stream. Similarly, if the path is one of descent in calm air towards the earth, the tail rises into line with the direction of motion. On the contrary, if the machine is climbing, the obliquely upward path tends to put the tail on a lower level than the head. As seen by a spectator on the ground, weathercock stability thus has the quality of making the machine seem to "look where it is going." Yachtsmen may see some connection between the longitudinal dihedral on an aeroplane and the use of a jib-sail on a boat.

Also, tending to keep the angle of incidence unchanged, it tends to limit the horizontal flight speed to a fixed velocity. If, with a given angle, the speed is increased by increasing the power output from the engine, the lift will exceed the weight and the machine will climb. Conversely, if the relative speed is decreased by closing the engine throttle, the machine will descend. It is of fundamental importance to bear in mind that any raising of the machine to a higher level in space involves the expenditure of power over and above that necessary for support in horizontal flight.

Whether possessed of longitudinal stability or not, therefore, a machine that is to be made to climb must expend more power in the operation, for it is impossible to continue to steer the machine upwards by any system of control unless the manœuvre is accompanied by an increase in the power output.

Conversely, so long as the power output is sufficient to support horizontal flight, the machine that is longitudinally stable in the weathercock sense will not descend. On such a machine, steering from one altitude to another would, therefore, be accomplished by manipulating the throttle of the engine. This point in the argument has an especial interest in so far as some engines have not been noted for their susceptibility to throttle control.

Weathercock equilibrium not being stability in the absolute sense is liable to oscillation, and the presence of some suitable organ under the pilot's control naturally suggests itself as a desirable adjunct. It is, in fact, a feature of all modern aeroplanes, and it is called the elevator.

Ordinarily, the elevator is a hinged flap forming an extension of the fixed tail plane. Sometimes it is a separate member carried in front of the main planes. The name is apt to be misleading in so far as it may give rise to an impression that the elevator itself possesses some quality that enables it to lift the aeroplane to a higher level in space. It is for this reason that emphasis was laid just now on the need for bearing in mind that an increase in the engine power output is an essential to all continued climbing operations. Momentary "jumps" may be accomplished by using the elevator, but it is at the expense of the energy stored in the machine's own mass and motion, and so inevitably reduces the relative speed.

Originally the elevator was often called the horizontal rudder, a term that was not only open to criticism on the same score as is the word "elevator," but was also a word that gave rise to much confusion as to which of the two rudders was implied. The elevator, as a physical object, consists of a horizontal plate, but its field of operation is vertical. On the other hand, the ordinary steering rudder is a vertical plate controlling horizontal movements of the machine. The use of the term "elevator" has, therefore, at least, the merit of avoiding this confusion.

As an elevator is fitted to all modern machines it is necessary to consider the extent to which it may conceivably be used for purposes beyond the scope of its initial duty, which is to enable the pilot to damp out the oscillations of weathercock longitudinal stability.

In the first place, it is necessary to observe that as the elevator is normally neutral, the initial effect of giving it an angle of incidence is to alter the centre of pressure in the system. If the elevator forms an extension of the tail, the effect of depressing it is temporarily to increase the lift under the tail end of the machine, which thereupon rises.

For a small deflection of the elevator, the tail will not rise indefinitely, because there will come a time when the further ascent is prevented by the now negative angle of the fixed tail plane itself. Thus, the resetting of the elevator angle causes a change in the longitudinal axis of the system about which the aeroplane is stable, which in turn represents, for the case in question, a finer angle of incidence on the part of the wings.

If the machine is to be supported in horizontal flight with the wings thus set, it is essential that the speed should be increased. Provided, however, that the engine has requisite reserve power there is no fundamental objection to the assumption. Indeed, it is on this principle that modern aeroplanes demonstrate the quality of variable horizontal speed with their reserve engine power

It is self-evident, however, that there must be a limit to this practice, for the range of angles suitable for flight is none too extensive. Moreover, the very existence of these limitations suggests at once that there is some liability of the elevator control being abused in practice, both through lack of appreciation of the consequences and through over-confidence of the pilot in his own personal skill.

One limiting condition is reached when the speed has been reduced to a minimum by making the angle of incidence extremely large. Such a tail-down attitude is called by the French *cabré* and, in the limit, the machine so situated is said to become " stalled."

In order to recover his normal flying speed, the pilot must dive, and it would seem that the height needed to obtain the requisite velocity and to flatten out into a horizontal path again is often far more than is commonly supposed. An experiment by Orville Wright relating to this very point is recorded in a private letter dated 26 November, 1912, from Mr. Griffith Brewer to Mr. Alec Ogilvie, from which I have their permission to publish the following abstract :

" Orville has been going into the cause of a number of accidents, where for some unexplained cause the machine has suddenly pointed downwards and has not been corrected before coming into contact with the ground. This type of accident has occurred in several cases after gliding down from a considerable height, and after being straightened out at perhaps fifty feet from the ground, the machine is seen to turn downwards and to continue to turn down until it strikes the ground.

" In some cases such accidents have been attributed to the fouling of the control wires, but in an inquest held by the American authorities on the wreck of an army machine the control wires were found to be intact.

" The conclusion that Orville has come to is that these accidents are caused by the stalling of the machine, and he has been making experiments in the air in order to test the effect of stalling in actual practice. He went to a height of 300 ft. and stalled the machine, and as he had expected the machine turned slowly downward, and for a period of at least five or six seconds after first stalling, the elevator tail was useless and the moving of the lever had no effect on the inclination of the machine whatever. The machine pointed downward at a very steep angle, possibly 60 degrees, before it had gathered sufficient speed to bring it under control. Instead of dropping 50 or 60 ft. in this recovery, however, he dropped about 200 ft. before he could straighten her out, and he says that he did not stall her to the worst position possible, and he would not be surprised if it would be necessary in some instances to have 300 ft. clear below to enable the stalling to be corrected in time to save a smash."

The problem is one of the greatest interest and importance, but does not appear to render itself readily to a simple solution. It is, I think, commonly supposed that the recovery depends on the measure of control available in the elevator, but it seems to me that there is a limiting rate at which the velocity acquired by the head-first descent can be changed into a horizontal direction of flight without loss of speed. If it depended only on the elevator, then consider the case of the early Wright biplanes which had the elevator in front and no horizontal tail plane.

The fore-and-aft dihedral depended on the pilot's control of the elevator angle, although it was the practice of the constructors of the machine to provide the elevator lever with a friction brake attachment so that it would stay in any position that it was set. In the case of a dive, it was within the bounds of possibility that the pilot might exaggerate the use of the elevator to such an extent that it might take charge and turn the machine completely upside-down. Thus, the elevator would finally assume the position behind the transverse axis, which should properly be occupied by a tail. With the elevator in front, it was thus certainly possible to turn the machine into a horizontal attitude at any moment, while diving, but it would by no means be equally certain that the machine would fly off horizontally in consequence.

The other extreme limiting condition in the use of the elevator occurs when the angle of the planes has been made so fine that they require the utmost speed available from the engine to obtain the necessary lift for the support of the machine in horizontal flight. Beyond this point, the path must of necessity be downward. In this case it would, indeed, seem as if the danger depended primarily on the range of the elevator and the brusqueness with which it is used. Thus, again consider the case of the early Wright biplanes with the elevator in front: it was presumably possible to turn the machine head-first downwards in an instant, but it is evident that doing so would not all at once obliterate the momentum of the machine in a horizontal direction.

A bullet shot horizontally from a rifle, or a stone thrown horizontally from the hand, begins to descend at once under the influence of gravity, but the horizontal component of the motion causes the path pursued to be a curve approximately in the form of a parabola.

In the case of an aeroplane with sufficient range of elevator control it may be assumed possible to turn the head downwards so much as to receive air pressure on the top side of the wings. But if this happens the machine will tend to slow down in its horizontal motion more quickly than the pilot, who, in consequence, will be caused to leave his seat. It seems fairly safe to assume, therefore, that no pilot will voluntarily use the elevator to this extent under such circumstances.

Assuming that there is to be no top pressure on the wings, then the path of flight is a curve depending on the speed itself, and the height requisite to recover the horizontal depends, I suspect, on the steepness of the angle of descent to which the dive is carried.

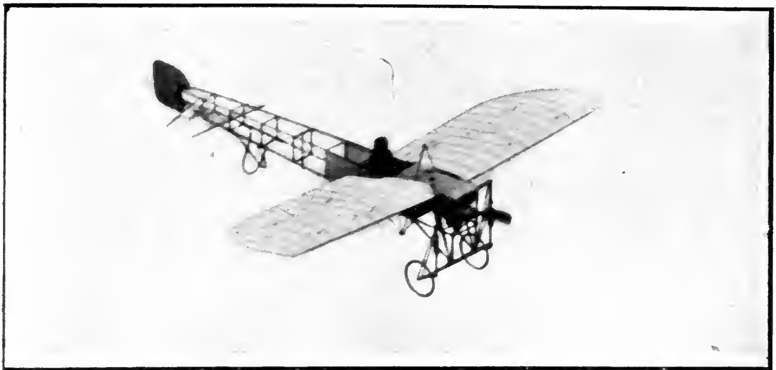
Sufficient has been said to show that such extreme conditions of flight are primarily due to the exaggerated use of the elevator as an organ for acquiring variable *horizontal* speed. If the normal longitudinal stability of the system were untampered with, the machine would neither become stalled nor would it dive of its own accord. On the other hand, neither would it have a variable range of horizontal speed unless means were found for altering the area of the wings in flight, which would be a more efficient method although one involving considerable mechanical difficulty in its execution.

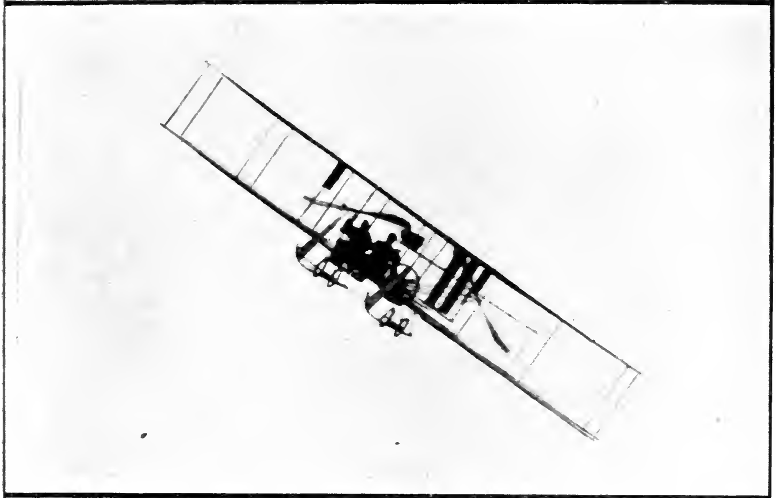
It is, indeed, the procedure followed by nature in the design of birds, which have feathered wings that they can extend and contract at will. Dr. Hankin, who has made such interesting observations of the detail movements of birds in the air, describes how the wings are half folded in what he terms "fast flex gliding." Sparrows and other small birds while flying fast may be observed completely to close their wings periodically when performing what Lanchester has termed "leaping flight." Dr. Hankin has also described how soaring birds will dive with partially folded wings and then suddenly extend them aloft in a transverse dihedral so as to swing themselves into a horizontal attitude by temporarily raising the centre of resistance above the centre of gravity.

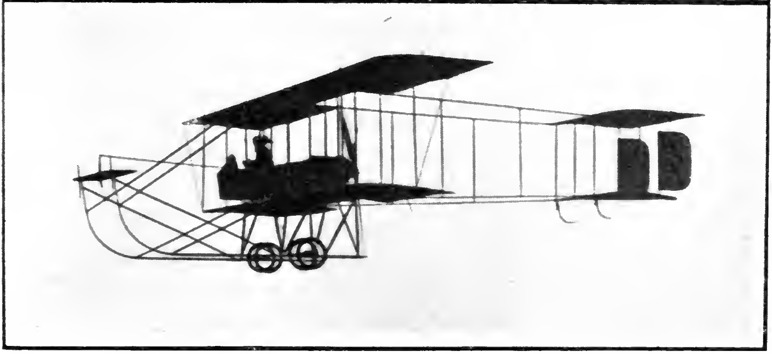
It must be remembered, however, that the speed in this case is above that required for horizontal flight, and so the flattening out can be performed with great rapidity. The same applies to an aeroplane that has acquired an excessive speed by a dive from a great height, the problem being, I think, largely different from that related to the least height in which it is possible to recover the horizontal flight speed after being stalled. But there is just one point that is worthy of attention in this matter, which is that some forms of aeroplane may conceivably become locked in a head-first attitude by disproportionately great resistance of the undercarriage as compared with that of the wings at very high speeds, and especially on steep slopes. On such machines, it would seem desirable to have means whereby a resistance surface might in emergency be raised above the pilot's seat so as to introduce a turning couple about the transverse axis of a kind that will augment the elevator action.

Speaking of excessive speed with wings full spread raises the question of the effect that might be produced by flexible wing surfaces, such as are sometimes advocated. It would be very awkward if there were any tendency on the part of such sections to flatten excessively during a dive to such an extent as to delay the recovery.

The presence of a fixed tail on modern machines is due, it has been explained, to the inherent instability of the cambered wings of single curvature. If a wing-form of







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1. Gustav Hamel making a spiral glide on a Bleriot monoplane.
2. F. P. Raynham banking on a Wright biplane.
3. Pierre Verrier in level flight on a Maurice Farman biplane.

adequate lift-resistance ratio were available that also was in itself stable in longitudinal equilibrium, there would theoretically be less need for the tail. From the latest research of Eiffel, who has been investigating the qualities of the reflexed wing, in which the trailing edge curls upwards, it would appear that longitudinal stability is potentially available in such a form. Mr. W. R. Turnbull also had this section under observation in his laboratory at Rothesay, Canada, as long ago as 1905, and recorded the same fact.

Other very interesting experiments on this aspect of the subject were made by Mr. E. N. Fales at the Massachusetts Institute of Technology in 1912, and the results draw special attention to the importance of the position of and magnitude of the maximum camber. From the article contributed by Mr. Fales to *Engineering* of 28 June, 1912, it appears that a flat-bottomed wing having a maximum camber of 0·125 situated 0·145 of the chord from the leading edge had a travel of the C.P. that was in the direction for inherent stability between the angles of 2° and 10° incidence. Other similar wing sections, but with different maximum cambers, were found to possess natural longitudinal stability for a small range of angles in the flight region, but the example quoted seems to be the best of the series.

The importance of these tests lies, of course, in the fact that the stable portion of the range covers angles of incidence commonly used in flight.

If a wing section of some such form as this proved to be reasonably good from an aerodynamic standpoint, it would potentially serve as a means of eliminating the long fuselage that characterizes modern aeroplane design. In doing so it would also relieve the machine of appreciable weight and reduce its rotational inertia about the transverse axis. In fine, it would promote sensitive longitudinal stability of the weathercock order. A tail flap of sorts would presumably be necessary in its fundamental capacity of a damping organ under the pilot's control; if used for varying the horizontal speed by altering the angle of attack it would still render the machine liable to be stalled.

Attention has already been drawn to the intimate relationship between speed maintenance and longitudinal stability, and in one form or another most devices that have been invented as longitudinal stabilizers have been based on the principle of regulating the velocity of the machine. It is, therefore, important to recognize that this function is simply and conveniently performed by the longitudinal dihedral, which in some form or another is a characteristic feature of all successful aeroplanes, and that any form of hand control enabling this principle to be neutralized must inevitably be attended with risks to any pilot who is not fully appreciative of its purpose and limitations.

CHAPTER VIII

PRINCIPLES OF PROPULSION

Propeller in front *v.* propeller behind—Two screws *v.* one—Military requirements—Size and efficiency—Size and speed of flight—Rankine's theory—Wing *v.* propeller—Aeroplane *v.* helicopter—Aero engines.

NOTHING moves unless it is pushed, for even falling bodies need the impetus of gravity to urge them earthwards. Aeroplanes, therefore, must be driven by other force than their own weight if they are to fly indefinitely, and the instrument used for this purpose is the propeller, which is, of course, driven by the engine.

The propeller exerts a thrust [1] on the machine by virtue of the reaction derived from the draught that it creates when it revolves. In principle it is a fan; in blowing the air backwards it drives the aeroplane forwards. It is permissible and proper to regard each blade of a propeller in the same light as the wing of an aeroplane. Each blade deflects air backwards as it moves; the combined effect of both blades operating always in the same region when the machine is standing still produces a concentrated flow of air, which becomes a very pronounced draught. Technically, this draught is called the slip stream. When the aeroplane is in flight the propeller screws itself continually into fresh air, and maintains its thrust without creating so much draught. That is to say, it deflects a greater mass of air without accelerating it to such a high velocity.

In some aeroplanes, the propeller is situated in front, at the very nose of the machine; in others, it is placed behind the main planes. Ordinarily there is only one propeller, but from the first the Wright biplane was fitted with two, and this uncommon feature is still retained in the modern

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[1] See Appendix on Newton's *Laws of Motion.*

design of this machine. A very interesting biplane incorporating three propellers and two engines has also been evolved by Messrs. Short Brothers.

The question of propeller position is one that hitherto has mainly been governed by structural convenience. On the conventional type of monoplane, for example, a single propeller must be situated at one end of the fuselage or the other, and consensus of opinion has elected to place it in front. Fishes propel themselves from the tail, and propellers on boats are also placed astern, so it is not for lack of example that the screws of monoplanes fail to find themselves thus situated. A propeller at the rear extremity of a monoplane fuselage, however, would quite obviously be an inconvenience for several reasons. Such a machine was, however, once built.

Considerations of equilibrium prevent the engine being placed on the tail, while the separation of engine and propeller by any considerable distance involves the use of shafting that adds otherwise unnecessary weight. Also, even a moderate-sized propeller measures 9 ft. in diameter, and the clearance necessary to prevent its striking the ground on landing would call for a more substantial undercarriage beneath the tail than is at present necessary. Many other considerations might be mentioned in this connection, but really the only reason for drawing attention to the matter is that the use of aeroplanes for military purposes has given rise to much discussion out of which there has been formed an opinion, which meets with considerable support, to the effect that the propeller on any military machine should preferably be behind the pilot and the observer. It is apparent that a stern-driven monoplane of the modern type, which has a long box-girder backbone, is a design of considerable difficulty, but assuming a departure from this type, a monoplane with its propeller behind is not only a possibility, but already an accomplishment.

If, as seems probable, the quality of high speed is specialized in monoplane design with a view to employing them for military purposes solely in the capacity of scouts, the inconvenience of the present position of the propeller, regarded from the point of view of being an obstruction to shooting with a gun, may continue to be of secondary importance. Where the chances of evading capture may depend on the ability to fly faster than the enemy, capacity for speed is naturally a quality of first-class importance.

On the other hand, a machine that is designed to carry a gun with a reasonable amount of ammunition and is expected to be able to cruise about at moderate speeds for long periods of time, is far more likely to be a biplane than a monoplane on account of the large wing area that would be necessary to support the weight under such conditions. The mere specification of the ability to carry a gun involves the absence of any vital structure from in front of the machine, and if the box-girder backbone continues to be used as it now is, even in biplane construction, the removal of the propeller to the rear of the main planes also involves its duplication and the introduction of an intermediate transmission between the engine and the two screws.

The question as to whether a gun is or is not necessary on an aeroplane for military purposes is one that will probably have to find its final solution in war, but from hearing the subject discussed among army officers I am left with the impression that the aeroplane pilot need fear but little from any land artillery. This may not, in fact, prove to be the case, but I have heard several artillery officers express the opinion that it would be almost impossible to hit an aeroplane with any sort of weapon at present in use. If such is the case, then it is apparent that aeroplanes must be fought in the air, and that in addition to the high-speed scouts it will also be necessary for armies to possess a squadron of aerial destroyers.

For relatively slow speeds and the efficient utilization of high power, two propellers are not only advantageous but may prove necessary, for there is a limit to the diameter of a single screw that conveniently can be employed on a machine of even large size. At any rate, the problem of propulsion in its broader aspect resolves itself into laying hold of as much air as possible in a given time. High flight speeds facilitate this to an extent that renders comparatively small propellers efficient, but when the necessary volume of air is not brought under the action of the propeller blade by the high velocity of the machine itself, the only efficient alternative is to increase the effective diameter, for it is an extremely wasteful process to augment the thrust by accelerating the velocity of the slip stream.

This procedure applied to a single propeller is limited by considerations such as the ground clearance afforded by a reasonable height of undercarriage when the machine is a monoplane, and also to some extent by structural difficulties in the propeller itself. A single propeller of about 12 ft. in diameter is, however, successfully used in the Cody biplane.

If the choice of a small-diameter propeller forms an arbitrary detail in the design of a slow-speed machine, the use of twin screws is indicated as the proper course to pursue for efficiency. The thrust that is available from a propeller depends on the mass of air dealt with in a given time and on the acceleration imparted thereto.

A fan standing stationary experiences a thrust due to the reaction of the draught that it creates, and its energy is entirely utilized in creating that draught. On an aeroplane, the purpose of the propeller is to move the machine, and the power lost in the propeller draught, which is commonly called the slip stream, is only so much wasted energy.

It is necessary to create a draught in order to experience any thrust at all from a propeller, but while the lost power is proportional to the mass of the air in motion, it is also proportional to the *square* of the slip-stream velocity. Any increase in the speed of the propeller draught is thus comparatively wasteful, but any increase in the speed of the machine, which would obviously bring a greater mass of air under the action of the propeller in a given time, is obviously a move towards efficiency. There is, therefore, an elementary relationship between diameter and speed of flight, thrust, and efficiency.

If the same thrust is required at a slower speed of flight, it can only be obtained by a relatively higher velocity in the slip stream or by increasing the propeller diameter; the latter is potentially the more efficient method.

It was Rankine who first clearly enunciated the true theory of propulsion in fluids, and the opening paragraph of the classic paper that he read at a meeting of the Institution of Naval Architects in 1865 was as follows:—

> "Every propelling instrument, whether a paddle, a screw, or a pump, drives a ship by means of the forward reaction of the current of water which it sends backwards. That reaction is transmitted by the propelling instrument to the ship, and when the ship moves uniformly it is equal and opposite to her resistance."

Before Rankine's time, apparently, theory assumed the propulsive effort derived from a propeller to be the equivalent of the resistance that the instrument itself would experience if dragged inertly through the water. In fine, it assumed that the mass accelerated by the instrument in its capacity of propeller was only equal to the mass that it was capable of bringing to rest as an obstruction. In reality there is an immense discrepancy between the forces in the two cases, and it is very much in favour of the propeller. Theory thus, for once in a while, provided an underestimate instead of an overestimate of the limiting case.

If for water we substitute air, Rankine's theory sums up the case of the aeroplane with equal conciseness. It serves no useful purpose, however, to consider the paddle, for the flapping wing is the only form in which it would be likely to exist, and such a mode of propulsion on an aeroplane would involve considerable mechanical difficulty in its execution.

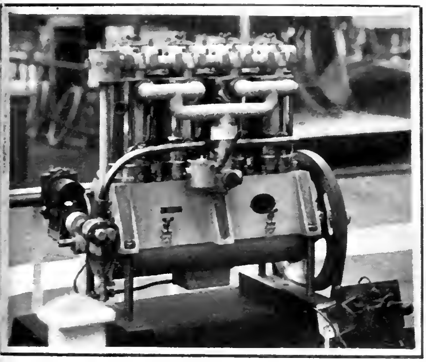
There are two equally important points of view from which to regard a propeller; one already mentioned concerns the relationship between disc area (area swept out by the blade in rotation) and speed. The other is the analogy between the blade of the propeller and the wing of an aeroplane. The blade of a propeller is an aeroplane in principle, but its flight path is a helix, and so the shape of the blade varies from shoulder to tip. In this respect only does it, in principle, differ from the wing of an aeroplane, which is designed to fly straight. The design of a good propeller is, however, a matter requiring special experience, as well as an appreciation of theory, and, like many another important subject that has been mentioned, its detail discussion would be outside the scope of this book.

What, however, it is within the scope of these pages to emphasize is that there is no difference in principle between the means whereby a propeller exerts its horizontal thrust and those whereby an aeroplane wing exerts its vertical lift. Both forces are reactions due to the same fundamental cause, which is the continuous acceleration of fluid mass.

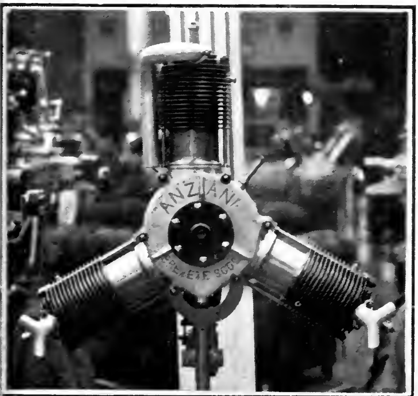
A bird's wing is aeroplane and propeller combined, its flapping motion relative to the bird's body giving the propulsive effort, while its mere presence as an extended surface in motion suffices for the aerodynamic support. Birds frequently glide long distances on outstretched rigid wings, in which case these organs of flight are no longer propellers.

Two advantages of the flapping wing over the propeller are its large area and more convenient position. Its most serious drawback as a piece of mechanism would be the structural complication of having moving parts in a vital place and the fundamental objection to reciprocating motion in engineering generally. Nature is limited to reciprocating motion because arteries of necessity cross the joint.

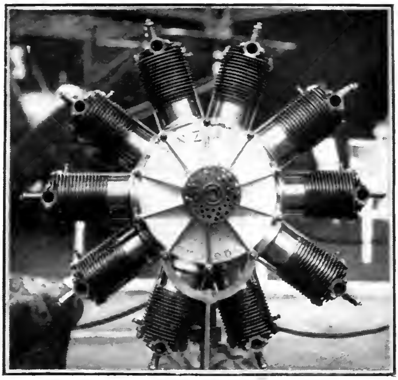
While discussing propellers a word may well be said on the subject of the use that it is sometimes proposed should be made of propellers mounted on vertical shafts so as to lift the machine directly into the air. Several helicopters, as they are called, have been built at one time or another, but none has been successful, nor have I any authentic record of any such device remaining air-borne for any appreciable length of time. It appears to me that those who profess to believe in the helicopter as a possible flying machine tend rather to ignore, as did the would-be pioneers of the aeroplane in the olden days, the fact that the troubles may be expected to begin from the moment that they first succeed in getting the machine itself aloft. There is no reason that



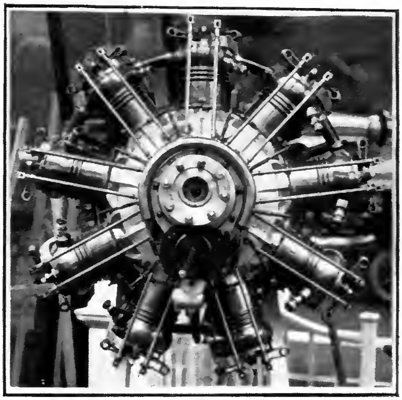
1. The four-cylinder British-built Green engine.



2. The three-cylinder Anzani.



3. The nine-cylinder Anzani; a stationary radial engine of 100 h.p.



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4. The nine-cylinder water-cooled Canton-Unne radial type engine.

I can see why such an apparatus should be easier to fly, i.e. control in respect to stability and direction, than is an aeroplane.

In so far as the helicopter is supposed to represent a machine capable of hovering over a fixed point, the argument takes on a special aspect that naturally introduces the airship into the comparison as an alternative, and possibly preferable, means of performing the same purpose. The aeroplane accomplishes a journey while supporting itself in the air, and in principle it may be said that the journey is merely incidental to this mode of support. If the purpose of flying were to stand still in space, the aeroplane might well be criticized for its limitations on this score. On the other hand, if the journey is useful, then the aeroplane is undoubtedly the more economical machine, and even if the journey itself is of no consequence, it may equally be shown that this mode of flight offers better prospects of economy in the utilization of power for the purposes of support than does the helicopter.

From what has been said on the subject of propellers it will be apparent that the "aerial umbrella" must be of very large diameter in proportion to the weight supported if it is not to be unnecessarily wasteful of power.

It is no part of the purpose of this book to deal fully with the mechanism of aeroplane engines, but it would nevertheless seem proper in an introduction to the subject at large to say something with reference to the action of so important a member of the aeroplane's anatomy, and the chapter on the principles of propulsion seems the best place for this purpose.

It must always be realized that the evolution of the successful aeroplane had of necessity to await the development of a satisfactory engine. Long, long ago, when engines were unknown, man had no other thought than that he would have to fly by his own muscular effort if he ever flew at all. When the steam engine was introduced, Sir George Cayley was at pains to calculate how nearly plausible was the idea of self-propelled flight with the prime movers then at hand. What really made the aeroplane possible, however, was the motor-car. The introduction and development of the self-propelled vehicle perfected the high-speed internal combustion engine to a point at which it could be adapted to the requirements of aeroplane flight.

While it is true to say that the automobile was the forerunner of the aeroplane in this respect, it would hardly be accurate to suggest that all the would-be flyer had to do was to take the engine out of his motor-car and put it on board an aeroplane in order to be able to fly. More than one early pioneer tried, in fact, to do so, but the result was not such as one might describe as an unqualified success. When the Wrights had developed their glider to a point at which they considered themselves justified in building a power-driven aeroplane, they were at a loss to find a satisfactory engine for their purpose, so with characteristic enterprise they set to work to design and construct one for themselves, and it is only fair to say that all the really successful aeroplane engines have been specially designed in the first instance for their particular work.

This, however, does not affect the principle of their operation, for the petrol engine that drives the aeroplane works in precisely the same way as the petrol engine that drives the motor-car. The difference is one of construction, mainly in respect to the relative disposition of parts with the object of saving weight. It is very important that the aeroplane engine should be as light as possible for the power that it develops, which object has led designers to contrive various means by which the maximum use is made of a minimum amount of material. Thus, for example, in the famous Gnome rotary engine, the successful working of which at one time did more than any other single thing to develop flying, the cylinders are placed radially round the crank chamber, which much shortens the overall length of the engine. The cylinders and casing of the motor are caused to revolve instead of the shaft, and being the heavier part they save the weight of a fly-wheel. In its principles of operation, however, the Gnome engine works just like any other engine. A note on this subject appears in the Appendix.

The best-known British-built engine that is at the present time most nearly allied to motor-car practice in its design is the Green, which has upright cylinders in line. In detail construction, one of its most pronounced features is the use of copper water-jackets instead of jackets cast integrally with the cylinders themselves as is common practice with engines built for use on motor-cars.

Many engines built for aeroplane work are air-cooled, that is to say they have radiating fins outside their cylinders and depend on the relative wind to prevent their cylinder walls and valves from becoming overhot. An interesting novelty produced by the Wolseley Co. at the Aero Show of 1913 was an engine in which the exhaust valves only were water-cooled. Many considerations, which it would be outside the scope of this book to discuss, enter into the question of air versus water-cooling. There is, for example, the question of lubrication and also the question of fuel economy, which raises in its turn the question of compression pressure. Other things being equal, a high compression pressure prior to explosion tends towards economy in fuel consumption and to a high power output from a given size of cylinder.

Most engines that have been designed for aeroplane use have differed from typical motor-car practice in having their cylinders arranged in two rows set at an angle to each other; such motors are generally referred to as belonging to the V type. It will be understood that a multiplicity of cylinders is necessary in order to smooth over the intermittent operation of each cylinder separately. The cranks on the crankshaft are set at suitable angles, so that the explosions in the different cylinders occur as nearly as possible at equal intervals of time. When an engine has four cylinders in line an explosion occurs once every half revolution of the crankshaft.

One of the most important considerations affecting the practical success of an aeroplane engine, from the standpoint of its popularity with pilots, is absence of vibration. In this connection, those who advocate ordinary four-cylinder vertical engines with high compression often, I think, forget the standard of smoothness to which pilots have from the first been accustomed in the low-compression

Gnome engines, which have seven or even fourteen cylinders contributing to an even-turning moment. Moreover, an engine on an aeroplane occupies a somewhat different position from that of the prime mover of a motor-car, and it is such as to exaggerate rather than diminish the effect of irregular operation.

CHAPTER IX

CONCERNING RESISTANCE

Wing resistance and body resistance—Streamline flow—Relative importance of the head and the tail of a body—Fair-shaped struts—The gain in lift due to reduction or resistance—Surface friction.

SUBMARINES, torpedoes and fishes have this much in common, that their bodies offer the least resistance to motion through the water that is compatible with their primary purpose of enclosing a variety of vital parts. If man found it as uncomfortable to remain exposed at high speeds in the atmosphere as he does to being submerged in the sea, aeroplanes would have had bird-like bodies from the first. On the whole, it is fortunate, however, that pioneer constructors did not have this further necessity added to the numerous difficulties that they have had to surmount.

It is a reasonable presumption, nevertheless, that the bird is the ideal flying form. Its body, one may suppose, is the proper shape for low resistance in air, its wings are devoid of struts and wires, its tail is without rigging and its landing chassis, which consists of a pair of delicate legs, ordinarily folds away when in flight.

Above all, Nature's wonderful gift for making a good mechanical job of joints for oscillating motion enables the bird to use its wings for propulsion by simply flapping them. This is an economy indeed, for not only does it make use of the whole of the supporting area for propulsive purposes, but it avoids the extreme inconvenience of an object like a propeller, which makes it necessary to hold the body of an aeroplane at a great height above the ground. Indeed, the mere presence of the propeller in the design of an aeroplane involves a departure from natural lines that brings much difficulty in its train. There is small prospect of successful artificial flapping flight, however, so it is necessary to make the best of the situation.

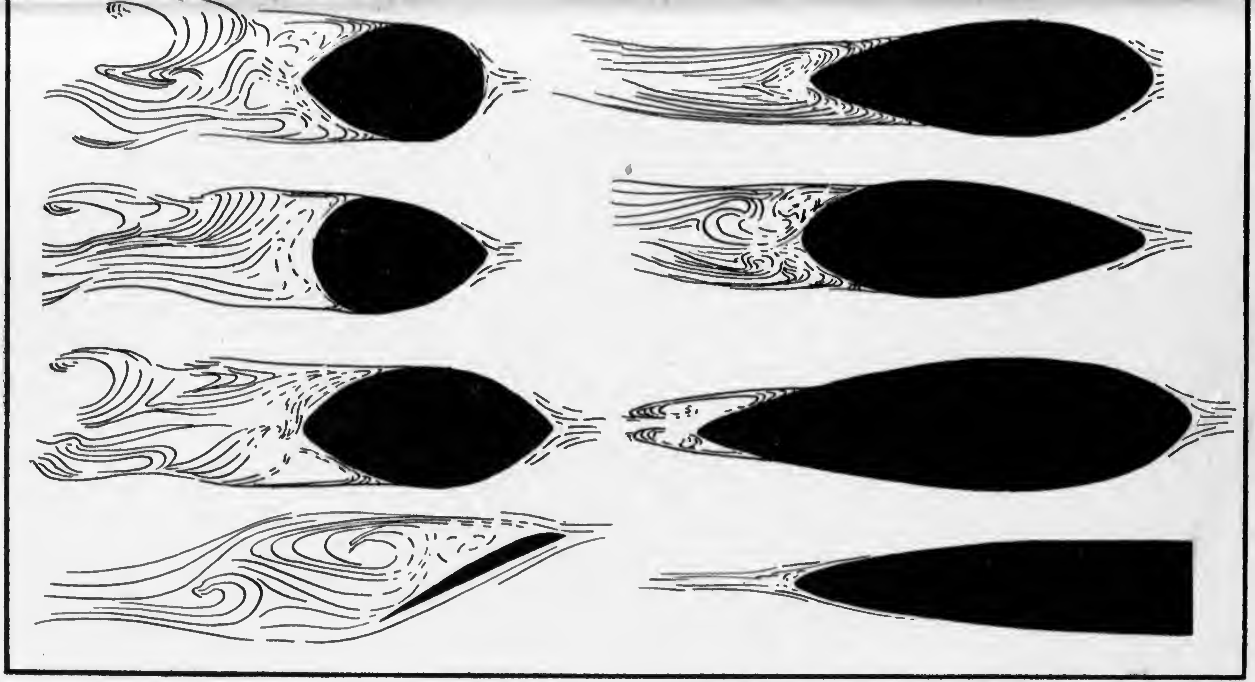
The limitations in propulsion, which have to some extent been discussed in the preceding chapter, render it all the more important to be chary of introducing unnecessary resistance. The resistance to flight is preferably considered as consisting of two separate but equally essential parts. One part is the resistance of the wings pure and simple ; the other part is the resistance of the body and of the superstructure by which the wings are attached to the body.

There is very good reason for so dividing the study, for while the size of the wings depends on the speed at which they are intended to fly, the size of the body depends only on what it has to carry, which, for the sake of comparison, may be supposed to remain a constant quantity.

In the chapter devoted to the cambered wing, some detailed consideration is given to its resistance and lift. There is, for any particular section at a given angle of incidence, a fixed relationship between these two factors, and the relationship is independent of speed. For a given weight to be supported at a given speed there is thus a certain wing area that will satisfy the conditions for a given expenditure of power.

It is modern practice, however, to aim at a wide range of horizontal speed, and so the wing is required to support its load at a variety of angles of incidence which in themselves correspond to different ratios of lift to resistance. Thus, suppose a wing is used that has a best ratio of lift to resistance of 12½ to 1 at, say, 4 degrees angle of incidence. When flying very fast, the angle of incidence will be finer, and when flying slowly it will be more coarse. At each end of the range we may suppose, for the sake of example, that the resistance is one-tenth of the load. For any given wing section to be used, tests such as are referred to in the chapter above mentioned will enable a chart to be drawn showing the wing resistance for any speed throughout the range.

In this chapter, therefore, it remains only to consider the resistance of the body and of the superstructure generally.



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Diagrams prepared from photographs published in the Technical Report of the Advisory Committee for 1912, showing the nature of the flow in the wake of various strut sections. The flow is from right to left in the picture. The two lower diagrams show a wing section set at a steep angle of incidence, and the aft portion of a dirigible envelope. Immediately behind the obstruction in each case is a region of dead water. In this region there is not much turbulence, but the pressure is negative and therefore adds to the resistance of motion. Further aft the fluid flow is more turbulent, as is indicated by the swirling lines. Where the above diagram is blank the flow of the fluid may be regarded as taking place in steady streamlines. Note the advantage of the longer sections in the two lower right-hand sketches

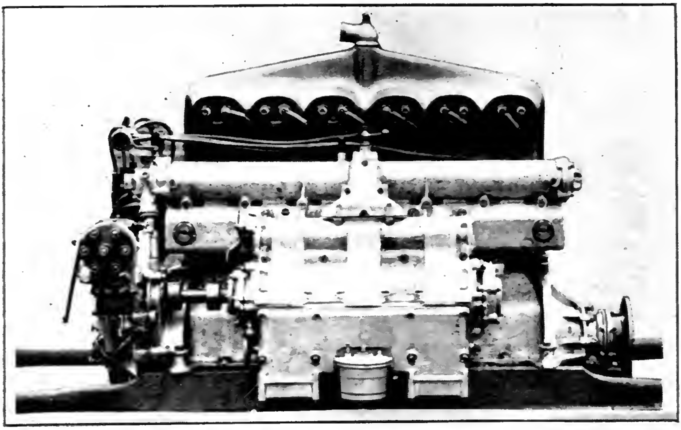
Moreover, as totally enclosed bodies are not yet commonly in vogue it is the superstructure that more particularly calls for attention, although the principles underlying low resistance in the one will apply equally to a design for low resistance in the other. In the main, the superstructure resolves itself into a study of the resistances of struts and wires.

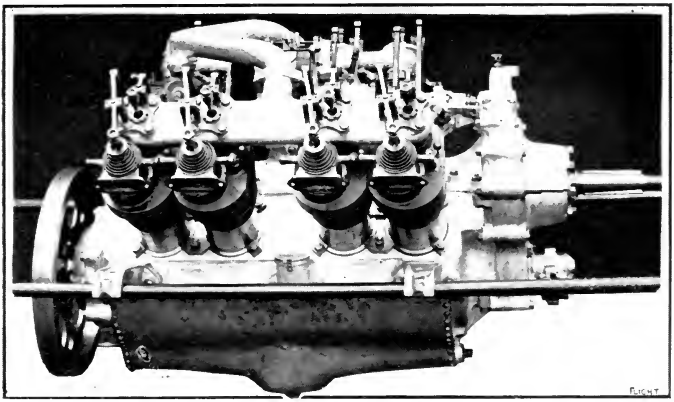
When a solid object is a partial obstruction to a fluid stream, the stream divides at some point in front of the obstacle and passes around it in a series of well-defined lines that ultimately close together again at some point behind the obstacle. By suitably colouring the fluid, these streamlines, as they are called, can be rendered visible. They show clearly and distinctly on a *time-exposed* photograph, which indicates that the direction of motion of the fluid particles at any fixed point remains constant.

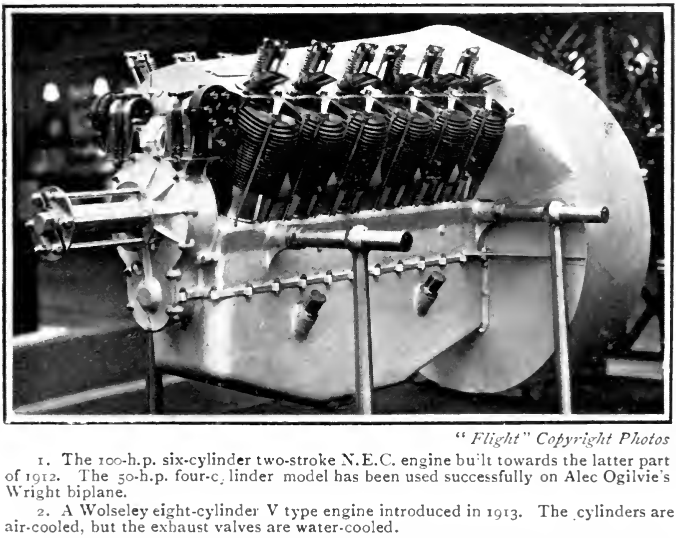
In some cases these streamlines conform to the profile of the obstruction itself for the greater part of its length : such objects are then said to be of fair shape or good streamline form. They offer the least possible resistance to motion in the fluid, having regard, of course, to the size of the obstruction.

Obstructions that are not of streamline form give rise to surfaces of discontinuity. The streamlines in the fluid diverge from contact with the walls of the object and enclose a region of turbulence between themselves and the solid wall. Such a pocket of eddies and dead water always exists immediately behind the obstacle, and being a place of negative pressure (suction) it exerts a drag on the object over and above the frictional resistance of the fluid in contact with its sides. Shapes that give rise to excessive regions of turbulence thus experience a disproportionately high resistance to flight.

It is by no means easy to specify off-hand a profile for a good streamline form, and it is equally difficult to select at sight from a number of shapes those that are likely to prove of least resistance when tested. The problem of choosing the best section for aeroplane struts and the like is still further complicated by the need to consider weight and







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1. The 100-h.p. six-cylinder two-stroke N.E.C. engine built towards the latter part of 1912. The 50-h.p. four-cylinder model has been used successfully on Alec Ogilvie's Wright biplane.

2. A Wolseley eight-cylinder V type engine introduced in 1913. The cylinders are air-cooled, but the exhaust valves are water-cooled.

3. The twelve-cylinder V type air-cooled Renault engine with fan attachment for cooling the cylinders. The model of this make most in use in England during 1912 was the eight-cylinder 70-h.p.

strength, which is, of course, the basis of all design intended for structural purposes.

That the subject is of first-class importance is apparent from many points of view. In the first place, it must be borne in mind that every pound saved in resistance of the superstructure means an increase of six pounds or more in carrying capacity of the machine, and vice versa. This statement is based on the fact that modern aeroplanes experience an inclusive resistance to flight of one-sixth of their weight or thereabouts. The power available for the purposes of comparison is, of course, assumed to be constant, and it follows that if one of two similar machines has its head resistance diminished by, say, 20 lb. it can in principle carry 120 lb. more useful load inside its body, where the presence of the extra weight will not give rise to other resistance than an extra load on the wings. If, actually, the added weight were taken solely in the wings the advantage would be even greater than this, for the wings, without their rigging, ordinarily offer a resistance of less than one-tenth the weight that they carry.

It is clear, therefore, that a reduction in head resistance is worth attaining; the question arises, however, whether the amount to be saved is an appreciable quantity. To answer this question in the affirmative it suffices to record the result of tests made on strut sections at the National Physical Laboratory, the most complete series of which thus far completed are those that were made for Mr. Alec Ogilvie and presented by him to the Aeronautical Society in order that they might be published for the benefit of those interested in aeroplane construction.

This series included a wide range of shapes, numbering 57 in all. Each was most carefully made and was exactly 1 in. wide at its maximum beam. They were all tested at a uniform speed of 20 miles per hour, and the resistances were then calculated on a basis of 100 ft. of strut at 41 miles per hour.

The section of greatest resistance was a rectangle of 2 to 1 ratio, which had a resistance of 46·4 lb. per 100 ft. at 41 miles per hour. The next highest resistance was a circular section, which represented 36·4 lb. per 100 ft. at 41 miles per hour. From these two tests alone it is clear that the circle and the rectangle are to be studiously avoided, for a rectangle of 2½ to 1 ratio suitably whittled away into a fair shape had its resistance reduced to 5·7 lb. !

The high resistance of the circular section draws special attention to the disproportionate resistance of single wires, which are also of circular shape. It should be worth while arranging wires in pairs one behind the other and carefully binding them with tape into a fair shape, for although this artifice may not give the least resistance possible there is good reason to regard it as a probable improvement on the single wire alone. In any case, the duplication of vital wires is dictated on the score of safety.

From what has been said about streamlines and the flow of a fluid round an obstacle it will be recognized that the tail end of the section is fundamentally more important than its head. The blunt edge should always be in front when cutting through fluids.

Any sort of entry will necessarily suffice to divide the stream, and it is not difficult to devise a reasonably good shape. Aft of the maximum beam, however, the tail must taper gradually. The feature most to be avoided is any sudden change in the curvature. There should be a gradual joining of the head to the body and a gradual falling away of the body into the tail. When the object is long compared with its diameter, the sides may be parallel.

If a shape is less than, say, four diameters long, it seems preferable to use flat tips rather than introduce sharp changes of curvature in the sides for the sake of forming a sharp point fore and aft.

From an investigation of the streamline flow illustrated by various examples in the Technical Report of the Advisory Committee, it appears that the convergence of the stream at the extremity of the tail is not unaccompanied by turbulence even with the best forms. It would seem, therefore, that the very tip of the tail may in most cases be cut off with advantage, for its presence adds weight without improving the flow.

A theoretical streamline form properly experiences only frictional resistance, but such perfection is not attained in practice. It is interesting, however, to consider the nature of surface friction, at least to the extent of recognizing that in one part it consists in cutting through the viscous cohesion of the fluid particles and in another to the spinning of those particles as if they were rolling against the surface of the body with which they are in contact. If the friction were solely of the first kind it would increase directly as the speed; if solely of the second kind it would increase directly as the square of the speed, as does the wind pressure on the face of a flat plate. Being partly of one kind and partly of the other, its rate of increase is, for ordinary velocities, represented by some power of the speed that is less than two.

The experimental determination of the surface friction coefficient is less simple than it might appear, for there is considerable difficulty in eliminating effects that are not due to friction proper. To Dr. Zahm in America is due the credit for conducting the first important series of experiments on this subject. His coefficient is discussed in the Appendix.

CHAPTER X

THE CAMBERED WING

Lilienthal's research—The cambered wing compared with the flat plate—The tangential—Advantages of uneven distribution of pressure.

MUCH has been said in preceding chapters about the advantage of the cambered wing as compared with a flat plate, when used as a supporting surface for aeroplanes. The broad fact of its superiority has long been known, but its qualities in detail still leave much to be investigated. Much has, however, already been ascertained by the research conducted in various laboratories, notably by Eiffel in Paris and by the National Physical Laboratory at Teddington, whose work in this department is under the direction of the Advisory Committee for Aeronautics appointed by the Government.

Lilienthal was one of the earliest investigators of the cambered surface, and he it was who first drew attention to one of the most important phenomena contributing to its superiority for lifting purposes. When the wind strikes an inclined flat plate, the resultant pressure remains perpendicular to the surface for all angles of incidence. If the plate is upright and faces the wind, the pressure is wholly a resistance to motion, but when the angle is less than a right angle the pressure, which is tilted in sympathy with the plate, may be regarded as partially lift and partially resistance.

Of these two components, the upward pressure or lift may be regarded as represented by the cosine of the angle, while the resistance corresponds to the sine. Thus the resistance in terms of the weight supported is represented by the tangent of the angle ; conversely, the ratio of the lift to the resistance cannot exceed the cotangent of the angle. Although the numerical values of lift and resistance do not necessarily bear a constant proportion throughout the full range of inclinations to the cosine and the sine of the angle respectively, the cotangent limit to the lift:resistance ratio of a flat plate holds good as a law. Under actual test, the flat plate does not show a ratio of lift to resistance that is anywhere as much as the cotangent of the angle of inclination, owing to the frictional resistance of the air flowing over the surface of the plate ; but it is none the less important to recognize the cotangent as a theoretical limit to the ratio of component pressures that might obtain if the plate were frictionless.

It is important to recognize this limit to a flat plate, because so doing facilitates a proper appreciation of the significance of the qualities of the cambered wing, which does actually demonstrate ratios of lift to resistance that exceed in magnitude, at certain angles, the cotangent of the angle of inclination. In fine, the cambered wing exceeds even the *theoretical* limit to the lift:resistance ratio of the flat plate over one part of its useful range of angles.

When a cambered wing is tested against a flat plate for lift and resistance, the comparison establishes three broad conclusions beyond all doubt. Firstly, the cambered wing exerts an appreciable lift when the chord is horizontal to the relative wind, whereas the flat plate is neutral in this attitude. Secondly, the absolute lift is superior to that of the flat plate at all useful inclinations. Thirdly, the ratio of lift to resistance is also superior throughout the same range.

Detailed investigation of these qualities also reveals two further points of first-class importance. One is that the cambered wing continues to lift upwards while inclined downwards to the relative wind until the negative angle of inclination is several degrees below the horizontal. The precise angle of zero lift increases in negative value with an increase of camber ; for wing sections in common use it is in the order of 2 degrees. The second further point of importance is that the resultant pressure on the surface is inclined forward from the perpendicular to the *chord* throughout part of the range of useful angles of inclination.

This latter feature is the most important of all the qualities associated with the action of the cambered wing, for the forward inclination of the resultant occurs at angles of inclination that are of great service in flight. In a series of sections of different cambers tested at the National Physical Laboratory, it was found that the curves graphically illustrating the ratio of lift to resistance crossed the curve of cotangents in the neighbourhood of 5 degrees. The greatest extent of the forward inclination, indicated by the presence of these curves on that side of the curve of cotangents, was reached for most of these sections at angles of inclination between 10 and 12 degrees. Some of these graphs are shown on page 307.

Although the resultant pressure is inclined forward of the normal to the chord, it still slopes backward, of course, from the perpendicular to the line of flight. Were it otherwise, the wing would have less than no resistance and so be an example of perpetual motion, which is against the laws of Nature. It is, indeed, sufficiently paradoxical that it should be possessed of the quality of being able to help pull itself along, so to speak, by developing an up-wind component force. It was this force that Lilienthal called by the name "tangential."

As this reduction of resistance is most marked between angles of 5 and 12½ degrees inclination, which represent the upper range of angles used in flight, it is obviously of great practical importance, especially when the nature of the curve of cotangents that limits the lift:resistance ratio of the flat plate is borne in mind.

With a flat plate, at the finer angles the lift itself is feeble and the lift:resistance ratio is poor. When the lift:resistance ratio assumes its greatest magnitude, which is in the order of 7½ under actual test, the angle of incidence is still only 3 or 4 degrees and the lift coefficient is still too small for practical purposes. Its value is about 0·1 or thereabouts, whereas at the same angle of incidence, i.e. between 3 and 4 degrees, the lift coefficient of a cambered wing section suitable for aeroplane use is more likely to be in the order of 0·25, or 2½ times as much as the flat plate. At the same time, the lift:resistance ratio will be nearer 12½ than 7½, so there is not only a gain in lift but also a reduction in resistance by using a cambered wing in place of a flat plate at this angle of inclination.

But, for angles greater than 3 or 4 degrees, the advantage of the cambered wing is still more pronounced. Although the flat plate continues to increase its lift coefficient with increasing angles up to about 0·5 for an angle of 12½ degrees, the accompanying resistance increases in greater proportion, and so the lift:resistance ratio falls rapidly as is indicated by the characteristic curve of cotangents. With cambered wings, on the contrary, not only does the lift coefficient increase to about 0·65 for an angle of 12½, but the lift: resistance curve crosses the curve of cotangents in the neighbourhood of 5 degrees, and although the ratio thereafter falls off considerably, the rate at which it does so is much less rapid than is the case with the flat plate. This is due, as has been explained, to the advantageous effect of the up-wind component, which tilts the resultant pressure forward of the normal to the chord throughout a range of angles extending from about 5 degrees to 12½ degrees inclination.

These lift coefficients are absolute constants and so do not vary with the atmospheric conditions. In order to convert them into "pounds lift per square foot of wing area" they may be multiplied by the factors on page 344. The values thus obtained are correct only for a particular atmospheric density, etc. (factor connecting lift and speed)

Beyond about 12½ degrees inclination, the cambered wings tested at the N.P.L. decreased in lift:resistance ratio very rapidly and they also decreased their lift coefficients. Obviously, the point at which this happens may well be termed the critical angle. Its exact value depends on the section of the wing and notably on the position of the maximum camber. It varies considerably as between one wing and another of different form.

None of the numerical quantities thus far quoted must be taken as applying indiscriminately to all wing sections, but it helps, I think, to fix ideas about general statements if figures are given where possible.

It will be clear from the preceding explanation that the great practical advantage of the cambered wing over the flat plate is its wide range of useful attitudes, which extend over several degrees of inclination where a high ratio of lift to resistance is well maintained. In aeroplanes, where alterations in the attitude of the machine are contrived by the use of the elevator for the purpose of altering the angle of incidence of the wings so that the machine may be supported in the air at different speeds, this quality is important to the extent of being essential. Thus, the most suitable wing for practical purposes on modern machines is not one with a mere peak of very high lift:resistance ratio at some particular angle, but rather one that has a good broad top to its characteristic curve of lift:resistance ratios.

Having discussed the broader distinctions between the cambered wing and the flat plate, it will be of interest to consider the operation of the wing in greater detail. What is without doubt the most important phenomenon associated with the forces exerted by wing or a flat plate is that the upper surface is much more effective to produce lift than the lower surface. Variations in its camber practically govern the characteristics of the wing section as a whole, and, in general, the upper surface contributes about three-quarters of the total lift.

It is, therefore, proper practice to design wing sections with the contour of the upper surface as the starting-point and to adjust the lower surface to suit structural convenience. Indeed, the lower surface might even be flat without very seriously affecting the more important qualities of the wing.

In models, where wing surfaces often consist of one thickness of silk laid on an exposed frame, the frame itself should be on the under side, where its projection is of less consequence.

Against the lower face of the wing the air strikes by impact, and there is a theoretical limit to the magnitude of the positive pressure caused thereby, which cannot have a coefficient exceeding 0·5. This limiting value is, however, attained at one spot only along the cross-section of the wing. Somewhere, just under the leading edge, the relative wind may be supposed to have its motion arrested, but elsewhere the effect of the surface is merely to deflect the air stream. The pressure reaction due to the downward acceleration of the mass is thus, as a whole, much less than the limiting value 0·5.

Actually, at about 12½ degrees angle of incidence the positive pressure normal to the surface on the under side of a flat plate reaches a maximum coefficient of about 0·17, and remains constant up to about 20 degrees angle of incidence. If the under face of the wing is concave, as is usual in modern practice, the positive pressure may rise to higher values, say, in the order of 0·2 for an angle of incidence of 15 degrees. At 5 degrees angle of incidence, the coefficient of normal pressure on the under side of a wing such as is used in flight is probably in the order of 0·07.

The lifting effect of the upper surface is, of course, necessarily due to the existence of a region of negative pressure (suction) above the section.

This partial vacuum is most pronounced over the leading edge of the wing, which ordinarily dips below the line of flight so that the upper surface in front appears to face the relative wind. The existence of a suction on a portion of the wing surface that appears as if it should be subjected to direct pressure is a paradox that is explained by the existence of a cyclic or eddying disturbance around the leading edge of a wing in flight. This has the effect of causing the true relative wind to approach the wing with an upward trend.

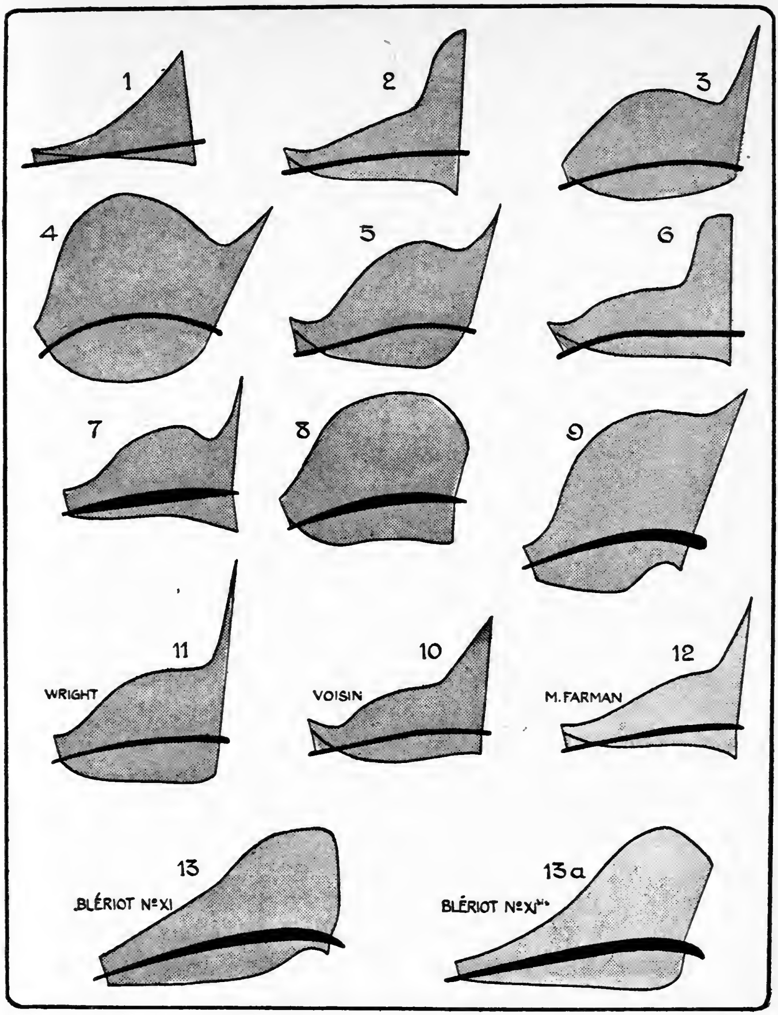
In a wing tested at the National Physical Laboratory, a point on the upper surface adjacent to the front edge was found to be facing the line of flight at 20 degrees negative angle of incidence when the wing as a whole was inclined at about 12½ degrees positive angle of incidence. Had the relative wind been parallel to the line of flight at the point under observation, there would obviously have been a local *down* pressure due to the 20 degrees negative angle of inclination of the surface at that point. In actual fact, however, there was a strong local suction having a *lift* coefficient of 1·5. It was apparent, therefore, that although the local surface faced the line of flight, it was, in fact, in the lee of the local relative wind, owing to the upward trend of the relative wind when approaching the leading edge.

Similarly, a corresponding point on the lower surface, which was apparently shielded from the line of flight by the leading edge of the wing itself, was found to be located in a region of positive pressure having a lift coefficient of 0·5. It will be observed that the lift coefficient at this point attained to the maximum theoretical limit, but it will also be observed that the lift due to suction on the upper surface was three times as great. There is no theoretical limit to the numerical magnitude of the coefficient for the suction on the upper face.

The distribution of pressure from leading to trailing edge is far from uniform, and to this lack of uniformity the remarkably high lift:resistance ratios of the cambered wing are due.

From what has already been said of the conditions in the vicinity of the leading edge, it should seem natural that the greatest intensity of pressure and suction should occur at that point. This is, in fact, the case whether the aerofoil is a cambered wing or a flat plate, but whereas the flat plate cannot possess a dipping front edge it gains nothing in efficiency from the irregular distribution of the pressure.

The cambered wing, on the other hand, has the normal local direction of the forces on its dipping front edge tilted up-wind, and so the greater the local suction the greater is the up-wind component of the lift and the more does the wing help itself along through the air. If the pressure distribution were uniform from leading edge to trailing edge, the drag of the suction on the surface aft would balance the pull of the suction on the dipping front face, and there would be no force parallel to the chord other than the resistance due to friction. The resultant pressure would then be normal to the chord and, therefore, devoid of Lilienthal's tangential up-wind component, which is the



"Flight" Copyright Drawings

Diagrams illustrating the distribution of pressure over various wing sections inclined at an angle of 6 degrees incidence. The wing sections are those of Eiffel's series, but the diagrams have been drawn in a modified form to that in which they are presented in Eiffel's book. The shaded portion above each section indicates suction, while the shaded portion beneath the section is pressure. The wing is supported in flight by the combined suction and pressure on its surfaces. The forward tilt of the diagrams accompanying the cambered sections illustrates graphically the presence of the up-wind component, which Lilienthal called the "tangential," that is one of the causes contributing to the greater merit of the cambered wing as compared with the flat plate. In the flat plate No. 1 it will be observed that there is no forward tilt, consequently the ratio of lift to resistance cannot possibly exceed the cotangent of the angle of inclination.

making of the cambered wing from the standpoint of lift: resistance ratio.

It is self-evident that there can be no other than a frictional force parallel to the chord of a flat surface.

In a cambered wing, too, the uneven distribution of pressure on the upper surface only lasts throughout a range of angles. At the critical angle the character of the fluid flow over the surface suddenly changes. It becomes extremely unsteady as the angle of incidence increases from, say, 12½ degrees to about 20 degrees, and afterwards the distribution becomes uniform over the whole upper surface, which thereafter demonstrates a constant coefficient of suction in the order of 0·3.

When this happens, the up-wind component disappears entirely and the resistance is thus increased enormously. With this loss of high lift:resistance ratio there is also a reduction in the lift coefficient, as has been explained.

On the lower surface, if flat, the lift coefficient ceases to increase at about 12½ degrees and tends to fall after about 20 degrees angle of incidence. In this region, i.e. from 12½ to 20 degrees, the local pressure near the trailing edge may become negative, that is to say there may actually be a suction downwards on this part of the wing.

When the under surface is concave and the angle of incidence is progressively decreased from about 12½ degrees, the local pressure will be observed to drop suddenly at a point commencing just behind the leading edge. When the angle is very fine, the pressure distribution is appreciably uniform over the lower surface, which then demonstrates a lift coefficient of about 0·25.

From the similarity between this value and the coefficient 0·3 for the upper surface at angles of incidence about 12½ degrees, it is supposed that a pocket of dead water forms under the lee of the dipping front edge and gradually spreads over the whole lower surface as the angle of incidence becomes finer. It is, at any rate, the existence of a dead-water region on the lee side of the wing at steep angles of incidence that causes the steady suction coefficient and its uniform distribution over the upper surface to occur.

Further details of the analysis of the forces on a cambered wing appear in the Appendix.

Other questions that have been investigated at the National Physical Laboratory include the effect of aspect ratio on the lift coefficient and lift:resistance ratio. Aspect ratio is the ratio of the span to the chord, and a series ranging from 3 to 1 to 8 to 1 was tested with the following results. The maximum lift coefficient remains practically constant in value while occurring at finer angles with increasing aspect ratios. The lift:resistance ratio, however, increased from 10·1 to 15·5 as the aspect ratio increased from 3 to 8. For these maxima, the corresponding lift coefficients are practically constant; hence, the effect of aspect ratio is mainly related to a change in resistance.

By comparison, a series of flat plates with aspect ratios ranging from 3 to 1 to 5 to 1 showed increasing maximum lift coefficients with increasing aspect ratios, but did not indicate any change in lift:resistance ratio—a result that is in both respects opposite to those obtained with cambered wings.

It may be remarked that whereas the maximum ratio of lift to resistance for a flat plate might be expected to be about 12 to 1 from the known value of the coefficient of friction, the best actual lift:resistance ratio demonstrated is less than 8 to 1. The difference is presumably due to the effect of the edges, for a real plate cannot be an infinitely thin plane.

In the use of wings on aeroplanes it has been explained that they are sometimes set so as to have a dihedral angle, that is to say so that they slope upwards from shoulder to tip. According to tests made at the N.P.L. over a range of dihedral angles from 166 degrees to 193 degrees the lift and resistance coefficient showed no appreciable change. It will be observed that the range of dihedral angles covers the condition in which the tips point downwards, or rather the wings slope downwards from shoulder to tip as well as when they slope upwards.

A very important investigation among the series of tests conducted at the N.P.L. is that related to the interference of one wing with another when one wing is placed over the other as in biplane construction. It will be understood that in principle an aerofoil derives its upward lift from the downward acceleration of a mass of air. The suction or region of negative pressure over the upper surface and the pressure region under the lower surface are incidental details revealed by the analysis of the forces. In broad principle, the cambered wing, like the inclined flat plate, or the sloping roof of a house, is a deflector of the air *en masse* and it derives its lift from the reaction due to the continuous deflection of a stratum in a downward direction.[1] In flight, it continues so to accelerate downwards a certain mass of air per second, and it is apparent that its disturbance in the atmosphere extends upwards as well as beneath the wing.

It has been common practice, originating with the Wrights who made some experiments on the matter, to make the gap between the planes of a biplane equal in height to the chord length of the plane. It would appear, however, from the N.P.L. test that there is an appreciable reduction in the lift coefficient when the gap is only of this height, the loss being in the order of 17 per cent. Even with a gap equal to 1·6 times the chord the reduction in lift coefficient is still as much as 10 per cent. On the other hand, the resistances of the planes of a biplane do not suffer the same effect. Thus, the lift:resistance ratio of the system is reduced in approximately the same proportion as is the reduction in the lift of the planes themselves.

There is a slight advantage amounting to about 5 per cent both in the lift and the l.:r. ratio of a biplane system in which the upper plane is advanced relatively to the lower plane to a distance equal to about 0·4 of the gap. This staggered-plane system has been employed in the construction of a few machines, but mainly from the point of view of a less restricted outlook that it affords the pilot and passenger. There is also some reduction in the resistance of the struts thus set obliquely in a staggered biplane. In this

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[1] See Appendix on Newton's *Laws of Motion*.

connection it may be remarked that increasing the gap of a biplane in order to increase its lift:resistance ratio is to some extent discounted by the increase in resistance that will accompany the increased length and weight of the struts.

PART II

INTRODUCTION

THUS far this book has been devoted to the principles of flight and to the operation of aeroplanes in general. It has also referred to some of the salient features of various machines commonly to be seen by those who visit aerodromes, but it has scarcely more than mentioned by name the men by whose ability and perseverance these successful craft have been evolved.

Contrary to custom, I purpose concluding this attempt at an introduction to the study of flight by a résumé of the history of its development, which ordinarily would be placed first in such a book. My reason for so doing is that the full interest of the work performed by those who " lived before their time " can only be appreciated by those who understand something of the reasons that militated against success. History is fascinating indeed, but only when the mind approaches the subject with an intelligent interest in the details of what is afoot. Otherwise, the chronological sequence of events presents to the reader nothing more attractive than a bare ladder in which the rungs are all more or less alike. When the past is reviewed from the standpoint of some little knowledge of the present, however, each rung stands out with a well-defined individuality, shows itself in fact to be the life's work of a pioneer.

By the same reasoning, I have thought it well to preface the history of the subject at large by some particular account of the work of those whose influence has been especially pronounced, and whose accomplishments ought always to be remembered by the present-day student. It is, therefore, to the work of pioneers like Lilienthal, the Wrights, the Voisins and Henry Farman that the ensuing chapters are mainly devoted. There is also some brief reference to the work of Dunne and Weiss, who have devoted themselves to the study of natural stability.

The remarkable, but comparatively little-known work of Prof. J. J. Montgomery, who made some successful glides in California in 1884, and whose subsequent designs of 1905 were sufficiently stable to enable the parachute jumper Maloney to make several glides from altitudes of upwards of 1000 ft., is referred to in Part III.

This second part of the volume contains an account of the Military Aeroplane Trials, which serves in some measure as a standard of performances for modern machines. Another chapter is devoted to some mention of the hydroaeroplane, as representing the latest phase of aviation, and the section concludes with a chapter related to accidents and the lessons they teach.

CHAPTER XI

THE WORK OF OTTO LILIENTHAL

Bird flight as the basis of aviation—The practice of gliding—Experiments at Rhinow—The artificial hill—Researches on the cambered plane—Lilienthal's tangential.

FIRST among those whose work stands out as being of pre-eminent importance is Otto Lilienthal. His perseverance in the art of gliding opened the door to the practice of flying before engines suitable for aeroplanes were available. Born on 24 May, 1848, at Anclam in Pomerania, he died on 9 August, 1896, from a fall during one of his experiments. His interest in flight developed at the early age of thirteen, when with the aid of his brother Gustavus he tried to make practical experiments at school. Their initial attempts, like those of so many others, related to the use of flapping wings. The advent of the Franco-Prussian War in 1870, however, demanded Lilienthal's attention in another and less pleasant direction. Before the end of 1871, nevertheless, he was again at work on his hobby of flight.

Realizing that his past failures were largely due to an incomplete study of first principles, he set himself very closely to examine the shape and resistance of birds' wings in motion through the air, and he satisfied himself as to the unquestionable advantage of the cambered plane when compared with the flat plate. He also arrived at the conclusion that the probable explanation of the soaring flight of birds was due to the existence of winds with an upward trend. His observations led him to remark that such air currents had an average upward slope of 3½ degrees with the horizon. In 1889 he published his first pamphlet, entitled *Bird Flight as a Basis of Aviation.*

Two years later, in 1891, he decided that it was time to resume his practical experiments, and for this purpose he constructed his famous gliding apparatus. This consisted of a pair of rigid outstretched wings formed by cambered planes. The span from tip to tip was 23 ft., and after various modifications the area was adjusted to 86 sq. ft. The planes were formed by cotton twill, stretched over a framework of willow, and varnished with a preparation of wax. The machine weighed about 40 lb. and had neither a tail nor a motor.

In adopting the principle of trying to obtain some experience in the air with the use of a motorless machine, Lilienthal recognized the true route to the conquest of the air, which man had been seeking for centuries without success. Almost everyone, not even excepting Lilienthal himself at first, had supposed that it would be necessary either to fly by muscular exertion or by the aid of an engine. A man's muscles are unsuitable for the purpose of flapping wings, even supposing them to be strong enough in the first instance, but, up to Lilienthal's time, a suitable engine had not been forthcoming, notwithstanding the wonderful achievements of one or two who had specialized in this direction.

Lilienthal was able to see clearly that flight could be achieved, within limits, without a material engine, by using gravity as the motive power. He realized that if he were content to fly always downhill he might obtain considerable scope for practice in the art of aviation and it was by his perseverance in this simple and clear-minded conception of a practicable solution to the problem that Lilienthal did more for the progress of flight than any man up to his time.

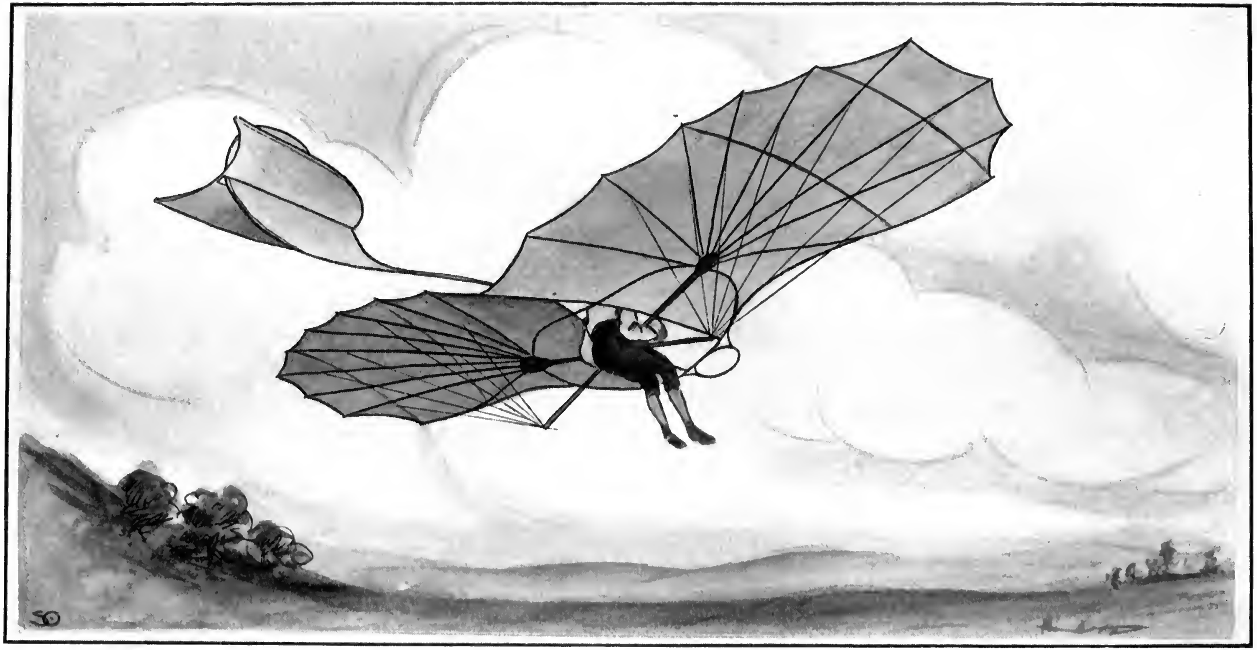
His first experiences were obtained by jumping off a spring-board in his garden, with his glider arranged under his arms. Afterwards he practised jumping off mounds in a field between Werder and Gross-Kreutz. It was at this place that he found the fluctuations of the wind so disturbing that he decided to fit a tail to his glider in order to give it more stability of direction. Hitherto, he had confined himself to practising in a calm. The culminating point of these experiences was the accomplishment of glides of about 80 ft. in length from a height of about 19 ft. His gliding angle was thus a slope of 1 in 4.

Next year, in 1892, a still better practice ground was found between Steglitz and Südende, where the hills were some 30 ft. in height. A new glider was built having an area of 171 sq. ft. and a weight of about 53 lb. With this, glides were made in winds up to 16 miles per hour velocity; the flight speed through the air being about 33 miles per hour. At the best, the gliding angles had a tangent of 1 in 8.

Once again Lilienthal decided to move his quarters, and in the middle of 1893 transferred his apparatus to Maihöhe, which also was near Steglitz. It was here that he built his first gliding tower, which consisted of a shed for housing the glider. The roof was about 33 ft. above the ground, and so afforded a sloping start for the glide. The glider used during these experiments differed from the preceding machines in being so made that the wings could fold up for convenience in housing. Unfortunately, the climatic conditions in this locality were not very suitable for such experiments, so during the same year Lilienthal moved over to the Rhinow Mountains, near Rathenow, where there exists a fine range of hills some 200 ft. in height, having slopes in every direction from 10 to 20 degrees.

As it is necessary that glides should be started head to wind, a hill open on all sides is almost essential to continued progress. If limited to gliding in one direction, the experimenter is tediously kept waiting for a favourable day. It was at Rhinow that Lilienthal made some of his best glides with a machine weighing about 44 lb. The total weight in flight was 220 lb., with himself on board. The span was 23 ft. and the area 150 sq. ft. With this apparatus glides of 800 ft. were accomplished from a starting-point 100 ft. above the ground.

It was at Rhinow that Lilienthal met with his first and, with the exception of the last and fatal calamity, only serious accident. He thus describes his experience in the *Aeronautical Annual*, edited and published by James Means at Boston:



"Flight" Copyright Sketch

Lilienthal and one of his gliders with which he practised gliding experiments in Germany from 1891 to 1896.

"In my experiments made before Easter from the still higher mountains near Rhinow, I perceived that I had to bear with the upper part of my body a good deal towards the back to prevent my shooting forward in the air with the apparatus. During a gliding flight taken from a great height this was the cause of my coming into a position with my arms outstretched, in which the centre of gravity lay too much to the back; at the same time I was unable—owing to fatigue—to draw the upper part of my body again towards the front. As I was then sailing at about the height of 65 ft. with a velocity of about 35 miles per hour, the apparatus, overloaded in the rear, rose more and more, and finally shot, by means of its *vis viva*, vertically upwards. I gripped tight hold, seeing nothing but the blue sky and little white clouds above me, and so awaited the moment when the apparatus would capsize backwards, possibly ending my sailing attempts for ever. Suddenly, however, the apparatus stopped in its ascent, and, going backward again in a downward direction, described a short circle and steered with the rear part again upwards, owing to the horizontal tail which had an upward slant; then the machine turned bottom upwards and rushed with me vertically towards the earth from a height of about 65 ft. With my senses quite clear, my arms and my head forward, still holding the apparatus firmly with my hands, I fell towards a greensward; a shock, a crash, and I lay with the apparatus on the ground.

"A flesh wound at the left side of the head, caused by my striking the frame of the apparatus, and a spraining of the left hand, were the only bad effects of this accident. The apparatus was, strange to say, quite uninjured. I myself, as well as my sailing implements, had been saved by means of the elastic recoil-bar, which, as good luck would have it, I had attached for the first time at the front part of the apparatus. This recoil-bar, made of willow wood, was broken to splinters; it had penetrated a foot deep into the earth, so that it could only be removed with difficulty.

"My brother, who also took part in these experiments and had been able to get a perfect side-view of my unsuccessful flight, said it had looked as if a piece of paper had been sailing about in the air at random. In my thousands of experiments this is the only fall of that kind, and this I could have avoided if I had been more careful."

In 1894, that is to say the very next year, Lilienthal decided on yet another change of head-quarters, mainly owing to the inconvenient situation of his existing practice ground. In order that he might have just what he required, he had an artificial hill constructed at his place in Gross-Lichterfelde, near Berlin. The hill was 50 ft. in height and had a base of 230 ft. in diameter. On the top of the hill was a roofed cavity forming a shed for the gliders. Here Lilienthal commenced experiments with an entirely new type of glider, this machine being a biplane of which the upper and lower planes were, however, constructed on similar lines to his original monoplane gliders, with which he had hitherto been making trials, and the way in which his biplane was evolved is thus explained in an article that he wrote specially for the *Aeronautical Annual* in 1896.

" My experiments in sailing flight have accustomed me to bring about the steering by simply changing the centre of gravity.

" The smaller the surface extension of the apparatus is the better control I have over it, and yet if I employ smaller bearing surfaces in stronger winds, the results are not more favourable. The idea therefore occurred to me to apply two smaller surfaces, one above the other, which both have a lifting effect when sailing through the air. Thus the same result must follow which would be gained by a single surface of twice the bearing capacity, but on account of its small dimensions this apparatus obeys much better the changes of the centre of gravity.

" Before I proceeded to construct these double sailing machines, I made small models in paper after that system, in order to study the free movements in the air of such flying bodies and then to construct my apparatus on a large scale, depending on the results thus obtained. The very first experiments with these small models surprised me greatly on account of the stability of their flight. It appears as if the arrangement of having one surface over the other had materially increased the safety and uniformity of the flight. As a rule it is rather difficult to produce models resembling birds, which, left to themselves, glide through the air from a higher point in uniformly inclined lines. . . , I myself doubted formerly very much that an inanimate object sailing quickly forward could be well balanced in the air, and was all the better pleased in succeeding in this with my little double surfaces.

" Relying on this experience, I constructed first a double apparatus, in which each surface contains about 97 sq. ft. I thus produced a comparatively large bearing surface of about 194 sq. ft. with but about 18 ft. span.

" The flights undertaken with such double sailing surfaces are distinguished by their great height. . . . I often reach positions in the air which are much higher than my starting-point. At the climax of such a line of flight I sometimes come to a standstill for some time, so that I am enabled while floating to speak with the gentlemen who wish to photograph me, regarding the best position for the photographing.

" At such times I feel plainly that I would remain floating if I leaned a little towards one side, described a circle and proceed with the wind. The wind itself tends to bring this motion about, for my chief occupation in the air consists in preventing a turn either to the right or left, and I know that the hill from which I started lies behind and underneath me, and that I might come into rough contact with it if I attempted circling."

At this point Lilienthal had acquired considerable ability in his accomplishment of gliding flight, and he decided that it was well worth while trying to introduce the power element into his machine. His object was, it seems, not so much to be able to fly a greater distance in a straight line as to be able so to control the direction of his apparatus as to take advantage of changes in the wind, with a view to soaring more or less indefinitely.

For this purpose, he built a light machine weighing about 88 lb. fitted with a motor capable of developing 2½ h.p. for about 4 min. The mechanism was designed to move the wings in such a way as to imitate the wing action of a bird, but although the apparatus was actually constructed and tested exact details of it do not appear to have been published, for Lilienthal unfortunately met his death before he had had time to develop this side of his work.

Lilienthal thus describes, in the above-mentioned article to the *Aeronautical Annual,* his reasons for wishing to fit an engine on his machine :

" My experiments tend particularly in two directions. On the one side I endeavour to carry my experiments in sailing through the air with immovable wings to this extent ; I practise the overcoming of the wind in order to penetrate, if possible, into the secret of continued soaring flight. On the other hand, I try to attain the dynamic flight by means of flapping the wings, which are introduced as a simple addition to my sailing flights. The mechanical contrivances necessary for the latter, which can reach a certain perfection only by gradual development, do not allow yet of my making known any definite results. But I may state that since my sailing flights of last summer, I am on much more intimate terms with the wind.

" What has prevented me till now from using winds of any strength for my sailing experiments has been the danger of a violent fall through the air, if I should not succeed in retaining the apparatus in those positions by which one insures a gentle landing. The wildly rushing wind tries to dash about the free floating body, and if the apparatus takes up a position, if only for a short time, in which the wind strikes the flying surfaces from above, the flying body shoots downward like an arrow, and can be smashed to pieces before one succeeds in attaining a more favourable position in which the wind exercises a supporting effect. The stronger the wind blows, the easier this danger occurs, as the gusts of wind are so much the more irregular and violent.

" As long as the commotion of the air is but slight, one does not require much practice to go quite long distances without danger. But the practice with strong winds is interesting and instructive, because one is at times supported quite by the wind alone. The size of the apparatus, however, unhappily limits us. We may not span the sailing surfaces beyond a certain measure, if we do not wish to make it impossible to manage them in gusty weather. If the surfaces of about 150 sq. ft. do not measure more than about 23 ft. from point to point, we can eventually overcome moderate winds of about 22 miles per hour velocity, provided one is well practised. With an apparatus of this size it has happened to me that a sudden increase in the wind has taken me way up out of the usual course of flying, and has sometimes kept me for several seconds at one point of the air. It has happened in such a case, that I have been lifted vertically by a gust of wind from the top of the hill, floating for a time above the same at a height of about 16 ft., whence I then continued my flight, against the wind.

"Although, while making these experiments, I was thrown about by the wind quite violently and was made to execute quite a dance in the air in order to keep my balance, I yet was always enabled to effect a safe landing, but still I came to the conviction, that an increase in the size of the wings or the utilizing of still stronger winds which would lengthen the journey in the air, would necessitate something being done to perfect the steering and to facilitate the management of the apparatus. This appeared to me to be all the more important as it is very necessary for the development of human flight that all, who take up such experiments, should quickly learn how to use the apparatus safely and understand how to use the same even if the air is disturbed. It is in the wind that this practice becomes so exciting and bears the character of a sport, for all the flights differ from each other and the adroitness of the sailing-man has the largest field for showing itself. Courage also and decision can be here shown in a high degree."

Before Lilienthal had had time properly to develop his power-driven machine to a degree that would have made him feel justified in publishing particulars of his scheme he was unfortunately cut off from further active work in this world by a fatal accident that took place during a glide at Rhinow on 9 August, 1896. So far as can be ascertained, Lilienthal was then using a rather worn-out machine that was about to be discarded. At the moment, it was being employed for the purpose of testing the action of a new member that was presumably an elevator.

He had intended making as long a flight as possible, and hoped to exceed the 12 or 15 seconds duration that was commonly the limit of his glides. Whilst at a height of some 50 ft. from the ground, however, some part of the machine broke and the apparatus fell headlong, burying Lilienthal beneath the debris. Lilienthal's spine was broken, and he died within 24 hours, thereby rendering the world poorer to an extent that is only faintly measured by his own apparent accomplishments up to that point.

Like all the pioneers of flight, Lilienthal was generous to his co-workers in freely publishing the results of his experiences. His most notable researches are those from which he compiled his table of lift and resistance values for cambered planes. (The important feature of these investigations was the experimental evidence thereby provided to the effect that a cambered plane has the direction of its resultant pressure inclined forward of the chord throughout a range of angles of inclination. The horizontal component in the line of the chord Lilienthal called the "tangential.")

It will have been evident from what has already been said that Lilienthal was deeply interested in the subject of bird flight. According to his own accounts, some of his most interesting and instructive observations in this direction took place at a comparatively late period of his work, when he visited the village of Vehlin near Glowen on the Berlin-Hamburg Railway. In this quiet little spot, storks make their nests on the roofs of almost every cottage and afford what is probably a unique opportunity for close and, so far as is possible, accurate observation of soaring flight. Here is a paragraph that Lilienthal wrote after his Easter holiday at Vehlin :

> "Three things are essential for soaring : a correct shape of wing, the right position of wing, and a suitable wind. In order to judge of these three factors and their changeable effect, we have nothing but our practised eye to depend upon.
>
> "Just how much the cross-section of the wing is arched when the stork is resting on the wind can be determined only by eye measurement ; similarly, the position of the wing to the direction of the wind and to the horizon. But, when hundreds of storks give one the opportunity to observe the same in clear weather close at hand, what is seen is impressed so indelibly on the mind that it enables one to draw correct conclusions as to the existing laws.

" In general, one can say that when the stork flies with wings spread horizontally and allows itself to be borne by the wind alone, it is but seldom that a stronger gust of wind causes the stork to draw in its wings.

" The parabolic profile of the wings has a depth which I consider to be about one-twentieth of the breadth of the wing. The pinions are mostly spread out, but do not lie in one plane ; but the more they are to the front, the higher are the points, certainly because they would otherwise hinder one another in their bearing capacity.

" When in this position the stork passes slowly against the wind above the observer, the head and neck are, as a rule, stretched straight out ; but if one imagines that soaring is possible in this position, that it causes little resistance, he will be surprised to see a stork, sailing in this manner, suddenly, without changing its position, lay its head back and rattle joyously. While we human beings are striving to find the proper shape for the wings, building theory on theory, flying takes place in nature in a wondrously simple way, quite as a matter of course."

CHAPTER XII

THE WORK OF WILBUR AND ORVILLE WRIGHT

The first inspiration—The introduction of wing warping—Experiments at Kitty Hawk—Camber and the centre of pressure—Testing the glider as a kite—The ominous wind tap—Building the engine—The successful flights.

THE Wrights commenced their own gliding experiments four years after Lilienthal's death, and they so improved the control and design of the aeroplane that its use became comparatively safe instead of highly dangerous. Starting in 1900 they made experimental flights downhill against the wind over the sand dunes on the North Carolina coast.

These practical trials alternated with laboratory research and lasted three years. In 1903 they designed and constructed a larger machine to take an engine, which also they built in their own workshop.

On 17 December of that year they succeeded in making four free flights, rising from level ground against the wind.

It was a triumph of systematic progress, and so thoroughly did they continue to do their work that by the end of 1905 they had made several flights exceeding 20 miles in length, lasting more than half an hour in duration.

So far ahead were the Wrights in the new art, that more than two years elapsed before anyone else flew a circular course of five-eighths of a mile. It is impossible to overestimate the service rendered to aviation by the Wrights' systematic methods. They progressed in an entirely unknown art without accident through scientific forethought and a capacity for taking infinite pains. They attempted no new experiment without a reason, and they passed through no new experience without investigating its cause.

To the day of his death, which terminated an attack of typhoid fever, on 30 May, 1912, Wilbur Wright knew more than any man of the practical science of flight, and it was as a scientist that the Aeronautical Society desired to honour his memory when the Wilbur Wright Memorial Fund was created specifically for the endowment of a scientific lecture to be delivered annually under its ægis. Wilbur Wright was a member of the Society and, with his brother Orville, was recipient of its Gold Medal.

The following is Wilbur Wright's own story of how he came to take up the study of aviation:

"My own active interest in aeronautical problems dates back to the death of Lilienthal in 1896. The brief notice of his death which appeared in the telegraphic news at that time, aroused a passive interest which had existed from my childhood, and led me to take down from the shelves of our home library a book on *Animal Mechanism*, by Prof. Marey, which I had already read several times. From this I was led to read more modern works, and as my brother soon became equally interested with myself, we soon passed from the reading to the working stage.

"It seemed to us that the main reason why the problem had remained so long unsolved was that no one had been able to obtain any adequate practice. We figured that Lilienthal in five years of time had spent only about five hours in actual gliding through the air. The wonder was not that he had done so little, but that he had accomplished so much. It would not be considered at all safe for a bicycle rider to attempt to ride through a crowded city street after only five hours' practice, spread out in bits of ten seconds each over a period of five years; yet Lilienthal with his brief practice was remarkably successful in meeting the fluctuations and eddies of wind gusts."

Having made such calculations as were possible in the light of the knowledge of the time, Wilbur Wright and his brother Orville decided to build a glider of 200 sq. ft. area capable of support at about 18 miles per hour, and it was their intention to try to fly this machine in the wind on the side of a hill as a kite with the pilot on board so that experience in riding the air might be obtained without actual motion over the ground. This was an entirely new idea on the subject of practising aviation and was the direct outcome of Wilbur Wright's appreciation of the limitations that had impeded Lilienthal's progress, rapid, nevertheless, as that had been.

They built their first machine in 1900, but being unable to obtain suitable material they made it only 165 sq. ft. in area. It was a biplane constructed on the trussed bridge principle introduced by Chanute, but differing from the Chanute biplane in several respects. Its front main spar formed a bluff entering edge, its planes were double surfaced and had a special arrangement of the tie wires that enabled them to be all tightened simultaneously by merely shortening two of them. In addition, the Wright glider introduced certain entirely new ideas of a radical kind; thus, for example, the pilot was to lie prone on the lower plane in order to reduce the body resistance, and as he would then be no longer able conveniently to move about in order to maintain the balance, the apparatus was equipped with an elevator and a system of wing warping control. In any case, the Wrights would have introduced some such system of control, for, apart from the question of body resistance, they had come to the conclusion that Lilienthal's method of balancing was neither so quick nor so effective as was necessary.

A movement of the body to one side or other of the centre of the machine, which was Lilienthal's method of balancing, afforded only a very small restoring couple at its best. In Wright's system the effect of warping the wings increased with the velocity of flight and, moreover, the warp itself had its maximum value at the tips of the wings and therefore possessed the greatest possible leverage over the centre of gravity of the machine.

From the very beginning, the Wrights decided to build a machine without a tail, for the very simple reason that they considered such a member likely to be more bother than it was worth. This, at any rate, was the conclusion that they had arrived at after studying the experiences of Lilienthal and Chanute. Their first trial with the 1900 machine took place at Kitty Hawk, North Carolina, in the summer of that year. Some trials were made by flying the glider as a kite, with the pilot on board, and the machine was also flown alone, with the control mechanism operated from the ground by cords.

In general, the results were satisfactory and particularly so in respect to the system of control. But the calculations for area and velocity appeared to be at fault inasmuch as the machine and pilot were only supported in a wind of about 25 miles per hour when the angle of incidence was 20 degrees instead of at the anticipated value of 3 degrees. They also made some tests of lift and resistance, and found that the machine would support a weight of 52 lb. with a pull of only 8·5 lb., which, in conjunction with the deficiency in total lifting power that they had observed, led them to suppose that they might have made the camber of their planes too small, as it was only about 0·045. They also thought that the fabric of the surfaces might be too porous, as it was not " doped."

Having made these preliminary experiments they took the machine to a point four miles south known as the Kill Devil Sand Hill, which has a 10-degree slope towards the north-east. Here they made a few actual glides at flight speeds through the wind of from 25 to 30 miles per hour. The tangent of the gliding angle was about one in six and they satisfied themselves that the machine was capable of gliding at a somewhat less angle than 9½ degrees. These tests concluded their work for 1900 and they at once set about building a new machine for next year.

The 1901 model had its area increased to 308 sq. ft. and the camber of the planes increased to 0·083. It was estimated that the machine and the pilot would be supported at 17 miles per hour with an angle of incidence of 3 degrees. In the summer of 1901 they again went into camp, where they were joined by E. C. Huffaker, Dr. G. A. Spratt, and, for a period of a week, by Octave Chanute. The initial trials with the new machine were not very satisfactory, and it was some little while before they could make a glide at all, for their estimated position for the centre of gravity was nearly a foot misplaced from where the pilot ultimately had to locate his body.

Even when a glide of some 300 feet was accomplished, Wilbur Wright experienced the greatest difficulty in keeping the machine steady, having to use the elevator in a far more vigorous manner than on the earlier model. Once or twice the machine tilted as Lilienthal's glider once did and lost headway in mid-air, but on each occasion the operation of the elevator saved the situation and brought the machine safely to earth. On one of these occasions it had even commenced to slide backwards in the air before it recovered itself. These experiences the Wrights naturally considered to be of extreme importance and to justify their contention that the front elevator was a far safer device than the tail.

The difficulty of getting the machine to glide steadily bothered them considerably for some time, for although they were forced to suppose that it was due to a reversal in the travel of the centre of pressure at small angles of incidence, they were loath to adopt this explanation, believing that they had already guarded against this effect. Wilbur Wright's observations on this point were as follows :

"In deeply curved surfaces the centre of pressure at 90 degrees is near the centre of the surface, but moves forward as the angle becomes less till a certain point is reached varying with the depth of curvature. After this point is passed, the centre of pressure, instead of continuing to move forward with the decreasing angle, turns and moves rapidly towards the rear. The phenomena are due to the fact that at small angles the wind strikes the forward part of the surfaces on the upper side instead of the lower, and thus this part altogether ceases to lift, instead of being the most effective part of all as in the case of the plane.

"Lilienthal had called attention to the danger of using surfaces with a camber as great as one-eighth of the chord, on account of this action on the upper side ; but he seems never to have investigated the camber and angle at which the phenomena entirely cease. My brother and I had never made any original investigation of the matter, but assumed that a camber of one-twelfth of the chord would be safe, as this was the camber on which Lilienthal based his tables. However, to be on the safe side, instead of using the arc of a circle, we had made the camber of our machine very abrupt at the front so as to expose the least possible area to this downward pressure.

" While the machine was building, Messrs. Huffaker and Spratt had suggested that we should find this reversal of the centre of pressure, but we believed it sufficiently guarded against. Accordingly, we were not at first disposed to believe this reversal actually existed in our machine, although it offered a perfect explanation of the action we had noticed in gliding."

In order to test their theory on the reversal of the travel of the centre of pressure they carried out some experiments with a glider used as a kite and were able to observe in a very marked way that the centre of pressure did reverse its direction of travel as suggested. Accordingly they proceeded to reduce the camber of their planes. This change proved entirely satisfactory, the glides being steady and the machine answering the elevator movements perfectly. Their confidence in the machine soon became such that they were able to glide in winds as high as 27 miles per hour. Many further tests were also made with the glider as a kite and particularly were these useful in comparing estimates of the lift and drift. Incidentally, they served to corroborate Lilienthal's theory of the forward inclination of the resultant pressure on cambered planes at small angles, although they gave numerical results at variance with Lilienthal's data. The following is Wilbur Wright's summary of some of the tests :

" While at Kitty Hawk we spent much time in measuring the horizontal pressure on our unloaded machine at various angles of incidence. We found that at 13 degrees the horizontal pressure was about 23 lb. This included not only the drift proper, or horizontal component of the pressure on the side of the surface, but also the head resistance of the framing as well. The weight of the machine at the time of this test was about 108 lb. Now, if the pressure had been normal to the chord of the surface, the drift proper would have been to the lift (108 lb.) as the sine of 13 degrees is to the cosine of 13 degrees, or $\frac{\cdot 22 \times 108}{97} = 24{\cdot}6$ lb.; but this slightly exceeds the total pull of 23 lb. on our scales. Therefore, it is evident that the average pressure on the surface, instead of being normal to the chord, was so far inclined towards the front that all the head resistance of framing and wires used in the construction was more than overcome.

"In a wind of 14 miles per hour, resistance is by no means a negligible factor, so that 'tangential' is evidently a force of considerable value. In a higher wind which sustained the machine at an angle of 10 degrees, the pull on the scales was 18 lb. With the pressure normal to the chord, the drift proper would have been $\frac{\cdot 17 \times 98}{\cdot 98}$[1] $= 17$ lb., so that although the higher wind velocity must have caused an increase in the head resistance, the tangential force still came within 1 lb. of overcoming it. After our return from Kitty Hawk we began a series of experiments to accurately determine the amount and direction of the pressure produced on curved surfaces when acted upon by winds at the various angles from zero to 90 degrees. These experiments are not yet concluded, but in general they support Lilienthal in the claim that the curves give pressures more favourable in amount and direction than planes; but we find marked differences in the exact values, especially at angles below 10 degrees. We were unable to obtain direct measurements of the horizontal pressures of the machine with the operator on board, but by comparing the distance travelled in gliding with the vertical fall, it was easily calculated that at a speed of 24 miles per hour the total horizontal resistances of our machine, when bearing the operator, amounted to 40 lb., which is equivalent to about $2\frac{1}{3}$ h.p."

Among other points investigated was the problem of soaring in winds with an upward trend, and although they considered themselves too inexpert actually to attempt anything of this nature on their own part, they would

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[1] The travel of the centre of pressure made it necessary to put sand on the front rudder to bring the centres of gravity and pressure into coincidence, consequently the weight of the machine varies from 98 lb. to 108 lb. in the different tests.

frequently make the glider soar at the end of two *vertical* ropes attached to the forward spar at each extremity of the machine. This method they found to be very useful as a means of testing any alteration in the machine, but Wilbur Wright drew attention to the danger of making numerical calculations from the slope of the hill and the wind velocity for any other conditions than those in which the ropes attached to the machine are vertical to the horizon ; in other words, allowances for obliquity of kite line are open to serious error.

As the result of their experiments for 1901 they came to the following conclusions :

" In looking over our experiments of the past two years, with models and full-size machines, the following points stand out with clearness :

" 1. That the lifting power of a large machine, held stationary in a wind at a small distance from the earth, is much less than the Lilienthal table and our own experiments would lead us to expect. When the machine is moved through the air, as in gliding, the discrepancy seems much less marked.

" 2. That the ratio of drift to lift in well-shaped surfaces is less at angles of incidence of 5 to 12 degrees than at an angle of 3 degrees.

" 3. That in arched surfaces the centre of pressure at 90 degrees is near the centre of the surface, but moves slowly forward as the angle becomes less, till a critical angle, varying with the shape and depth of the curve, is reached, after which it moves rapidly towards the rear till the angle of no lift is found.

" 4. That with similar conditions, large surfaces may be controlled with not much greater difficulty than small ones, if the control is effected by manipulation of the surfaces themselves, rather than by a movement of the body of the operator.

" 5. That the head resistances of the framing can be brought to a point much below that usually estimated as necessary.

" 6. That tails, both vertical and horizontal, may with safety be eliminated in gliding and other flying experiments.

" 7. That a horizontal position of the operator's body may be assumed without excessive danger, and thus the head resistance reduced to about one-fifth that of the upright position.

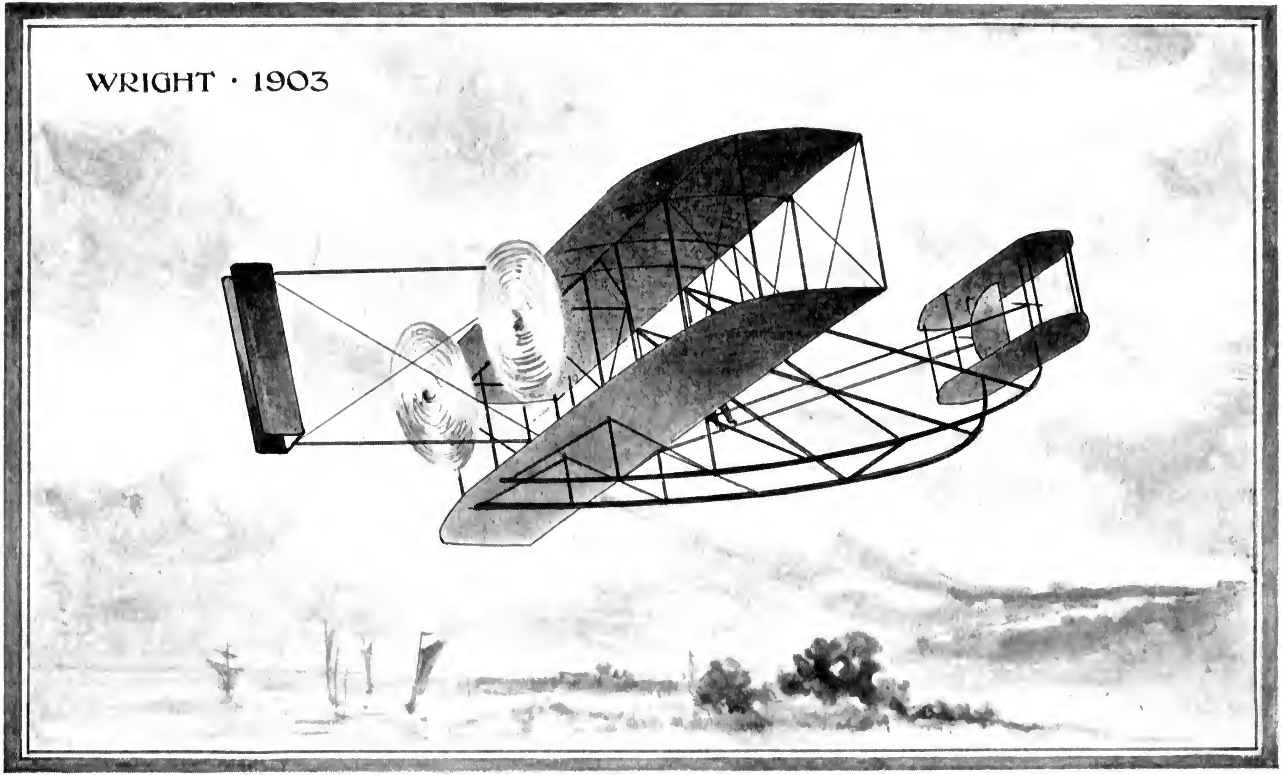
"8. That a pair of superposed, or tandem surfaces, has less lift in proportion to resistance than either surface separately, even after making allowance for weight and head resistance of the connections."

In the interim between the experiments of 1901 and those of 1902 the Wrights conducted laboratory experiments, the results of which have not yet been made public.

Their 1902 glider was again a biplane having an area of 305 sq. ft., a span of 32 ft. and a chord of 5 ft. The elevator had an area of 15 sq. ft. extra, and there were two vertical tail planes carried on an outrigger at the rear measuring 6 sq. ft. in area each. Initially these tail planes were rigidly attached to the outrigger and not used as a rudder. At a later period, when the tail plane was reduced to half its original value, the tail in question was pivoted to act as a rudder.

They again took their machine out to Kill Devil Sand Hill and again found it to have idiosyncrasies of its own that had not been noted in either of the preceding models. This time the machine tended to be rather unstable laterally. In both the earlier types, the spars of the main planes were arched slightly, and as the 1902 model had straight spars it was supposed that the trouble might be due to this cause, so the necessary alterations were made to reproduce the arching. The first glide subsequent to this change was made by Orville Wright and had an alarming result, for seeking to balance the machine laterally the pilot neglected to pay attention to the elevator, so that the machine tilted badly and finally fell backwards to the ground, where it was smashed.

Subsequent tests showed that the machine was still unstable, and various reasons led to the tail being regarded as the offending member. Sometimes it was found useful, but more often than not it was considered disadvantageous. Consequently one of the vertical planes was removed and the remaining one mounted on pivots so that it could be



"Flight" Copyright Sketch

The Wright biplane, which was the first machine to make really successful flights. The first of these took place in America in December, 1903.

used as a rudder. With this change their troubles ended, and they were able to set to work seriously in the gaining of further experience in actual gliding flight. On this period Wilbur Wright observes as follows:

"During a period of five weeks, glides were made whenever the weather conditions were favourable. Many days were lost on account of rain. Still more were lost on account of light winds. Whenever the breeze fell below 6 miles per hour, very hard running was required to get the machine started, and the task of carrying it back up the hill was real labour. A relative wind of at least 18 miles per hour was required for gliding, while to obtain a speed of 12 miles by running required very severe exertion. Consequently, unless the wind blew in our faces with a speed of at least 6 miles, we did not usually attempt to practice; but when the wind rose to 20 miles per hour, gliding was real sport, for starting was easy, and the labour of carrying the machine back uphill was performed by the wind.

"On the day when the wind rose to over 16 metres a second we made more than a hundred glides with much less physical exertion than resulted from twenty or thirty glides on days when the wind was light. No complete record was made of all the glides made during the season. In the last six days of experiment we made more than 375, but these included our very best days. The total number for the season was probably between 700 and 1000. The longest glide was 622½ ft., and the time 26 seconds.

"On the last day of experiment we made a few attempts at records. A line was drawn a short distance up the slope as a starting mark, and four trials were made. Twice the machine landed on the same spot. The distance was 165⅛ ft., and the angle of descent exactly 5 degrees; time 6½ sec. From a point higher up the slope the best angle was 5 degrees 25 min. for a glide 225 ft.; time 10¼ sec. The wind was blowing about 9 miles per hour. The glides were made directly to windward and straight down the slope. Taking 7 degrees as a conservative estimate of the normal angle of descent, the horizontal resistance of the machine was 30 lb., as computed by multiplying the total weight, 250 lb., by the tangent of the angle of descent. This resistance remained nearly constant at speeds between 18 and 25 miles per hour. Above or below these limits there was a somewhat rapid increase. At 18 miles the power consumed was 1 to 1½ h.p.; at 25 miles, 2 h.p. At the slower speed, 166 lb. were sustained for each horse power consumed; at the higher speed 125 lb. per h.p. Between 18 and 25 miles the h.p. increased almost in exact ratio to the increase in speed, but above or below these limits the power increased rapidly, and with a constantly accelerating ratio.

"On two occasions we observed a phenomenon whose nature we were not able to determine with certainty. One day my brother noticed in several glides a peculiar tapping as if some part of the machine were loose and flapping. Careful examination failed to disclose anything about the machine which could possibly cause it. Some weeks later, while I was making a glide, the same peculiar tapping began again in the midst of a wind gust.

"It felt like little waves striking the bottom of a flat-bottomed row-boat. While I was wondering what the cause could be, the machine suddenly, but without any noticeable change in its inclination to the horizon, dropped a distance of nearly 10 ft., and in the twinkling of an eye was flat on the ground. I am certain that the gust went out with a downward trend which struck the surfaces on the upper side. The descent was at first more rapid than that due to gravity, for my body apparently rose off the machine till only my hands and feet touched it. Towards the end the descent was slower. It may be that the tapping was caused by the wind rapidly striking the surfaces alternately on the upper and the lower sides. It is a rule almost universal that gusts come on with a rising trend and die out with a descending trend, but on these particular occasions there must have been a most unusual turmoil during the continuance of the gust, which would have exhibited a very interesting spectacle had it been visible to the eye."

His experiences up to this period Wilbur Wright made public in two papers read before the American Western Society of Engineers, but his subsequent work in 1903, which culminated in the achievement of continuous flight, took place as far as possible in seclusion and was for a long time shrouded in mystery.

Having brought their gliding experiments to a pitch of perfection so that they could not very well hope to gain much more experience along these lines, they decided to take the next and most important step of all, which was to build an engine-driven machine that would make them independent of the winds and of the contour of the ground.

Although at this period automobiles had developed the high-speed petrol motor in a manner that made it obviously the type of prime mover they needed, nevertheless, the Wrights, like Langley, who at this time was engaged in the construction of the machine for the American army, were unable to buy exactly what they required. They set to work, therefore, to construct an engine for themselves. It consisted of a four-cylinder four-cycle motor designed on simple but in some respects very original lines. This power plant when complete on the machine included two chain-driven wooden propellers revolving in opposite directions.

It was December, 1903, when they attained success. On the 17th of that month they made four free flights from level ground against the wind. This performance took place in secret and many doubted its accomplishment when the rumours of the happening began to spread. An interesting and rather sad contemporary event that is often forgotten is that nine days previously Langley had made his final attempt to launch his own machine at Arsenal Point near Washington, and was unsuccessful.

In 1904 the Wrights made many more successful flights, and in 1905 they improved the control of their machine to a point at which they felt confident in introducing it to the public. Their subsequent achievements are matters of well-known history and may be studied in relationship to the record of the movement at large elsewhere in this volume.

CHAPTER XIII

THE WORK OF VOISIN AND FARMAN

Early experiments on the Seine—The first aeroplane factory—Delagrange as the first customer—The early Voisin biplane—An English pupil—Farman's successful circular flight—Farman becomes a constructor.

WHEN, in the early days of the new art in France, the aerial exploits of Henry Farman and Leon Delagrange were exciting the attention of the whole world, few people knew who were the real designers of the flying machines that these pilots were doing their best to use. The men in the background to whom due credit did not come until later were, in fact, the two brothers Voisin and their engineer M. Colliex. It was at their factory that they had established on the outskirts of Paris at Billancourt-sur-Seine that the first really successful French aeroplanes were built.

Several years prior to the time when Delagrange and Farman took to the air, the Voisin brothers were already at work on aviation. In 1904 they constructed for M. Archdeacon, who was a great patron of the science and by whose encouragement early progress was much assisted, some large box kites, and it is very clear that their later work, that is to say the machines they built for Farman and Delagrange, was based upon the results of those kite experiments. There was a resemblance, at any rate, between the two types of aircraft, and to this day the large biplane with vertical side panels is familiarly known as a " box kite " among pilots.

Experiments were conducted over the Seine with the early Voisin kites by towing them behind a fast motor-boat. On these occasions M. Voisin himself was the pilot. Much time was necessarily occupied over an apparently small amount of progress, but it must be remembered that in those days the work had to begin at the very beginning and one of the greatest difficulties, which is not always realized by those who now look back on the past, was to find any suitable place where it was possible to make any sort of practical trial with a full-sized man-carrying machine.

Archdeacon, Voisin, Bleriot, Santos Dumont and Esnault Pelterie were all doing their level best to solve the problem of flight, and each naturally set about the task in his own particular way. During the latter part of 1904 and the early part of 1905 Archdeacon, Bleriot and Voisin appear to have been very closely associated in their research, and Voisin, it seems, ought properly to have the credit of being the constructor of the early aeroplanes that went by the name of Archdeacon and Bleriot. One of the early Bleriot biplanes built by Voisin looked from the front like a flattened ellipse, for at the extremities the upper and lower planes joined one another by a curved panel. The same box-kite principle, however, was still apparent, and it was evidently supposed that the new form of extremity would help to stabilize the machine. From a photograph of the apparatus, it appears that two propellers were fitted, and unless the photograph is deceptive it would seem that the angle of incidence between the planes and the propeller shaft was enormous, far greater than would be feasible for really successful flight.

Most of the early work, however, was carried out on machines that had no motors, the idea being to tow them either behind a motor-car or a motor-boat. As Esnault Pelterie soon found out to his cost, however, towing an aeroplane by a motor-car is a dangerous business, especially when you happen to have forgotten to install any means of communication between the pilot on board the kite and the driver of the car. It is very doubtful, too, whether Voisin would have lived to build the successful aeroplanes that he subsequently constructed had it not been for the fact that he made his experiments over water instead of over the land. On one occasion the machine took a header into the Seine, and it was several anxious moments before the pilot was seen to emerge none the worse for his ducking.

Experiment by trial and error of this sort may teach slowly, but it teaches its lesson in a way that is not readily forgotten, and by the time the Voisins had decided to make a business of building aeroplanes they were also in a position to be able to give their customers some sort of a guarantee. There was, needless to say, a subtle distinction between guaranteeing that the aeroplane could fly and making any similar assurance as to the ability of the pilot, but there is no doubt that the first firm of aeroplane constructors made good their title from the day that they went into business.

The first order they obtained was one from M. Delagrange, the second was from Henry Farman, who bought a duplicate machine, except in respect to certain minor details.

One of those details proved of some importance in the relative progress made by these two pioneer pilots. The early Farman machine had its landing carriage wheels mounted on castors, while the Delagrange aeroplane was not thus equipped. It was, however, found very necessary to allow this freedom of movement to the wheels in order that they might adjust themselves more readily to inequalities of the ground and also to any slight leeward drift of the aeroplane when landing.

Another consideration that helped Farman to make successful flights before Delagrange, was that he took the precaution of making adequate arrangements for the use of an aerodrome. He succeeded, in fact, in obtaining permission to make his trials on the army manœuvre ground at Issy les Moulineaux, and it soon became very evident that anything less commodious than a field of these dimensions was of comparatively small use to the budding flyer. When a man is attempting to teach himself how to fly he needs to be as free as possible from the worries of other things, and he does not want to have to bear in mind that there is a hedge or ditch some yards ahead which he must of necessity fly over or fall into.

The Voisin aeroplanes supplied to Farman and to Delagrange were, as has been mentioned already, of the box-kite kind, that is to say they were biplanes and they had vertical panels between those planes, which produced a cellular form of construction. In all there were four such panels between the main planes, two at the extremities and two about midway between the centre of the machine and the extremities of the wings. The centre part of the space between the planes was occupied by a girder-like construction supporting the engine and pilot, the pilot sat in front of the engine and the engine drove a propeller by a direct extension of its crankshaft. The propeller was thus situated immediately behind the main planes, and a portion of the trailing edge was cut away so as to clear the propeller blades.

The same girder member that supported the engine and pilot was continued forwards in order to carry the elevator; this projecting portion was covered in with surfacing material. Extending behind the main planes were four long booms braced together by thin ash struts and steel wire; at the extremity of this outrigger was the tail. The tail was similar in construction to the main planes, but consisted of a single cell. Standing upright in the middle of the tail cell was the pivoted rudder plate, which was under control from the pilot's seat by means of wires coupled up to a drum that was operated by a wheel arranged in much the same way as a wheel is often used for steering motor-boats. The elevator was operated by jointed rods, which were also coupled up, through a sliding collar on a shaft, to the same wheel. The elevator was operated by pushing the wheel as a whole bodily forwards, which depressed the leading edge of the elevator plane.

There was no wing warping or any other form of direct lateral control. The aeroplane was designed to be stable laterally; if canted, the pilot was supposed to steer in such a way as to accelerate the outer wing tip so as to increase its relative lift and thereby restore balance. For the same reason, it was necessary to steer wide and proceed leisurely when trying to turn a corner, otherwise the outer wing tip would accelerate too much and the machine would be liable to slide inwards towards the ground. As nobody who practised in those early days cared about flying too high, or was indeed able to climb very much with the engine power available, machines did not have to slip very far before they hit the earth : consequently, however great their power of recovery may have been in principle, the fact remains that they seldom had an adequate chance of demonstrating it in practice.

When on the ground, the early Voisin biplane rested on a pair of pneumatic-tyred wheels carried in brackets not unlike the back bracket of a bicycle in general appearance ; they were so arranged, however, as to afford a spring suspension and also a free pivoting movement about the columns supporting them. This landing chassis was arranged immediately under the main planes. The tail rested on a pair of much smaller wheels.

The total weight of the machine with fuel, etc., was about 1400 lb. and the total supporting surface, including the tail, which carried part of the weight, was about 535 sq. ft. Allowing 150 lb. for the pilot, the loading of the surfaces was a little less than 3 lb. per sq. ft. The span of the main planes was about 33 ft. and the chord 6 ft. 6 in. The tail was about 8 ft. span by the same chord as the main planes.

Various engines were tried in these machines at different times, but the first aviation engine of note was the "Antoinette" and it was with one of these that the Voisin biplane used by Farman was originally fitted. The engine had eight cylinders of 110 × 105 mm. bore and stroke : it was nominally rated at about 50 h.p. at 1100 revolutions per minute. The weight of the engine was stated to be 265 lb. The propeller, which was made of steel, had a diameter of 7 ft. 6 in. and a nominal pitch in the order of 3 ft. The pitch was adjustable by resetting the blades in the boss. At its best, the gliding angle of the machine was supposed to be between 1 in 6 and 1 in 7.

One of Voisin Frères' earliest customers was J. T. C. Moore-Brabazon, a member of the Royal Aero Club, who transferred his enthusiasm for motoring to a pastime that he thought would possess a far greater fascination. He went to France, and there learned to fly. Having obtained some degree of competency in the air, he brought his Voisin biplane, which was known as the " Bird of Passage," over to England and established himself at the aerodrome that the Royal Aero Club had then recently acquired in the Isle of Sheppey.

As that particular machine was weighed in detail it may be interesting to record some of the figures, which are as follows: Planes, 180 lb.; chassis, 250 lb.; tail planes, 55 lb.; tail wheels, 13 lb.; outrigger framework carrying tail, 40 lb.; rudder, 10 lb.; elevator, 32 lb.; engine and propeller, 320 lb.; radiator and water, 80 lb. The chassis portion included the girder and engine-bed, as already described. The engine was an 8-cylinder E.N.V. rated at 50 h.p. The total weight of the machine, according to the details, was thus only 980 lb. The area of the main planes was 445 sq. ft., the elevator had an area of 45 sq. ft., and the tail an area of 107 sq. ft. The rudder area was 16·5 sq. ft. The span was practically 33 ft., the chord 6 ft. 9 in., the front edge of the elevator was 7 ft. 7 in. from the leading edge of the main planes, and the front edge of the tail 13 ft. 4 in. behind the trailing edge of the main planes.

Most of the constructional work was of ash, with the exception of the steel tubing employed in the chassis. Being flexible, the ash was very liable to bend, and it was, on the whole, somewhat difficult to keep these early Voisin machines in shape. The main planes consisted of two spars across which light ash ribs were placed at intervals. The ribs were placed in pockets formed in the surfacing fabric, of which there was only a single layer. The planes were not hollow as they are in the system of double surfacing that is now commonly employed in aeroplane construction.

In order to appreciate what Voisin accomplished it is necessary to remove from the mind the almost commonplace character that aviation has already assumed to-day. Previous to 1908, it may be said that flying did not exist as an accomplishment so far as the world at large was concerned. Wilbur Wright and his brother had flown in America, but their success had passed from the public mind, for so soon as they could really fly properly the Wrights packed up their machines and came over to Europe to make negotiations of a commercial character. The early struggles of Delagrange and Farman on the flying-grounds at Issy thus possessed all the realism of pioneer work, as indeed they were. Day by day they made progress, but the progress consisted at first in a series of hops. Then they would be in the air for a few seconds at a time. Gradually the flights get a little longer, and by degrees the pilots essayed to turn round in the air, which was always recognized as the crucial point in the development of the art.

So strongly was this felt to be the case, that M. Deutsch de la Meurthe and M. Ernest Archdeacon jointly offered a prize of 50,000 fr. for whosoever should accomplish a closed circuit in the air of one kilometre in length. This prize Henry Farman won on 13 January, 1908, and the event very naturally aroused the greatest enthusiasm. It was, as those who had given the prize anticipated, the beginning of a new era in flying, for during the year 1908 aviation developed, as has been shown elsewhere, in a truly phenomenal manner. On 31 October of that year Farman himself flew from Chalons to Rheims, a distance of 27 kilometres.

As was only to be expected, the practical experience of flying taught Farman much about the desirable and undesirable points in aeroplane design, and it was not long before he began to suggest alterations which in many cases turned out to be improvements. In the course of time, too, he entered upon constructional work himself and established a factory of his own. The modern Farman aeroplanes are very different from the early Voisin on which Farman learned to fly, but in the history of aviation due credit essentially belongs to Voisin as the founder of the first aeroplane factory in the world.

Although the Farman machines of the present day have no sort of resemblance in appearance to the early Voisin biplanes out of which they were originally evolved, they have one factor in common in that they have always been characterized by a large wing surface in proportion to their weight. Taking the Maurice Farman of the Military Aeroplane Trials as an example, the area was no less than 666 sq. ft., of which 130 sq. ft. represented the area of the tail. The weight of the machine, empty, was 1318 lb., and it carried in flight a total weight of 1931 lb. The loading was thus only 2·9 lb. per sq. ft., which was practically identical with that of the early Voisin, which, however, carried far less useful weight.

The engine on the Maurice Farman in the Military Trials was a 70-h.p. air-cooled Renault. The main planes differed from each other in span, the upper member measuring 50 ft. 6 in. and the lower member 37 ft. exactly. The chord of both was 6 ft. 6 in. An elevator measuring 12 ft. by 2 ft. 3 in. was carried by an outrigger framework extending 12 ft. 3 in. from the leading edge of the main planes. Behind the main planes, at a distance of 14 ft. 7 in. from the trailing edge, was the biplane tail having a total area of 130 sq. ft. One very important difference between the later Farman aeroplanes and the early Voisin biplane was the absence of any vertical panels. The main planes were thus no longer cellular in formation except so far as the construction of the framework might be considered in this light.

Hinged flaps were also introduced into the trailing edges of the main planes, and these were coupled up to the control lever so as to permit the pilot to increase the effective angle of incidence of one wing tip or the other. A flap was also added to the trailing edge of the tail in order to assist the front elevator, and these two members were coupled up to work in unison.

This involved a modification of the control itself, and Farman introduced the vertical lever system in which the balancing flaps on the wing tips are operated by a sideways movement of the lever while the elevator was operated by moving the lever to and fro. The rudder on the Farman aeroplanes was controlled by a pivoted bar under the pilot's feet. In the Maurice Farman, as flown in the Military Trials, pedals take the place of a bar.

Another Farman detail much used by other designers is a form of landing carriage in which skids are combined with wheels so as to afford protection to the machine in the event of a wheel being buckled or coming adrift in a rough descent. The Maurice Farman machine has its skid members extended forwards so that they assist in the support of the elevator;

they are thus available to take the first shock even if the machine were to pitch on its head. Normally, the wheels, of which there are four, two to each skid, take the load. Each pair of wheels is coupled together by a short axle, and the axle is attached to the skid by an elastic strap and a radius bar.

Having such a light loading, the machine is capable of flying at comparatively low speeds and in the Military Trials it demonstrated that it could fly at just under 37½ miles per hour. Its fastest speed was 55·2 miles per hour. When gliding, its speed was 38 miles per hour and its slope of descent 1 in 6·8; it also showed itself to be capable of climbing upwards at a rate of 207 ft. per minute for the first 1000 feet of its ascent.

To mention all the successes that have been obtained by the Farman aeroplanes would be impossible, but to English readers one event in particular must always stand out very prominently, and that is the occasion of the London to Manchester flight. When the *Daily Mail* offered the extremely generous prize of £10,000 for a flight from London to Manchester everyone thought that it would be years before the event could possibly be accomplished. A sum of this magnitude, however, is no mean incentive to effort, and within a very short time there were evident signs that someone or other was likely to at least make the attempt. Two pilots in particular, Claude Grahame-White and Louis Paulhan, speedily made up their minds on the subject, and this remarkable event almost started as a race. Both competitors used Farman biplanes, but in those days Louis Paulhan had had very much more experience in the air than Grahame-White, who, comparatively speaking, was then a beginner. His pluck, however, was of an uncommonly well-seasoned kind, as many incidents in his attempt went to prove. Paulhan, as history has recorded, succeeded in accomplishing the journey and in winning a thoroughly well-deserved prize. His success formed another notable step in the progress of aviation, and it served in consequence as a great stimulus to future effort on the part of all who were engaged in the subject.

CHAPTER XIV

THE WORK OF DUNNE AND WEISS

Experiments on the hill-side—Soaring flight in the wind—The Dunne aeroplane—Its negative wing tips.

SIDE by side with those who pioneered the successful aeroplane as it is known to-day there has worked a small and scattered school of students whose object has more particularly been to devise a machine that should be comparatively independent of the pilot's control for its security of balance. In England, the names of Dunne and of Weiss are intimately associated with this field of research, and it seems proper to refer especially to the nature and results of their labours.

It was on the steep hill-side near his home in the south of England that the Weiss bird-like models used to be flown day after day in the wind with the object of teaching the experimenter how he might design a self-balancing craft. Hundreds of different gliders, some of which were large enough to carry several pounds' weight, were made and tried until at length he learned how to proportion the wings and the body so as to ensure stable flight. When the wind blowing up the hill-side was strong enough, these imitation birds would frequently soar upwards and backwards to a considerable height before gliding down into the wind towards the earth.

Having attained to a sufficient degree of confidence in his methods and in his design, José Weiss built a machine just large enough to carry a man. A frail-looking little object it was, too, just a pair of wings attached to a tiny coracle-like body that contained neither engine nor control. Underneath, was a kind of chassis on which the machine could stand upright or run along the ground. It seemed to me that anyone who flew in this device would need much confidence and even more pluck, but Gordon England, who became the pilot in question, evidently had sufficient of both qualities, notwithstanding that he took his risks smilingly.

Sitting in the little body of the machine he would be pushed off down the hill-side and gather way until such time as the relative wind was strong enough to bear his weight. Then the little aeroplane would gently leave the ground and glide steadily and securely through the air. In windy weather, soaring flight would to some extent often take place, the machine remaining over the same spot above the ground although flying all the time full speed through the opposing wind.

As this particular machine had no controls, or none that the pilot found of any use, his safety depended entirely on its natural weatherliness. To a limited extent he might influence the attitude of the machine by leaning his body this way or that, but as a means of control it would have been futile, for in the sort of weather that alone made these experiments possible any aeroplane not inherently capable of retaining its balance must inevitably have capsized in a few seconds.

It was necessary to fly in a high wind and on the side of a steep hill because the aeroplane possessed no engine. To have attempted to glide in a calm would have involved great difficulty in acquiring sufficient initial speed over the ground. Also, it would have involved great danger on landing, since the momentum (quantity of motion or product of weight and velocity) of the machine would be excessive, and any sudden contact with the earth's surface might have broken it to pieces and injured the pilot.

To have attempted to fly in a wind without using the side of a hill would have been equally futile, because there would have been no means of ascending to a useful height off the ground unless the machine had been towed like a kite by a rope attached to a motor-car, which is a very dangerous procedure.

The Weiss models were all very bird-like. Indeed, their designer was in the habit of experimenting on dead birds, the wings of which he would stiffen by various means of his own so as to cause them to remain extended in the attitude of flight. In this way he succeeded in making some specimens perform gliding flight. He also investigated the balancing property of the bird's head by using paper collars to extend the neck.

Others besides Weiss doubtless did as much or more in other parts of the world and their names equally deserve mention, Ettrich and Montgomery among them. It happens, unfortunately, that the detail of their work is not equally well known to me, which must serve as an apology if it is no excuse. It is not, however, so much with a view to drawing particular attention to the accomplishments of any one man that the work of Weiss is here mentioned, as with the object of illustrating the idea that inspires a certain school of thought in the realm of flight to-day.

How far the solution of the difficulties in this case may have been particular to the prevailing conditions rather than general to the broader problem of flight, may itself be an undecided question, but that only emphasizes the interest of the subject at large. It serves, too, as a reason for watching with particular interest the progress of those who are still working in this field : of men like J. W. Dunne, for example, who has developed quite a unique type of aeroplane as the result of his own particular line of research. His work is of especial value because it has been applied to the construction of full-sized aeroplanes of both the biplane and the monoplane class.

In the Dunne aeroplane the wings make a V in plan, each wing has a variable camber and angle from shoulder to tip. At the tips, the angle is negative and the leading edge of the wing dips considerably below the normal line of flight. The change of angle is gradual from shoulder to tip, and the front wing spar slopes downwards from the body. The surface of the wing is in part generated upon the surface of an imaginary cone, which serves as the basis on which the changes of curvature vary with the position along the span.

Owing to the V plan form of the wings, the wing tips lie considerably behind the shoulders. Their negative angle of incidence is very pronounced in normal flight and on the monoplane the extremities of the wings are downturned to a very marked extent, as may be seen from the photograph of this machine on page 53. It is important to realize that the extent to which the wing tips are retreated is very considerable. In the biplane, for example, the rear extremities of the wings lie more than 20 ft. behind the point of the V: the span of this machine is 46 ft. There is, therefore, every reason to regard the wing tips as representing the tail, which otherwise is not present as a definite member.

From the foregoing brief description it will be apparent that the Dunne aeroplane represents an actual example of the use of negative wing tips for stability, which was discussed in a previous chapter (p. 54). The theory of the subject that is there presented, however, is a purely personal one, and I do not presume to advance it as an adequate explanation of the inventor's claims in respect to this particular machine.

The control of the Dunne aeroplane is also an example of the differential negative angle, for the flaps on the wing tips alter the magnitude of the negative angle but never make it positive. Steering is effected by moving the flaps in opposite directions by the aid of separate levers, one on either side of the pilot. At one extremity the attitude of the flap increases the permanent negative angle of the wing tips, at the other extremity it diminishes the amount. The machine banks and steers its appropriate course without the aid of a rudder.

One pilot, Major Carden, has already secured his certificate on the Dunne aeroplane, and that this machine has in fact some real measure of stability in its design is shown by the following official notice issued by the Royal Aero Club in respect to a test conducted under its observation:

"ROYAL AERO CLUB OF THE UNITED KINGDOM.

CERTIFICATE OF PERFORMANCE. NO. I.

(Under the Competition Rules of the Aero Club.)

Flight of Aircraft Uncontrolled by Pilot.

"THIS IS TO CERTIFY that on the 11th December, 1912, a Dunne biplane was entered for trial by the Blair Atholl Aeroplane Syndicate, Ltd., the object of the trial being to show the behaviour of this biplane when flying without being controlled in any way by the pilot.

Particulars of Aircraft—

Type: Dunne Biplane, two seater. Overall span 46 feet. Total Lifting Surface 552 square feet.
Motor: 50–60 h.p. 4-cylinder Green.
Controls: Hand levers only, no automatic controlling mechanism, gyroscopic or otherwise, fitted.

"*Description of the Trial.*—The trial took place on Salisbury Plain on the 16th and 17th December, 1912. On the first flight on the 16th the wind was blowing in gusts up to 20 m.p.h., and the pilot ceased to manipulate all controls for a period of 1 min. 5 secs. whilst flying over a spot where irregular disturbances of the air were, from the actual experience of the official observer, known to prevail. The pilot only resumed operation of the controls at the request of the official observer, who was the passenger in the aircraft. During this period, the aircraft was quite stable laterally, there being an absence of both quick jerky movements and periodical rolling. The apparent effect of a gust was to cause the aircraft to turn steadily to the right or left.

"The second flight on the 17th was made under slightly better weather conditions, and the pilot ceased to manipulate all controls for two periods of one minute each. During one of these periods the controls were locked, and the aircraft described a complete circle of 360°, banking of its own accord at the correct angle. There was no feeling of side wind on the face of the Official Observer, thus showing absence of sideslip either inwards or outwards.

(Signed) "C. D. ROSE, *Chairman.*

(Signed) "HAROLD E. PERRIN.
February 4th, 1913."

It is interesting to observe, in the light of the decision of the foreign courts on the Wright patent case, that the Dunne aeroplane is practically the only actual flying machine that evades the rudder *cum* warp combination.

The essential difference between the Dunne aeroplane and, so far as I know, any other machine designed for inherent stability is that whereas several types have had upturned wing tip *trailing* edges, the Dunne obtains a very marked negative angle at the tip by depressing the *front* edge of the wing.

It might be argued that the virtues of the negative wing tip cannot very well be affected by whether it has an upturned trailing edge or a downturned leading edge. There is, however, another aspect of the situation that is best demonstrated with a paper model. If a postcard is held by its corners between the thumb and first finger of each hand, it will warp naturally so as to produce the Dunne type of wing with the downturned leading edge. One diagonal remains straight, while the other assumes a simple curve. It is only with difficulty that the cardboard may be warped so as to give an upturned trailing tip in conjunction with a cambered shoulder, and it will be observed that this effect is accompanied by a flattening of the middle portion of the wing thus represented, which thereby loses the advantages of a cambered section over that portion.

CHAPTER XV

THE BRITISH MILITARY TRIALS OF 1912

Assembling in fifteen minutes—The three hours' flight—Wind tests—Measuring the gliding angle—Cody's victory.

WHEN, as the result of somewhat tardy deliberation, H.M. Government at last decided seriously to develop aviation as a new arm in national defence, a competition was decided upon as the best means for ascertaining what types of aeroplanes were most likely to be useful. The event was thrown open to the world, and took place on Salisbury Plain not far from Stonehenge during the month of August, 1912. Thirty-two aeroplanes were entered, and 24 took up residence in the sheds that the Government had had built to receive them. The site selected had been the head-quarters of military aviation for some time, and was also one of the depots of the "Bristol" Flying School, so it was already an aerodrome well known to many pilots.

Of the thirty-two machines entered, twenty were British, ten were French, one was Austrian and one was of German construction. Of those that actually attended, seventeen were British and seven were French. The German and the Austrian machines did not materialize, having, it was said, already been purchased abroad. Of the seventeen British aeroplanes that were nominally in evidence, at least seven of the newer makes were either unfinished or untested on the opening day, and thus some of the very firms for whose benefit the trials had, in a measure, been organized, spoiled their own chances in competition with the older constructors who, for the most part, had entered well-tried models.

The aeroplanes arrived in packing-cases, in accordance with the rules, and the first episode in the event was their assembly under official observation against time. Two machines, the Avro biplane and the Hanriot monoplane, were put together and flown in less than fifteen minutes, the Bristol monoplane was similarly in the air in less than eighteen minutes, but the majority of machines took over an hour to erect. A few of the entries, as already remarked, were so far from being in a position to fly that their unfinished parts were quietly transferred to their sheds for completion, which process lasted in some cases several weeks and caused the sheds in question ironically to be described as factories by those whose business or pleasure it was to await the course of events.

During the whole of the month of August—the Trials commenced on the 2nd, and were not declared over till the 27th—the officers of the Royal Flying Corps were in attendance on the entrants, who were allowed to suit their own convenience about flying, provided that they notified the secretary of the meeting, Major F. H. Sykes, of their decision to undergo a test. Whenever the weather was officially suitable for flying, a blue flag was run up on the flagstaff as a sign to those who were ready that they would be permitted to come out and fly, but the weather was so bad and the prospect of three hours in the air so unpleasant that far less flying was accomplished than might have been the case had the three hours' qualifying test been optional as the first event, or had the competitors realized that the mere demonstration of the ability of their machines to go out in any weather would have done them much credit in the eyes of the judges.

In the memory of oldest inhabitants, England had never seen such an August since she became an island, and certainly Salisbury Plain during the Military Trials was the place of places in which to appreciate the probability of the estimate being a very true statement. It was a weary period of false hope. The wind blew incessantly and the rain, having converted the ground in the vicinity of the sheds into a deep quagmire, whipped a fresh top-dressing of creamy mud for each day's portion. Every morning at four o'clock many a weary head was raised heavily from the magnetic pillow to blink a sleepy eye at the tree-tops for any sign of a breeze.

The weather changes with startling suddenness on the Plain, and in the first light of dawn the air is apt to be calmer than at any other period of the day. To lie abed was to be certain of missing the best flight of the meeting, to go up to the sheds was to be still more sure of spending a freezingly cold hour or so sliding about in gum boots on the insecure surface of terra firma.

It was one of the conditions of the Trials that competing machines were to be put through a three hours' flight as a preliminary qualifying test, and it was the uncertain character of such an undertaking in such weather that delayed progress in the beginning. Some of the entrants had been smart enough to get their three hours' flight completed on the very first day, which was gloriously fine, and they, therefore, were able as occasion offered to make some headway with the other items that required less time. Later, when the judges decided that entrants might take their tests in any order they pleased, the business of the meeting proceeded apace and all the pilots who were able to demonstrate their machines as real flyers in the shorter tests also found an opportunity before the close of the event to complete the three hours' duration in the air.

It was an exhaustive trial in many respects, for the conditions set a high standard and left few aspects of the aeroplane in the dark. Every machine had to carry a passenger whose weight with that of the pilot had to be made up by ballast to a total of 350 lb. In addition, fuel and oil sufficient for a flight lasting 4½ hr. had to be carried, the weight of which, roughly speaking, represented another 350 lb. Thus, there was a load in the order of 700 lb. on board every machine.

During the three hours' qualifying flight, the pilot had to attain an altitude of 4500 ft. and maintain a height of at least 1500 ft. during one hour of the test. It was also essential that the machines should be shown to be capable of climbing to an altitude of 1000 ft. from the ground at a rate of not less than 200 ft. per minute, which test most of the competitors successfully accomplished when setting out for their three hours' flight.

The machines were also tested for speed with and against the wind, and besides having to fly their fastest they were also required to fly as slowly as the pilot considered to be safe. Competitors had, moreover, to show that if their engines were switched off in mid-air at an altitude of 1000 ft. their machines would cover a distance of 6000 ft. in gliding flight before alighting. Another test was to alight in a ploughed field and to ascend therefrom. Also, it was necessary to demonstrate in what distance each aeroplane could be brought to rest after alighting on the grass. Similarly, the aeroplane had to be capable of being steered while running on the ground, the ability to do which is in most machines derived from the blast of the propeller blowing on the rudder: some machines are, however, fitted with a pivoted skid under the tail, which is interconnected with the rudder mechanism. The final incident of the Trials was the dismantling of the machine and its attachment behind a motor-car for road transport, after which it was again assembled and flown for the last time.

No definite marks were awarded for performances in the various events, which were intended mainly to provide a uniform basis on which the judges could estimate the usefulness of the different types from the military point of view. Many other considerations besides actual achievements were in fact weighed in the balance before the award of the prizes, which amounted to £8900, was made.

Of that sum the Cody biplane won the first prize of £4000 open to the world and also the first prize of £1000 open to British subjects for machines manufactured wholly, except the engine, in the United Kingdom. The second prize of £2000 open to the world was secured by the French Deperdussin: a second prize was not awarded in the British section. Three third prizes of £500 each were won by British aeroplanes, two by the Bristol monoplanes and one by the British Deperdussin. Awards of £100 each were also made in respect to the performances of the Hanriot monoplane, the Maurice Farman biplane, the Bleriot monoplane and the Avro biplane.

The double victory of the Cody was a notably pop-

"*Flight*" *Copyright Photo*

S. F. Cody on the biplane with which he won the first prize in the British Military Aeroplane Trials of 1912.

ular win, for not only had Cody himself been a most persevering pioneer, but his close association with the army in connection with his well-known man-lifting kites had shown him many military requirements that he set himself to realize in the design of his very first machine. Although so large, the Cody biplane proved a handy craft under Cody's control, and it showed itself to be possessed of a remarkable range of speed. At its slowest, it flew at 48·5 miles per hour and its fastest speed was 72·4 miles per hour, which represents an increase of nearly 50 per cent on the minimum.

The fastest machine in the Trials was the Hanriot monoplane, which was timed to do 75·4 miles per hour; the slowest was the Maurice Farman, which made 55·2 miles per hour. The speed range of the Farman was considerable, however, for it showed itself to be able to fly at 37·4 miles per hour, which was a slower speed than any other slow speed demonstrated in the competition. A slow speed of this order has marked advantages when alighting, and it is especially useful for beginners. This ability to fly slowly on the part of the Maurice Farman is due to its immense area in proportion to its weight, the wing loading being less than 3 lb. per square foot: one machine, the Bristol monoplane, carried as much as 9 lb. per square foot.

The speed range of a machine is an indication of the reserve power available over and above that required to fly under the conditions of least resistance. It does not follow that the slowest speed possible on the part of a machine is necessarily its speed of least resistance; rather the contrary. The variation of speed is brought about by a variation in the angle of the wings and is made by an adjustment of the fore-and-aft balance with the elevator.

A wide margin of power is most important, as has already been explained, and it has also been pointed out that there are advantages in large lightly loaded wings of considerable span. In general, the monoplane is always more heavily loaded on its wing surface than is the biplane, and if one of the objects of its design is to fly as fast as possible with the power available, it therefore employs only so much wing area as may actually be required for the purpose.

CHAPTER XVI

SEA-PLANES

[This chapter is abstracted from the introduction to a report on the meeting of Hydro-aeroplanes held at Monaco in April, 1913, prepared by the author for the Aerial Defence Committee of the Navy League.]

HYDRO-AEROPLANES, or sea-planes, differ only from land aeroplanes in that they are designed to ascend from and alight on the water instead of on land.

Directly, this distinction affects only one part of the machine ; indirectly, it may affect structural detail in many parts, and even cause distinctions of importance to arise concerning the pilot's art of control.

Ordinary land aeroplanes are equipped with wheels on which they can gather speed preparatory to ascent into their proper element. Hydro-aeroplanes, or sea-planes as the Admiralty has decided to call them, have floats designed to permit of the same manœuvre on water.

It is an essential preliminary to flight, this getting up speed on the ground or on the water as the case may be, for an aeroplane is air-borne solely by virtue of its motion relative to the atmosphere.

The machine is driven over the face of the earth by the force of its propeller in order that it may make its own wind under the wings. The wings being set at an angle deflect this relative wind downwards, and so there is, by Newton's first law of motion, an upward reaction tending to lift the machine.

Not until the speed exceeds a predetermined minimum which depends on the size of the wings in proportion to the weight of the machine and its load, is the force under the wings sufficient to support continuous flight. Until that speed is attained, the aeroplane, in common with all other physical objects, is held down by the earth's attraction.

And so it is that one must speed up over the ground or over the water before it is possible to fly. Some machines require more room for starting than others, owing to the greater weight carried per square foot of wing area, but the large biplanes, which although heavy themselves are often very lightly loaded in respect to their wings, can generally ascend in a very short distance. Machines that have extremely powerful engines in proportion to the weight carried can also rise in a fairly short distance, because they are able to acquire their high speed at a relatively fast rate of acceleration.

The existence of a real wind also materially affects the situation, for a wind is a movement of the atmosphere in respect to the earth, and, therefore, it influences the distance that the aeroplane must travel in contact with the earth before it can acquire the velocity relative to the atmosphere on which it depends absolutely for its ability to fly.

For example, a head wind blowing against the machine in itself provides a certain amount of relative motion in respect to the wings, and the machine need not necessarily move so fast over the ground in order to acquire its proper flight speed through the air. On the contrary, a following wind makes it more difficult to rise quickly, because the machine must travel over the ground at the speed of the wind plus its own flight speed, before it can establish that relative motion in the atmosphere on which it depends for its aero-dynamic support.

The ability to rise readily is important, whether it be from land or water. In both cases a long run is likely to be intercepted by obstacles and so to terminate ineffectually, while, by subjecting the machine for a long period of time to the jolting of an uneven surface, the risks of structural damage are naturally increased.

Machines designed with undercarriages for alighting on land as a rule have elastic suspension devices for the attachment of the wheels, which absorb some of the shocks.

Hydro-aeroplanes, on the contrary, for the most part have their floats rigidly attached to the machine, which thus receives the full impact of the waves.

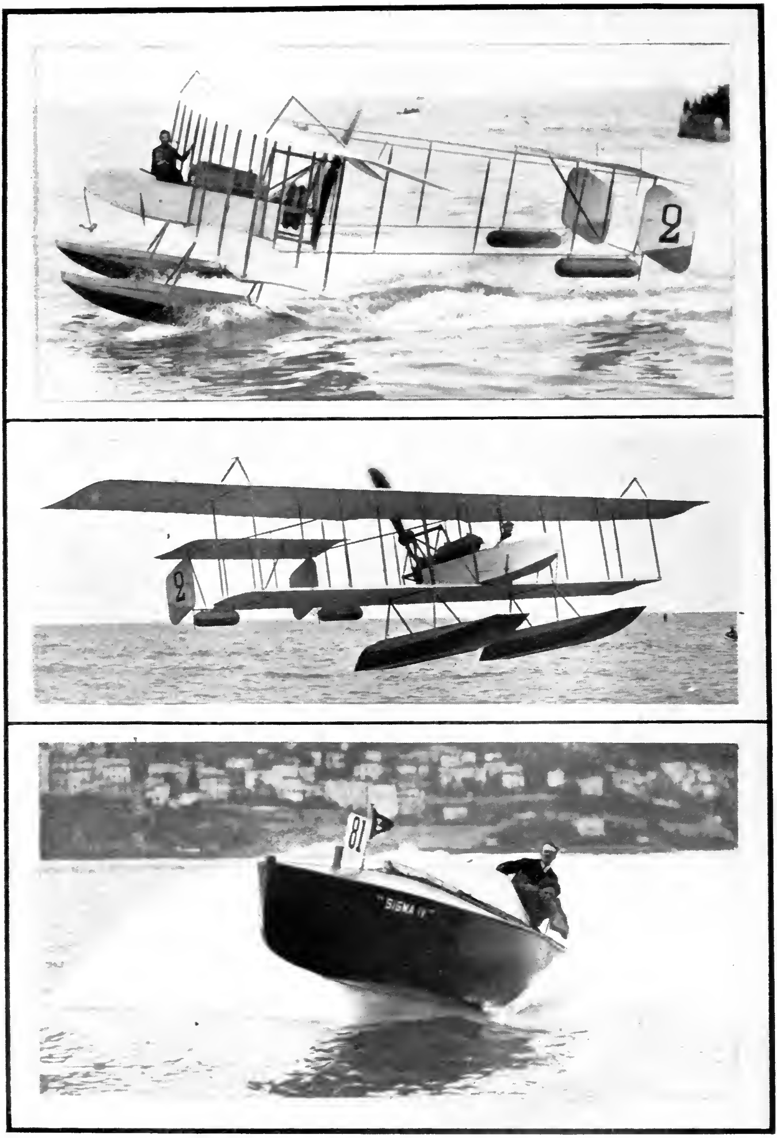
The water can be very hard under certain conditions, and the problem of designing an aeroplane that shall be reliable for use over water is far less simple than some people might suppose. It is not only necessary that it should be strong, it must also be light. Floats must not only be large enough to give buoyancy to the machine, but they must be so contrived as to reduce the resistance to motion on the water to a minimum.

The former condition could be satisfied by any sort of water-tight box of sufficient capacity, but the resistance to its motion through the water would altogether preclude the effective use of an ill-designed contrivance of this sort. Many of the floats actually in use on waterplanes have the appearance of being mere boxes, but in fact they are intended to have other qualities besides that of buoyancy.

Instead of ploughing through the water like an ordinary boat, the proper sort of float for the hydro-aeroplane should have the quality of rising to the surface when at speed. Such behaviour diminishes the resistance to motion very much indeed.

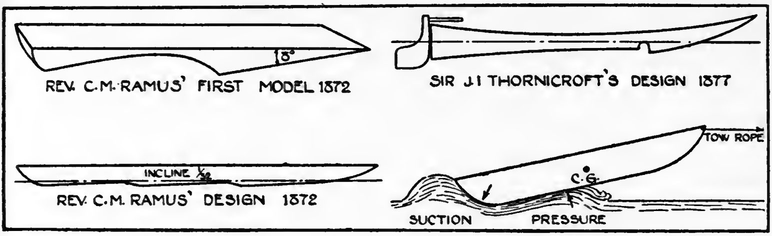
The ability to skim over the surface of the water is due in part to the support of the wings and in part to the inclined flat bottom of the boat, which wedges itself out of the water when the machine attains to a sufficient speed. It is possible for boats themselves to be so built that they will skim the surface of the water, and such craft, which are known as hydroplanes, are remarkable for their high speed.

They are at present built only in comparatively small sizes, but of late years they have achieved considerable popularity among enthusiasts in motor-boating circles. As some hydro-aeroplanes are fitted with hydroplane boats to accommodate the pilot and passenger, instead of box-like floats that behave as mere "webbed feet," it may not be altogether inappropriate to recall some interesting circumstances relating to the invention of this very modern type of watercraft.



The Henry Farman hydro-biplane about to rise and about to alight. Below is a fast flat-bottomed motor-boat, showing how the bows rise from the water at high speed.

It was in 1872 that the Rev. C. M. Ramus, who then held the living of Playden, near Rye, in Sussex, wrote a letter to the Admiralty informing them of certain experiments he had made that led him to suggest a radical departure from the orthodox design of ships. Interviews with the Director of Naval Construction took place and the following memorandum, signed by that official, was issued two days later :



"Flight" Copyright Drawings

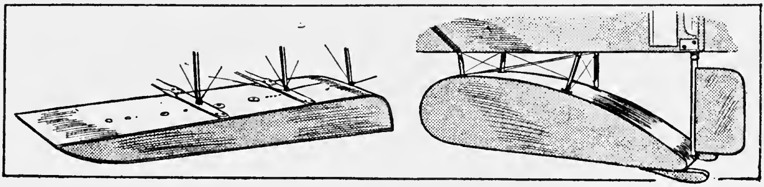
Sketches of the original designs for a hydroplane made by the Rev. C. M. Ramus in 1872. Sir John Thornycroft's first design is also shown, together with a sketch made by him to illustrate the forces that cause a towed boat with a rounded stern to rise up at the bows. A square stern for a hydroplane is essential. The notch in the bottom of most hydroplanes is a kind of intermediate square stern.

> " Rev. Mr. Ramus has to-day communicated to me the plan of designing steamships for great speed referred to in his letter of the 5th instant.
>
> " It consists in forming a ship of two wedge-shaped bodies, one abaft the other.
>
> " The object of this invention is to cause the ship to be lifted out of the water by the resistance of the fluid at high speeds.
>
> " The double wedge provides that while the bow is lifted by the foremost of the inclined surfaces, the stern is lifted by the after one, and these may be so placed with regard to each other that the ship shall always keep her proper trim."

It will be observed that Mr. Ramus's invention related to the use of a flat-bottomed boat in two lengths, that is to say the bottom sloped upwards from the stern to the centre of the boat and then began again at a lower level, whence it sloped upwards to the bows. In the centre there was, therefore, a sharp step or change of level from the front end of the stern portion to the rear end of the bow portion of the bottom of the boat, and it is this step that characterizes the hydroplane as a distinct type of watercraft. Sketches herewith show the Ramus design.

The object of the step is to assist the boat to skim the water on a level keel. A flat-bottomed boat pure and simple is in a sense half a hydroplane ; it automatically assumes an inclined attitude for the purpose of skimming the surface, and in so doing the bows rise clear out of the water. The somewhat curious spectacle of a fleet of small motor-boats proceeding round the course with their bows in the air is often a characteristic feature of modern high-speed racing.

The floats of the hydro-aeroplane of to-day are for the most part in a category corresponding to the flat-bottomed boat rather than to the class of the hydroplane proper, for owing to their short length it is the exception rather than the rule to find the distinguishing step in their construction. At the Monaco meeting of waterplanes in April, 1913, there was but one make of machine employing stepped floats ; all the others had floats with simple flat bottoms turned upwards at the bows.



"*Flight*" *Copyright Sketches*

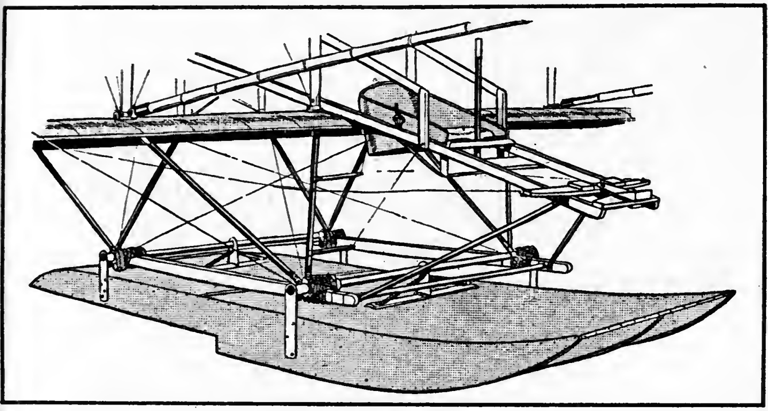
Front float and tail float used on the Short hydro-aeroplane exhibited at Olympia 1913. Messrs. Short Bros. have constructed many hydro-aeroplanes for the British Navy.

The stepped float alone, it seemed to me, demonstrated the hydroplaning quality of skimming the surface on a level keel. The other floats for the most part dug their heels into the water to a much greater degree, and usually created a stern wave of such size as to suggest the existence of much unnecessary resistance.

It is to be remembered that speeds that would be considered very fast for any sort of boat are very slow for flight. In consequence, it is not easy to acquire a proper flight-speed while trying to rise from the water, and it is only with considerable difficulty that pilots are able to get some machines " unstuck."

Anything that is potentially capable of reducing the resistance on the water is obviously a measure worthy of experiment, and I think the stepped float is properly to be regarded in this category.

A stepped float to be effective would necessarily be longer than most floats now in use, and preferably, I think, should be long enough to render a tail float unnecessary. They must also extend far enough forward and be so designed in the bows as to prevent them from diving under the surface if the machine descends rather steeply. This latter quality may in some measure be opposed to the realization of a fine cut-water such as some pilots consider desirable in order to reduce the impact of a rough sea.

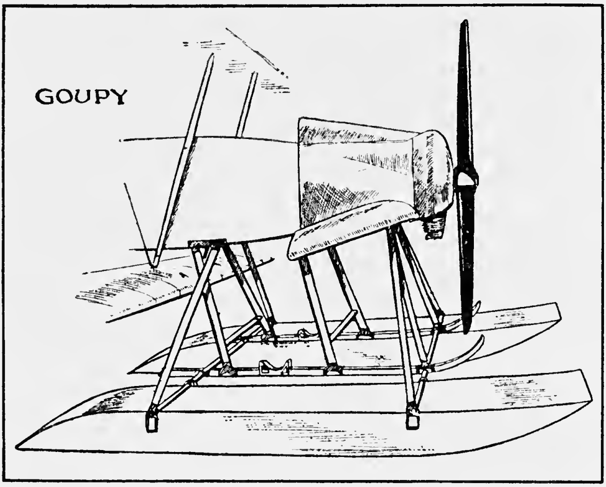


"Flight" Copyright Sketch

Main central float used on the "Waterhen," a machine built by the Lakes Flying Co., and flown for trial purposes over Lake Windermere.

By the aid of a proper float, a high water speed could be obtained with the wings of the machine at a fine angle, in which altitude they offer least resistance. Having accelerated to the utmost, the attitude of the wings must be quickly changed to a coarser angle in order to lift the machine into the air, and it should be possible with a suitably designed stepped float to facilitate the separation of the float from the water surface.

A float without a step tends to hinge on its stern in the water and so to hold down the machine. In order to overcome this, it seems to me that the rear step should be at such a level and of such an area as to tend to give an increasing resistance to immersion when the nose of the machine is being tilted up for ascent into the air.



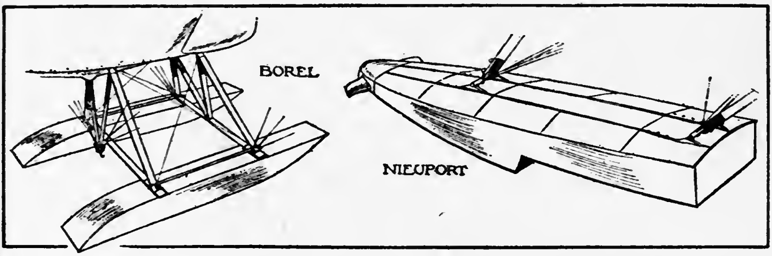
"*Flight*" *Copyright Sketch*

The Goupy undercarriage, with floats for alighting on the water.

Owing to alterations in the character of the wave at different speeds, I should expect it to be important to avoid placing the steps too close together, and I was rather surprised to observe the comparatively short pitch of the steps on the Nieuport floats used at the Monaco meeting.

In some stepped floats, air is admitted through a vent to the instep with the object of "lubricating" the after section with an air film. I have no information as to its efficacy.

Timber was used exclusively for the construction of the floats on the machines at Monaco, and apparently there were some instances of the employment of ordinary three-ply material. Experience in other directions does not suggest that ordinary three-ply wood is likely to prove durable for hydro-aeroplanes' floats. The best practice is more likely to follow the method adopted in modern high-speed boat construction, where the hull virtually consists of three shells interleaved with water-proof material. The shells are fastened together either by sewing with copper wire, or by riveting, or by fastening with nails that are turned over into the wood.



"Flight" Copyright Sketches

Types of floats used on the Borel and the Nieuport hydro-aeroplanes.

It was not possible to obtain exact information relating to the weight of the floats. Those used on the Henry Farman were stated to weigh about 140 lb. each. I was informed that the two floats on Prevost's Deperdussin weighed 130 lb. each. Judging by appearances, and the evidence of these figures, I should say that no float weighed less than 100 lb. and that some probably weighed nearly 200 lb. each.

With the exception of the Farman and Nieuport machines, all the floats employed at Monaco were rigidly attached to the framework of the machine. The suspension of the Farman floats was effected by means of elastic bands, this suspension being inside the floats on one of the two machines and outside on the other.

The Breguet machines employed rubber tension springs in one instance and steel helical springs in another.

For the most part, the tail floats were rigidly fixed to the backbones of the machines, but in one or two cases they were pivoted so as to turn in unison with the rudder. One such example was the Borel, and M. Borel, the designer, stated that, so far as his experiments had gone, he considered it to be an improvement that justified the complication. Some instances of machines having broken their backbones draw attention to the severe stresses induced by a tail float and raise the question of the desirability of trying to avoid its use altogether.

CHAPTER XVII

ACCIDENTS[1]

The importance of debris—Formation of the Investigation Committee—The Rolls accident—Wind shocks—Trick flying and its dangers—Upside-down in mid-air—Parke's dive—The risks of flying with an underpowered engine.

ACCIDENTS, to which vehicles of any description are liable, are so terrible in their power to bring suffering that the least civilization can do in memory of the victims of its progress is to take pains to learn the causes of the disasters and to apply the lessons they teach in such a way as shall minimize similar risks in the future. The theory is admirable, but the practical accomplishment of the task, which alone makes the idea worthy of any more respect than is due to the average pious wish, is no easy matter. Particularly is this true of accidents that take place in the air.

Trouble may overtake a flyer when he is far beyond the accurate observation of casual spectators on the ground, and if, as is too frequently the case, the result is fatal, there remains nothing but the debris out of which to reconstruct the event. How useful those poor fragments of a shattered machine may be, however, none who has not pursued an inquiry into the cause of an aeroplane disaster can possibly realize. The morbid interest in these melancholy affairs that makes some people take little

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[1] Having the privilege of membership of the Public Safety and Accidents Investigation Committee of the Royal Aero Club and having served on the Departmental Committee on the Accidents to Monoplanes, 1912, I feel that it is proper to acknowledge the advantages that I have received from these positions, which have enabled me to hear the personal views of others under circumstances that would not ordinarily have occurred.

pieces of wood and the like as mementoes of the occasion is well-nigh criminal in its disregard of the value that may attach even to the most insignificant part.

An instance in point may be cited in a case where two little brass wood screws were missing from an object of importance, and were ultimately recovered from a man residing in Liverpool; the accident took place within fifty miles of London! In connection with the same case a pond had to be dragged in order to recover a small piece of iron that had been thrown away by someone who had picked it up when the accident occurred. The evidence afforded by the parts in question proved to be of first-class importance in the reconstruction of the causes of the mishap.

The necessity for systematically investigating aeroplane accidents is obvious, and there already exists certain machinery that works to this end under the ægis of a committee known as the Public Safety and Accidents Investigation Committee of the Royal Aero Club. This Committee was formed in the year 1912, in order to meet the evident need for inquiry in such a way as would avoid the overlapping of the energies of separate organizations. The Royal Aero Club, as representing Great Britain on the International Aeronautic Federation, had already been filing particulars of aeroplane accidents during a considerable period of time, and were on the point of extending this work. At the same time, the Council of the Aeronautical Society, which devotes itself more particularly to the scientific side of aviation, was particularly anxious to give practical expression to the views of its Chairman, Major-General R. M. Ruck, C.B., who advocated that the technical aspects of each individual case should be examined by representatives of an authorized body. The Society, therefore, unanimously accepted the invitation of the Royal Aero Club to nominate representatives to serve on the special committee that the Club had decided to form under the chairmanship of Colonel H. C. L. Holden, C.B., F.R.S.

Obviously, the point of first importance in the investigation of accidents is to ensure the collection of reliable data. To this end the Committee proceeded to appoint representatives in all the principal centres, whose voluntary duty it is to proceed immediately to the scene of disaster, and, as far as may be necessary, take charge of the proceedings. The status of the committee in this matter has been recognized by the Home Office in the form of instructions to the police throughout the country, ordering them to prevent interference with aeroplane wreckage, pending the arrival of a Club representative. In this way an excellent start has been made towards the accomplishment of really useful work, and from the time of its inception the committee has unfortunately been only too busy.

One of the greatest difficulties associated with the investigation of an aeroplane accident is to establish facts relating to what was seen to occur by those on the ground. Eyewitnesses often differ as to essentials, and even as to the sequence in which things happen ; it is for this reason that solid objects picked up near a wrecked machine often afford most valuable clues. It has occasionally happened that certain things have come adrift in mid-air and have fallen from the machine while it was yet flying ; their relative positions along the line of flight may thus afford evidence as to the origin of the disaster and sequence of events that culminated in the final fall. Those whose misfortune it is to witness such accidents should thus be particularly careful to disturb nothing that they may find without first making in writing a note of the exact location, together with such other particulars as may seem to be of significance.

It is not surprising that eyewitnesses should often be unreliable ; few people train themselves to observe accurately, even under normal conditions, and the sight of an aeroplane accident is sufficiently disturbing to suspend the process of ordinary thought. A vivid recollection of the regrettable day when the Hon. C. S. Rolls was killed at Bournemouth, during the third flying meeting held in England, still remains with me ; with it also stays the recollection of the innumerable versions of the calamity that passed current during the day. Being an eyewitness myself, it interested me to hear the accounts of others who also said that they had seen everything ; and from that hour I came to the conclusion that even first-hand reports must be subjected to the utmost scrutiny.

On this particular occasion I happened to have very good reason for watching the machine in flight, for I believed that the pilot was about to make a performance liable to be fraught with danger. His purpose was to alight in a ring marked on the ground, and the wind was blowing in such a direction as to make it necessary for him to fly over the grand-stand when finally approaching the mark. The ring being at no great distance from the barrier would, I thought, involve a sharp descent, and I was anxious to see how so able a pilot would manœuvre his machine under these circumstances.

To anyone flying over the grand-stand the ring may have seemed unexpectedly close, and I was not surprised to see the pilot make a quick dive towards it. While still some height from the ground he tilted his elevator to flatten out ; the next moment the machine fell headlong, and poor Rolls was beneath it. In him, flight lost one of its most sincere and accomplished students. The cause of the disaster, there is small reason to doubt, was the springing of the booms that supported the tail of his machine, which were struck by the propeller and broken. The mere presence of the tail on this machine, which was a French-built Wright biplane, was an experiment at that time. Their failure was due to lack of structural stiffness, for they bent under the extra stress of the sharp manœuvre of flattening out, and so fouled the propeller blades.

When the elevator was used to reduce the steepness of the descent, the forces brought into play would tend to make the machine rotate about its transverse axis, which tendency would be resisted by the damping effect of the tail plane. Under ordinary circumstances, the Wright biplanes of that time had no horizontal tail planes, and so the inertia to rotation under the action of the elevator was small. Whether the pilot elevated to an extent likely to be dangerous under ordinary circumstances is beside the point. In his case, the effect of using the elevator was to throw a stress on the machine in mid-air that it had not properly been designed to withstand.

It is, of course, sometimes impossible to prevent fractures when an aeroplane makes a rough landing, for the sudden arrest of a moving mass may give rise to stresses that no reasonable structure could withstand. Even in mid-air, should the pilot completely lose his control at a great height, and the machine acquire a very excessive velocity of its own accord, stresses may be set up that may have fatal consequences. It is certain, however, that there is no excuse for failure under any normal condition of flight in which the pilot retains his command of the machine.

That parts of aeroplanes have given way in flight, the investigations of the Accidents Committee have shown beyond all doubt. There have been some cases of wings collapsing, and attention has thus been drawn particularly to the question of adequate bracing, both externally and internally, and to the strength of spars and ribs.

Some pilots of experience have spoken of having had their machines occasionally struck excessively sharp blows by the wind, but whether aeroplanes are in fact liable to be stressed to breaking-point by such sudden and incalculable forces remains an undecided point.

Several accidents have resulted from the deliberate performance of tricks in the air, such as were at one time notorious in America, where several pilots have been killed in front of the spectators. Catering to the sensations of the crowd, these men would display the most amazing nerve in making steep dives followed by banked turns in which the wings would approach to a vertical position. On one occasion a machine actually turned turtle through over-banking under such conditions, and the pilot was killed.

Much as the taking of useless risks is to be condemned as a disservice to the cause of aviation, it is important to recognize the potential value of dangerous practices that increase the individual pilot's skill in the handling of his craft. Dangerous flying is not in itself unjustifiable, but it is to be expected that anyone wittingly attempting feats of an especially risky character should make it a point of honour to avoid flying in places where a false move might involve danger to others.

One of the most remarkable escapes of which I have ever heard befell Captain H. R. P. Reynolds, of the Royal Flying Corps, while flying from Oxford towards Cambridge, on 19 August, 1911. Having started his flight in the morning, he was forced to descend near Launton, owing to a thick mist, but he restarted soon after seven o'clock in the evening, when the weather was both warm and fine. There was a suggestion of thunder in the air, which was so perfectly still that, describing his experience in a letter, Captain Reynolds remarks :

" I scarcely moved my control lever until I got to Bletchley, where it began to get rather ' bumpy.' I thought nothing of it at first, but suddenly it got so much worse that I began to think of coming down. There was a big black thunder-cloud coming up on my right front, which did not look reassuring. Below me there was what appeared to be very good landing-ground.

" At the time, I was flying about 1700 ft. altitude by my aneroid, which had been set at Oxford in the morning. I began to make a glide with the object of alighting in the field below. Directly I switched off the engine, however, I felt the tail of the machine suddenly wrenched upwards as if it had been hit from below, and I saw the elevator go down perpendicularly below me. I was not strapped in, and I suppose I clutched hold of the upright at my side.

" Before I realized anything more, I found myself in a heap on the top plane. I stood up, held on and waited. The machine, which was upside-down, just floated about in the air, sliding from side to side like a piece of paper falling. Then it overswung itself, so to speak, and went down more or less vertically sideways, until it righted itself momentarily the right way up. Then it slid down tail first and turned over upside-down again, whereupon it recommenced the old floating motion.

"We were still some way from ground and took what seemed like a long time to reach it. I looked round somewhat hurriedly, the tail was still there, and I could see nothing wrong.

"As we got close to the ground the machine was doing long swings from side to side. In the last swing we slid down, I think, about 30 ft. and hit the ground pretty hard. When quite high up my idea had been to jump and get clear of the wreckage. Fortunately, I hung on until practically the end, only jumping off, according to eyewitnesses, when about 10 ft. from the earth. Something hit me on the head, causing a slight scratch, but what it was I did not stop to inquire, being in far too much of a hurry to get away from the machine.

"When I went out to examine the wreck next morning, the tail and the elevator were practically unhurt. The undercarriage being uppermost in the air was quite untouched and the propeller was also undamaged. My own impressions of what occurred corresponded very well with what eyewitnesses told me they saw, but it was a pity that there was no one about who could give a technical account of exactly how the machine behaved. I was told that just before the smash there were two or three 'whirlwinds' in Bletchley and that one of these took all the leaves off a tree."

A somewhat similar accident occurred to Captain Aubry, of the French army, who was turned upside-down while driving a monoplane. His machine glided for perhaps 200 yards in this position, and then righted itself. The pilot regained control and made a safe descent!

Another pilot who looked death in the face and lived to recount his feelings was the late Lieutenant Parke, who passed through a singular experience during the Military Trials in August, 1912. Having finished the three hours' flight on his biplane one morning about breakfast-time, he proceeded to descend over the ground immediately in front of the sheds. His object was to make a spiral glide, but when he had descended a little way he thought that he was going rather faster than he had intended, and thereupon he raised his tail elevator so as to flatten out slightly.

He was surprised to find, however, that this action augmented his velocity, and after repeating the attempt he realized that he had lost control of his machine. According to eyewitnesses, the aeroplane dived head first in a steep spiral, and everyone who saw it felt certain that the next moment it would be dashed on the ground. To the astonishment of all, however, it suddenly flattened out in the most perfect manner, and flew off quite normally just as if the pilot had performed the manœuvre on purpose. But the pilot himself thought the end had come just as much as the spectators, and was as surprised as they were at his escape. This he owed to not losing his presence of mind in an apparently hopeless position. Having done everything that he considered proper by way of a control movement, he decided as a last resource to put the rudder hard over in the opposite direction to that in which he was holding it. The machine responded with amazing alacrity, and being well built did not fail structurally at the critical moment. Nor was the pilot overcome in the least at this sudden reversal of fortune, for he flew round the ground and landed up-wind in the approved manner with such apparent serenity that many of the paralysed spectators really thought they must have witnessed a stupendous "stunt."

Parke's dive, as it came to be known, drew particular attention to the manner in which the elevator may usurp the function of the rudder and vice versa when the machine is canted. It appears probable that the circumstances were such that the rudder and the elevator combined were in effect acting jointly as a rudder, owing to the canting of the machine. They thus locked the aeroplane in a spiral nose dive. Ruddering outwards at the last moment brought the machine into an attitude in which the elevator could act properly, and the aeroplane immediately responded to its influence. From considerations that have been discussed in the chapters on stability, it would seem proper in principle altogether to avoid ruddering inwards in emergency.

Lieut. Parke was subsequently killed by a fall while flying over the Wembley golf course, and his fatal accident was fundamentally due to leaving the Hendon aerodrome with an engine that was not then giving a sufficient margin of power. When he decided to return, he was flying at a low altitude, and his turn in the air brought him into the lee of some trees where he encountered atmospheric conditions that capsized his machine.

The dangers of flying with underpowered engines, or overloaded machines, which is the same thing, cannot be overestimated. Many accidents have been due to this cause, and it is one to which pilots of experience, who have every reason to know better, seem prone to succumb. They too often take the risk of leaving the aerodrome with an engine in a poor condition, on the off chance that it will pick up after a minute or so in the air.

So long as they keep within the confines of the aerodrome it is hardly possible to criticize such flying, inasmuch as it might often come within the scope of justifiable experiment. Aëroplanes must be tested, and those who test them must sometimes be prepared to take risks of this order. But it is neither safe nor justifiable to cross the boundary of the aerodrome in such a condition, and particularly is this true when the pilot carries a passenger.

It is not as if there could ever be any doubt in the pilot's mind as to the state of his engine, for it is merely necessary that he should make an invariable rule of ascending to an altitude of several hundred feet before leaving the precincts of the ground, in order to find out in time if it is pulling properly. The reasons why it is so dangerous to fly across country with a weak engine are twofold. In the first place there is no margin of power with which to combat bad weather, and in the second place the pilot may get trapped into the necessity of alighting on dangerous ground.

A weak engine implies that the machine is flying at a low altitude, and it may be that the pilot will thus fly over some boundary, and will have no means of safe return. The manœuvre of turning, as has been explained in the chapter on steering, involves extra power if it is to be carried out on the same level.

If the engine is weak, the machine necessarily descends while turning, and thus may be trapped behind the boundary that it has just crossed. A row of trees, a river wall, or a railway bounded by telegraph wires are all sufficient upon occasion to trap the unwary under such circumstances.

It is especially dangerous, for instance, to venture into the lee of trees and the like with a weak engine. In general, it is also risky in such cases to turn down-wind. Rivers and lakes are also likely to prove a trap to those who fly over them with an insufficient margin of power, for they are places where down-currents are apt to be prevalent through local differences of temperature between the land and the water.

In tropical climates heat eddies assume a really dangerous character even to a pilot flying a machine in full power. G. M. Dyott, who, with the late Capt. Hamilton, visited Central America with his monoplane, met with some very remarkable experiences over the plains of Mexico. There the sunshine is so hot that shadows cast by the clouds suffice to disturb the atmosphere in such a way as to produce whirling chimneys of ascending air. A machine passing through one of these chimneys may be lifted bodily some 20 or 30 ft. upwards. At other times, the whole atmosphere seems to be rising. In the evening, when the sun disappears behind the mountains, down-currents set in with dangerous suddenness. On one occasion Dyott was nearly trapped outside his aerodrome by a row of tall trees, although he was flying quite high at the time. Through the same cause Capt. Hamilton was once tossed upside-down in the air.

Across his knees was the control bridge, which helped him to keep in the machine, and above his head was the tripod mast carrying the stay wires to the wings. The machine landed on its nose upside-down, and the mast saved the pilot, who extricated himself from this extraordinary predicament unhurt !

While flying in the military manœuvres of 1912 Capt. Hamilton, who was then a member of the Royal Flying Corps, was killed by a derangement of the engine in mid-air. Aeroplanes should, of course, be so designed that the failure of the engine will be most unlikely to produce vital consequences. In this case, however, the wing stays were in some way broken by a fault originating in the power plant, and the pilot lost his life in the subsequent fall of the machine. Unfortunately, a brother officer who was a passenger on the aeroplane was killed at the same time.

It has been one of the most serious, as well as one of the saddest phases of latter-day disasters that two lives have so often been lost in the same accident. When, in the early days of flying, the pioneers used to tumble about with their machines, there were many bruises but few deaths. The tables seem to have turned against the flyer, for misfortune now points a most insistent finger to the necessity of making the art safer than it has been in the past. To this end there is no surer way than the systematic investigation of mishaps as they occur, which work the Committee of the Royal Aero Club does its best thoroughly to accomplish.

Accidents over water differ from accidents over land in the important particular that the more compact parts of the machine are not necessarily damaged by falling on to the water. On the other hand, the water readily damages the wing structure and lighter parts of an aeroplane. In view of this distinction, it seems important to take advantage of the opportunity thus offered of saving the power plant intact. If the power plant and the pilot occupy what is tantamount to an independent body, this member might conceivably be made water-tight, and even self-righting.

It is not only important to consider the saving of life, which in connection with military reconnaissance potentially means the acquisition of important information, but the salvage of a self-contained unit including the power plant would materially facilitate the re-erection of another complete machine. Whatever the characteristic design adopted may be, it seems to me that the above principle might usefully be regarded as one of the governing factors in the construction of waterplanes.

PART III

INTRODUCTION

IN the following chapters, the history of the conquest of the air is discussed as far as possible in chronological sequence, but at the same time with due regard to the contemporary influence of events. Very often it happens that those who work as pioneers in a new field of activity go over ground that has already been ploughed, and it is important therefore that those who subsequently record the doings of the period should as far as possible try to ascertain the extent to which knowledge gained in one part of the world has been known to experimenters elsewhere.

Although this book is, in other respects, strictly devoted to aviation—that is to say, to the branch of aeronautics that is related to aeroplanes as distinct from airships—it is inevitable that the development of both kinds of aerial navigation should come under review in any attempt to record the earlier history of man's invasion of the air. To ignore the coming of the balloon would be to leave unmentioned the first great stimulus of success that did so much to encourage others to work along the parallel line of research that ultimately led to the evolution of the aeroplane. Nevertheless, out of respect for the scope of the present book, the digression from aviation into aerostation has been limited to a single chapter giving only so much as seems of particular interest relating to this connecting link.

The more significant years in the history of flight run somewhat as follows. In 1848 Stringfellow first succeeded in demonstrating horizontal flight with a self-propelled model. From 1891 to 1896 Lilienthal made his gliding experiments, and was the first really to persevere in the systematic practice of the art of riding the air. In 1903 the Wrights, after three years' gliding and research, built and successfully flew their engine-driven aeroplane, which was the first practical flying machine that had ever been made.

That event happened ten years ago at the time of writing (1913). The intervening period is divisible into two parts. From the end of 1903 to the beginning of 1908 forms the first part: it was a preparatory period for the subsequent development that took place with such phenomenal rapidity.

The year 1908 was the great year in the annals of aviation, for the activities of that period constituted the real starting-point of modern advance. In January, Farman won the Grand Prix for the first circular flight accomplished under official observation. Wilbur Wright, whose work was previously but little known, flew in France during the summer of that year, and greatly encouraged others by his ability.

In 1909 Bleriot flew across the Channel. In 1910 Paulhan flew from London to Manchester. In 1911 there was the historic flight round Britain, in which Lieut. Conneau and Vedrines competed so strenuously. In 1912 the Military Aeroplane Trials on Salisbury Plain afforded concrete evidence of the first of the useful purposes for which the aeroplane is destined.

In the recording of history, it is undeniably difficult to know what to leave out, yet it is essential that much should be omitted, not only for lack of space, but in order that the mind may not be confused with many details that occupy no proper place in the sequence of events although meritorious enough in themselves. In what follows, I have endeavoured to hold the scales as justly as my knowledge of the circumstances will permit.

CHAPTER XVIII

ROMANCE AND EARLY HISTORY

Birds as an inspiration to man—Leonardo da Vinci as a designer—A bishop as an inventor—The impossibility of man-flight.

HAVING discussed the flying machine as at present it exists, and having detailed both its principles of action and the work of those more directly responsible for its success, it will be easier to appreciate in their proper light the early efforts of those who by slow degrees prepared the way for the accomplishments of the present age.

From a profusion of fable and myth, little of which, with the exception of the story of Icarus, has even become classic, it is difficult to select a suitable starting-point in antiquity from which to reconstruct anything in the nature of a chronological history of aeronautics. There is not the least doubt that man wanted to navigate the air from the earliest times, and it also appears that the two branches of the art, which are now related to the use of dirigibles and aeroplanes, were at first chosen indifferently as plausible fields wherein to seek a solution of the problem.

It should be recognized, however, that the fundamental idea of navigating the air by balloons is properly to be regarded as having been a more advanced thought in those days than the idea of flying, for in birds man had, from the very beginning, a visible example of the conquest of the air, and it was only natural that he should see in the imitation of their actions the first and brightest prospect of realizing his desire.

On the other hand, it would be a mistake to say that aviation was the only field of early thought, for several of the ancient, if probably unreliable, tales suggest buoyancy rather than dynamic support of the machines that are said to have flown. Thus, even in that very early legend, which dates back to 400 B.C., of Archytas, a philosopher of Taranto, who "constructed a wooden pigeon, which could fly by mechanical means. To wit, it was thus suspended by balancing, and was animated by an occult and enclosed aura of spirit,"[1] there is as much suggestion of flotation by means of some light gas as there is of sustentation by dynamic force.

Little profit, however, is to be gained by laborious inquiry into such very vague details, and indeed we may pass without hesitation to the well-known name of Leonardo da Vinci (1452–1519) as the first whose interest in the subject is authenticated by records that are still extant. The fertile mind of this many-sided genius sought to solve the problem by the design of a man-operated machine, but although it would be permissible to smile at such an idea if suggested in the light of present-day knowledge, it must be remembered that in da Vinci's time no engines were in existence, consequently anyone who thought of flying had necessarily to suppose that it could be achieved by his own muscular exertions.

Leonardo da Vinci's claim to fame is due to the fact that he was the first to prepare drawings representing definite ideas of how the artificial wings should be constructed and attached to the human body. His machine called for the use of the legs as well as the arms of the operator. It did not, of course, ever come to anything, but it is well worthy of note that his drawings are at least two centuries earlier than any other authentic record of a definite, even if impracticable, scheme for a flying machine.

The main interest in these earlier ideas lies primarily in the evidence that they bear of their author's conviction of the ultimate achievement of flight. The names of men who made public their notions on the subject deserve—especially when, like da Vinci, they had already established themselves in fields of orthodox work—to be handed down

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[1] Aulus Gellius, *Noctes Atticæ*, Lib. X, Cap. XII.

to posterity, for in those times ridicule was neither the only nor the least of the penalties liable to be suffered by men of advanced minds. It may be assumed that da Vinci's ideas were known to men of his own time, but it is important to observe that his writings could have had no influence on subsequent thought, for his manuscript and sketches were never published until more than three centuries afterwards.

Towards the end of the seventeenth century the navigation of the air was again brought forward by Francis Lana (1670), John Wilkins (1672), Besnier (1678), and Borelli (1680). Of these, the first mentioned, Francis Lana, a Jesuit priest, applied his knowledge of physics and mathematics to a quantitative analysis of the problem of the balloon. He was, it seems, the first to obtain a concrete idea of the requirements, and although his suggestion to use copper vacuum globes was, and still is, impracticable for mechanical reasons, it was, like da Vinci's, a definite conception. In any case, the fact that his calculations were sound in principle, besides being the earliest of their kind, gives Francis Lana an unquestionable claim to be remembered. Had Lana's vows of poverty not prevented him, he would have devoted money towards the practical application of his investigations on the subject, and in his writings he makes a touching appeal for someone to put his ideas to the test.

John Wilkins, Bishop of Chester, reviewing the subject of aerial navigation in his *Dedalus*, gave it as his opinion that a flying chariot having wings operated by some sort of spring offered the best chances of success. The importance of this reference lies in the suggestion that a spring should be used, for a spring in those days was about the only sort of mechanical prime mover known to civilization. John Wilkins, in having advocated its use, would thus appear to have been the first to appreciate the necessity of employing an engine to achieve flight. There is no account of the Bishop of Chester having made any practical experiments to corroborate his views on the subject.

Besnier, whose name will invariably be found in references to early ideas on flying, may be said to have obtained his fame through the Press, for his principal achievement seems to have been the publication of a design for a man-operated flying machine in the *Journal des Savants* of 12 December, 1678. His proposal was crudely simple and quite impracticable. It served, however, the useful purpose of drawing attention to this aspect of the subject again, and thereby of giving a point to the argument of J. A. Borelli, as set forth in his *De Motu Animalium*, published in Rome in 1680. This Neapolitan scientist discussed the flight of birds, and deduced from their anatomy that it would be impossible for a man to fly artificially by means of his own energy.

✓ Lib

Coming from such a source at a time in the world's history when there was no sort of engine other than a spring, this dictum of Borelli's was generally regarded as being, in effect, a statement that flight was impossible. His verdict appears to have been very generally known, and this expanded version of it was no doubt received with considerable favour by those people whose narrow minds lead them to regard any thought on such a subject as flying as a mere waste of time, if not as positive proof of insanity. The damping effect of Borelli's views on students of flight lasted for a long time after his death, for the subject of aeronautics appears to have been dropped for at least a century; it is interesting to observe, moreover, that Borelli's deductions on the inadequacy of man's muscular power to achieve flight still hold good.

Most flyers, even of later times, found it easier to lose money on the art than to practise flying to their own profit, so it may not be without interest to put on record the name of a man who in all probability was the first to obtain any material advantage from his connection with the subject. On 17 April, 1709, the King of Portugal made out the following order, in favour of a certain friar, Bartholomew Laurence de Gausman: "Agreeably to the advice of my Council, I order the pain of death against the transgressor. In order to encourage the suppliant to apply himself with zeal towards improving the new machine, which is capable of producing the effects mentioned by him, I grant unto him the first vacant place in my college of Barcelos or Santarem and the first Professorship of Mathematics in my University of Coimbra, with the annual pension of 600,000 reis during his life. Lisbon, 17th April, 1709."

What records there are of de Gausman's machine speak of the use of the attractive force of magnets and of pieces of amber, and in general reveal the inventor thereof to have been a visionary at the best, albeit one who introduced his impossible projects to some purpose, if he ever really obtained his post and his pension.

CHAPTER XIX

THE COMING OF THE BALLOON

Cavendish and hydrogen—The ingenious Dr. Black—The Montgolfiers and smoke—Pilatre de Rozier, pioneer pilot.

IN spite of legends to the contrary, it is extremely doubtful if any serious practical experiments on the navigation of the air had ever been made up to the beginning of the eighteenth century, nor would there seem to be any real likelihood of doing an injustice to anyone if we skip another half-century from the date of the closing record of the last chapter. By so doing we arrive at the time when Henry Cavendish made the civilized world acquainted with the existence of an extremely light gas that he called "inflammable air," but which we now know as hydrogen.

At this point it is impossible to do better than to quote the following passages from *The History and Practice of Aerostation*, written by Tiberius Cavallo, F.R.S., in 1785, less than twenty years from the date (1766) when Cavendish made known his researches in the 56th volume of the *Philosophical Transactions*.

"Soon after this discovery of Mr. Cavendish, it occurred to the ingenious Dr. Joseph Black, of Edinburgh, that a vessel might be made, which, when filled with inflammable air, might ascend into the atmosphere, in consequence of its being altogether lighter than an equal bulk of common air. This idea of the doctor's has been mentioned to me by two or three different persons. But . . . it appears that Dr. Black never actually tried the experiment ; nor do I know that any other person attempted it, before my experiments on this subject, which were made in the year 1782. The possibility of constructing a vessel, which, when filled with inflammable air, would ascend into the atmosphere had occurred to me when I first began to study the subject of air and other permanently elastic fluids, which was about eight years ago; but early in the year 1782 I actually attempted to perform this experiment; and the only success I had was to let soap balls, filled with inflammable air, ascend by themselves rapidly into the atmosphere, which was perhaps the first sort of inflammable air balloon ever made. I failed in several other attempts of a like nature; and, at last, being tired of the expenses and loss of time, I deferred to some other time the prosecuting of those experiments and contented myself with giving an account of what I had done to the Royal Society, which was read at a public meeting of the Society on the 20th June, 1782."

It may seem rather strange, having regard to what had gone before and what was to come, that the demonstration of the principle of buoyancy in air should have been viewed with such apparent apathy by men like Black and Cavallo, but it is extremely characteristic of the strictly limited interest that is often displayed by those who occupy pinnacles of their own special sciences. Here, in the discovery of hydrogen, was a means of overcoming the one practical disadvantage of the scheme proposed by the worthy friar Lana, whose copper globes would have been crushed out of all recognition long before they were exhausted to a degree sufficient for self-support. In Lana's day, however, no one knew of any sort of gas that was lighter than air with which the globes might have been filled, so that Lana really made the only suggestion that was possible, having regard to the limited knowledge of the period.

Thus matters stood in 1782, and the public at large remained totally unconscious of the means by which air had been brought within prospective invasion. Science had succeeded in leading man to the very threshold of the kingdom he desired to conquer, and yet he must needs have the assistance of an accident to enable him to set foot within the aerial world that was in due course to become his.

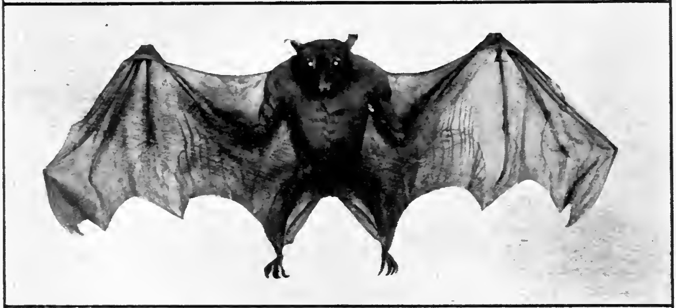
The historical experiments of the brothers Montgolfier are familiar to all, but it is not so generally recognized that although their balloon was essentially a premeditated invention, the true principle upon which it entirely depended for its success was a subsequent discovery, and to this extent the success of these experiments may be said to have been accidental. The Montgolfier balloons lifted themselves in the atmosphere because they were full of hot air, which is lighter than cold air, but Montgolfier imagined that the effect was caused by the smoky "substance" produced by the fires over which the balloons were inflated. The use of heat, which was incidental to the production of the desired smoke, thus appears to have been quite an accident, although, as a matter of fact, it was, of course, the sole cause of the successful result.

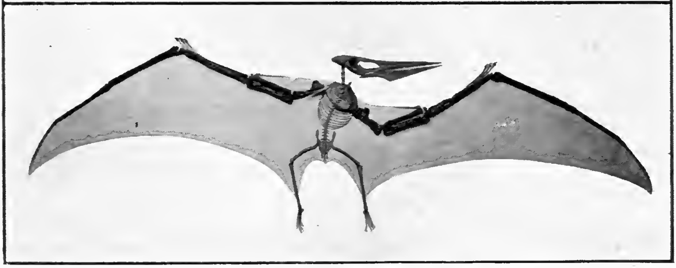
It is indeed strange that this truth should have remained unrecognized for so long, not only by the Montgolfiers, but by the scientists of the day; in fact it is somewhat remarkable that men should have been blind to this simple solution of the problem through all those years, seeing that the ascensional force of hot air is visibly demonstrated in many natural phenomena of daily occurrence. To any student of evolution the situation is not without its lesson—the picture of man forced to find the simple beginning among the things ready to hand, by being persistently denied success in his initial efforts to commence in those heights whither his imaginative mind so delights to wander. It is a point well worthy of reflection that there was scarcely a period in history when some form of hot-air balloon might not have been devised with reasonable success.

Popular belief is that the Montgolfiers were attracted to devote themselves to a study of the subject as the result of having read Dr. Priestley's *Experiments Relating to Different Kinds of Air*, and the traditional story of their invention of the hot-air balloon is that they observed the buoyancy of clouds in the atmosphere, and thought that they might reproduce the phenomenon by the aid of some corresponding cloudy substance that they might be able to manufacture. It occurred to them that smoke might be suitable, and according to Cavallo's history, "Stephen Montgolfier, the elder of the two brothers, made the first aerostatic experiment at Avignon, towards the middle of November, 1782. The machine consisted of a bag of fine silk, in the shape of a parallelopipedon, the capacity of which was equal to about 40 cu. ft. Burning paper applied to its aperture served to rarefy the air, or to form the cloud; and when this was sufficiently expanded, the machine ascended rapidly to the ceiling. Thus the discovery was made; and the reader may imagine the satisfaction it must have given the inventor." The successful result of this experiment is referred to in a report of the Academy of Sciences, dated 23 December, 1783, and signed by several members.

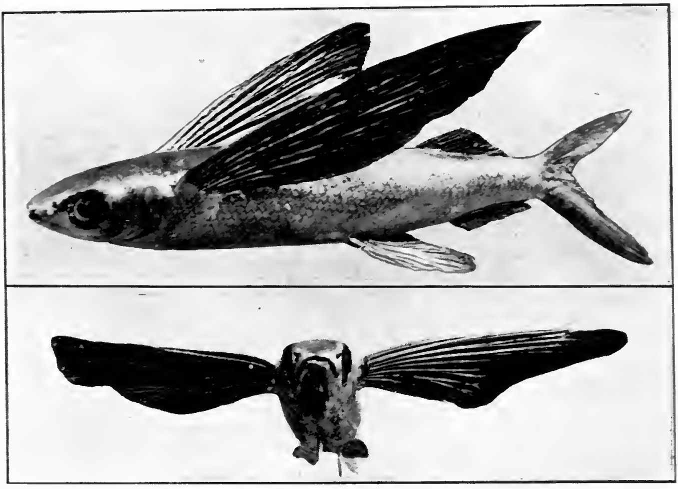
Having returned to their home at Annonay, situated about 36 miles from Lyons, the Montgolfiers proceeded to repeat the experiment in the open air. Encouraged by the success of their efforts, they then constructed large spherical paper-lined linen bags, one of which having a diameter of 35 ft. ascended to a height of about 1000 ft. on 25 April, 1783, and travelled a distance of about three-quarters of a mile before, the hot air being cooled, it settled to earth. Another experiment with the same balloon was repeated in public on 5 June, 1783, and as this really marks the birth of general interest in aerial navigation, Cavallo's account of the details is here reproduced:

"On Thursday, 5th June, 1783, the States Vivarais, being assembled at Annonay, MM. Montgolfier invited them to see their new aerostatic experiment. An immense bag of linen, lined with paper, and of a shape nearly spherical had its aperture, which was on its inferior part, attached to a wooden frame of about 16 ft. surface, upon which it lay flaccid like an empty linen bag. When this machine was inflated, it measured 117 English feet in circumference. Its capacity was equal to about 23,430 cubic ft.; and it had been calculated, that when filled with the vapour proper for the experiment, it would have lifted up about 490 lb. weight, besides its own weight, which, together with that of the wooden frame, was equal to 500 lb., and this calcula-





1. A Moluccan fox bat exhibited at the Natural History Museum, South Kensington.
2. A Collard fox bat exhibited at the Natural History Museum, South Kensington.
3. A pteranodon occidentalis from the chalk of Kansas, U.S.A. Model of a restoration exhibited at the Natural History Museum, South Kensington.



"Flight" Copyright Photos

Types of flying fish at the Natural History Museum, South Kensington. The upper photograph shows the exocetus cahiensis which inhabits the Atlantic Ocean. The lower photograph is a specimen of the exocetus spilapterus from the Indian Ocean.

tion was found to be pretty true by experience. The bag was composed of several parts, which were joined together by means of buttons and holes; and it is said that two men were sufficient to prepare and fill it; though eight men were required to prevent its ascension when full.

"MM. Montgolfier began the operation of filling the machine, which was done by burning straw and chopped wool under its aperture; and the spectators were told that this bag would be soon swelled into a globular form, after which it would ascend by itself as high as the clouds. The expectations of the whole assembly, the incredulity of some, the predictions of others, and the confusion of opinion, may be easily imagined, especially by those who had been present at experiments of this nature when the certainty of the success had been well established. The machine, however, immediately began to swell, it soon acquired a globular form, stretched on every side, made efforts to mount, and at last, the signal being given, the ropes were set free, and the aerostat ascended with an accelerated motion into the atmosphere; so that in about ten minutes' time it had reached the height of about 6000 ft. The discordant minds of the spectators were instantly brought to an equal state of silent astonishment, which ended in loud and unfailing acclamations, due to the genius, and mostly to the success of Stephen and John Montgolfier.

"The aerostatic machine, after having attained the above-mentioned elevation, went in a horizontal direction to the distance of 7668 ft. and then fell gently on the ground."

Montgolfier's success with his hot-air balloons succeeded in arousing the scientists of the day to an appreciation of the necessity for experimenting in a determined way with hydrogen. Although they were unaware of the commonplace character of what was then called "Mr. Montgolfier's gas," they had been sufficiently interested to find out by experiment that it could not possibly be the same thing as the inflammable air (hydrogen) with which they were already familiar in their laboratories.

Having remarked that this smoky substance was not nearly so light as hydrogen, they came to the very natural conclusion that the use of inflammable air in its place ought to give proportionately better results, and it was thereupon decided, in Paris, to experiment on a practical scale. The expenses of such an undertaking being heavy, a subscription to defray them was opened by M. Faujas de St. Fond, and the brothers Robert received a contract to construct a balloon under the superintendence of M. Charles, a professor of experimental philosophy. In due course, a ball-like bag (from which shape the term balloon is derived) was constructed of silk varnished with rubber solution. The diameter of the balloon was about 13 ft., and its weight, together with a stop-cock attached to the aperture, was 25 lb. The first attempt at inflation took place on 23 August, 1783, the hydrogen being generated from a mixture of iron filings and vitriol contained in "an odd sort of an apparatus, somewhat like a chest of drawers, lined with sheet lead, every one of the drawers communicating with a common pipe, to which the stop-cock of the balloon was adapted."

After working all day and experiencing innumerable difficulties that will at once suggest themselves to the minds of chemists, the experimenters only succeeded in inflating their balloon about one-third full, and it was not until 27 August that it was at last made ready for the public ascent, which successfully took place in the Champ de Mars. The balloon rose to an altitude of 3123 ft., and descended after a voyage of three-quarters of an hour in a field near Gonesse, about 15 miles away. The lift of the balloon at the time of its release was 35 lb., and the envelope was discovered in a torn condition when picked up after its descent.

On 11 September, 1783, the first balloon having an envelope of gold-beater's skin was successfully launched. The substance was suggested by M. Deschamps to the Baron of Beaumanoir, who had a balloon made of several pieces of it glued together, so that the finished envelope was about 19 in. in diameter. This was followed by a general craze for toy balloons, and soon all Paris became more than familiar with the invention.

In the meantime, the Montgolfiers were engaged in the construction of an air balloon for demonstration before the Academy of Sciences, which was successfully made on 12 September, 1783, in a private garden belonging to M. Revillon, a paper manufacturer of Paris, and in all probability an old friend of the Montgolfiers, who were engaged in the same trade. Another demonstration took place before the King and Queen of France on 19 September, 1783, and on this occasion three animals—a sheep, a cock, and a duck—ascended with the balloon as the first living passengers.

Thus far no man had attempted to make an ascent, and it remained for M. Pilatre de Rozier, who publicly offered himself to be the first adventurer, to have this distinction. Of the details of the event, which took place on 15 October, 1783, Cavallo gives the following account :

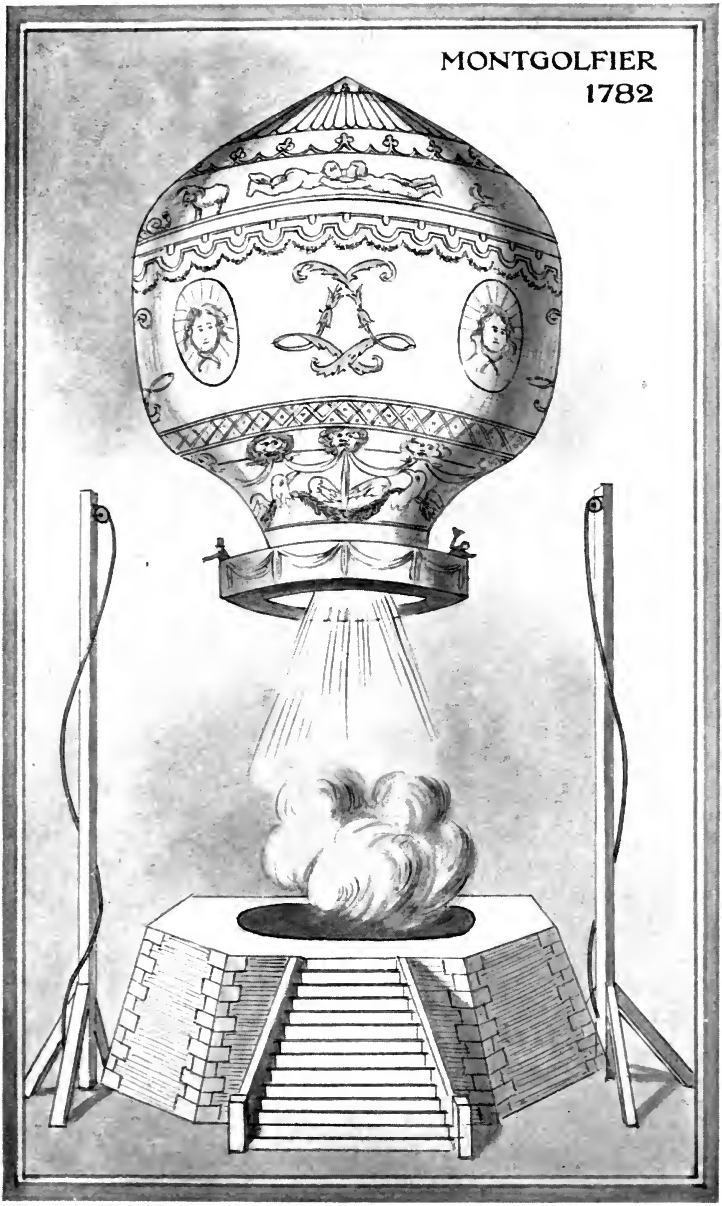
> " The accident which happened to the aerostatic machine at Versailles, and its imperfect construction, induced Mr. Montgolfier to construct another machine of a larger size, and more solid. With this intent, sufficient time was allowed for the work to be done ; and by the 10th October, 1783, the aerostat was completed, in a garden in the Fauxbourg St. Antoine. It had an oval shape, its diameter being about 48 ft., and its height about 74. The outside was elegantly painted and decorated with the signs of the zodiac, with cyphers of the king's name, fleurs-de-lis, etc. The aperture or lower part of the machine had a wicker gallery about three feet broad, with a balustrade both within and without, about three feet high. The inner diameter of this gallery, and of the aperture of the machine, the neck of which passed through it, was near 16 ft. In the middle of this aperture an iron grate, or brazier, was supported by chains, which came down from the sides of the machine. In this construction, when the machine was up in the air, with a fire lighted in the grate, it was easy for a person who stood in the gallery, and had fuel with him, to keep up the fire in the mouth of the machine by throwing the fuel on the grate through port-holes made in the neck of the machine. By this means it was expected, as indeed it was found agreeable to experience, that the machine might have been kept up as long as the person in

its gallery thought proper, or whilst he had fuel to supply the fire with. The weight of this aerostat was upwards of 1600 pounds.

"On Wednesday, the 15th October, this memorable experiment was performed. The fire being lighted, and the machine inflated, Mr. Pilatre de Rozier placed himself in the gallery, and, after a few trials close to the ground, he desired to ascend to a great height; the machine was accordingly permitted to rise, and it ascended as high as the ropes, which were purposely placed to detain it, would allow, which was about 84 ft. from the ground. There Mr. de Rozier kept the machine afloat during 4 minutes and 25 seconds, by throwing straw and wool into the grate to keep up the fire: then the machine descended exceedingly gently; and such was its tendency to ascend, that after touching the ground, the moment Mr. de Rozier came out of the gallery, it rebounded up again to a considerable height. The intrepid adventurer, returning from the sky, assured his friends and the multitude, which had gazed on him with admiration, with wonder, and with fear, that he had not experienced the least inconvenience, either in going up, in remaining there, or in descending: no giddiness, no incommoding motion, no shock whatever. He received the compliments due to his courage and activity; having shown to the world the accomplishment of what had been for ages desired and attempted in vain."

In subsequent captive balloon ascents of the same nature Pilatre de Rozier was sometimes accompanied by a passenger, the first of whom was M. Girond de Villette, the second being the Marquis d'Arlands. As the result of these numerous successful experiments the French Academy of Sciences printed and publicly published a report of them, and awarded a certain annual prize at its disposal, valued at 600 livres, to MM. Montgolfier for the year 1783.

Although this most memorable year 1783 was drawing to a close, it was not destined to pass before the new art that it had so auspiciously ushered into the world had culminated in an aerial voyage, which event took place on 21 November, 1783, when M. Pilatre de Rozier and the Marquis d'Arlands were again the aeronauts. The balloon



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A MONTGOLFIER AIR BALLOON OF 1783

The passengers were accommodated in a gallery surrounding the orifice.

employed was that in which they had already made their captive ascent, and the whole weight of the machine and travellers was between 1600 and 1700 lb.

According to Cavallo,

> "The aerostat left the ground at 54 minutes past one o'clock, passed safely over some high trees, and ascended calmly and majestically into the atmosphere. The aeronauts having reached an altitude of about 280 ft. took off their hats and saluted the surprised multitude. They then rose too high to be distinguished, so that the machine itself was scarcely distinguishable. When they rose, the wind was very nearly north-west, and it is said that the machine in rising made half a turn round its own axis. The wind drove them horizontally over the River Seine and over Paris. They passed between the Hôtel des Invalides and Ecole Militaire and approached St. Sulpice, but as they were rather low the fire was increased in order to clear the houses, and in rising higher they met with a current of air which carried them southward. They passed the Boulevard ; and at last, seeing that the object of the experiment was fully answered, the fire was no longer supplied with fuel and the machine descended very gently in a field beyond the new Boulevard about 9000 yards distant from the Palace de la Muette, which distance they ran in between 20 and 25 minutes' time."

Writing to M. Faujas de St. Fond afterwards, the Marquis d'Arlands refers as follows to one or two of the incidents *en route*.

> " At this time M. Pilatre said, ' You do nothing and we shall not mount.' ' Pardon me,' I replied. I threw a truss of straw upon the fire, stirring it a little at the same time, and then quickly turned my face back again, but I could no longer see la Muette. Astonished, I gave a look to the direction of the river. M. Pilatre then said, ' Behold, there is the river and observe that we descend.' ' Well, then, my friend, let us increase the fire,' and we worked away. . . ."

As is not infrequently the case in connection with developments of new movements in England, the news of the Montgolfiers' experiments failed to arouse any immediate activity in this country, but in November, 1783, an Italian, Count Zambeccari, who happened to be in London, made a balloon of oiled silk, 10 ft. in diameter, weighing 11 lb. It was inflated three-quarters full with hydrogen, and released in public from the Artillery Ground on the 25th of that month, having been exhibited for several days previously. It fell at Graffam, near Petworth, in Sussex, 28 miles distant from London, where it was picked up 2½ hrs. after the ascent.

In the same month of the same year the *Journal de Paris* opened a subscription to defray the expenses of constructing a hydrogen passenger balloon, then being built by the brothers Robert. This balloon, when finished, had a diameter of 27 ft., and the total weight, including the car, was 130 lb.; the lifting effect of the hydrogen that it contained was 604½ lb. An ascent was made on 1 December, 1783, M. Charles and one of the Roberts being the aeronauts. The descent occurred in a field near Nesle, about 27 miles from Paris. After M. Robert had left the car, M. Charles made a reascent, and probably attained an altitude of 10,500 ft., at which elevation he suffered from the cold and also from pain in the ears. The voyage lasted about 33 min., and was concluded by a successful descent in a ploughed field near the wood of Tour du Lay.

Early in 1784 the Montgolfiers finished the construction of a large balloon having a diameter of 104 ft., which ascended on 19 January from Brotteaux, near Lyons, with seven passengers. A rent in the envelope forced a rather hazardous descent some 15 min. after the start, but no one was hurt. In February of this year a free hydrogen balloon, unmanned, was launched from Sandwich in Kent, and was blown across the Channel into France, and in the same month a new aeronaut, M. Blanchard, destined to become famous in connection with a similar journey, made his appearance in Paris. Balloon ascents at this time were becoming common in France, and four ladies, the Marchioness and the Countess de Montalembert, the Countess de Podenas and Mademoiselle de Lagarde, made an ascent in a captive Montgolfier on 20 May, 1784.

According to a letter dated from Edinburgh 27 August, 1784, and published in the London *Chronicle*, a Mr. Tytler would appear to have been the first person to ascend in a balloon in Great Britain. The event is reported to have taken place on the morning of that day at Comely Garden, and to have resulted in a journey of about half a mile.

On 15 September of the same year an Italian, Vincent Lunardi, ascended from the Artillery Ground, London, with a hydrogen balloon 33 ft. in diameter. The event was successful, except in so far as the lift of the balloon was insufficient to enable a Mr. Biggin to travel as passenger. Lunardi made a temporary descent on the common of South Mimms, where he landed a cat that he had taken as a companion, together with a dog, and a pigeon; the final descent was made near Ware, in Hertfordshire. A feature of this voyage, which had also characterized some of those made by Blanchard, was an attempt to manœuvre the balloon by means of oars.

The next voyage in England took place on 16 October, when M. Blanchard made an ascent accompanied by Mr. Sheldon, professor of anatomy at the Royal Academy. In the meantime, the Roberts had achieved a voyage of 150 miles in France. On 30 November, 1784, Blanchard made another ascent in England, and was this time accompanied by an American, Dr. Jeffries, who subsequently attained to still greater prominence by crossing the Channel with Blanchard on 7 January, 1785.

Of both voyages Dr. Jeffries published his own narrative, and that relating to the Channel crossing is especially entertaining. It appears that Dr. Jeffries undertook to defray the expenses, and in addition bound himself, by an agreement with Blanchard, to jump overboard in case of necessity. An aspect of the impending experiment that it is difficult to appreciate at the present day, was the attitude of the general public towards the two pioneers. It appears that busybodies did all they could to persuade Dr. Jeffries to abandon the attempt, and in the end he had to apply to the Governor of Dover Castle for assistance to carry out his plan. January 7 being a fine day, a start was made at 1 o'clock, the balloon lifting 30 lb. of sand ballast, in addition to the passengers. Half-way across the Channel they had to throw overboard 15 lb. of ballast, and shortly afterwards the remainder was jettisoned, together with a bundle of pamphlets. More pamphlets, together with various little articles of ornament, also had to be thrown overboard, and among the latter was a bottle, about which Dr. Jeffries relates the following curious incident : " After which we cast away the only bottle we had taken with us, which, in its descent, appeared to force out a considerable steam, like smoke, with a hissing or rushing noise ; and when it struck the water we very sensibly (the instant before we heard the sound) felt the force of the shock on our car ; it appearing to have fallen directly perpendicular to us, although we had passed a considerable way during its descent."

Even thus the natural laws of gravitation were not appeased, and after casting away everything they could lay their hands on, " we began to strip ourselves, and cast away our clothing, M. Blanchard first throwing away his extra coat with his surtout ; after which his other coat and trousers ; we then put on and adjusted our cork jackets, and prepared for the event." But, happily for them, the " event " never took place, for just at the last moment the balloon ascended sufficiently to carry them over the French coast and deposit them in the forest of Guines, in Artois.

Here the two aeronauts met with a very enthusiastic reception, and Blanchard was not only presented by the French Government with a sum of 12,000 livres, with a pension annexed of 1200 livres per year, but as a perpetual memorial of this event, the place was to be called by his name.

This crossing of the Channel may be said to have demonstrated the application of the balloon to the kind of travel that has always been more particularly associated with aerial navigation, and at this point we may leave the progress of aerostation. The art increased in popularity, but no very remarkable development took place in the design and construction of balloons, those made by the brothers Robert having had, from the first, most of the essential features of a good aerostat.

CHAPTER XX

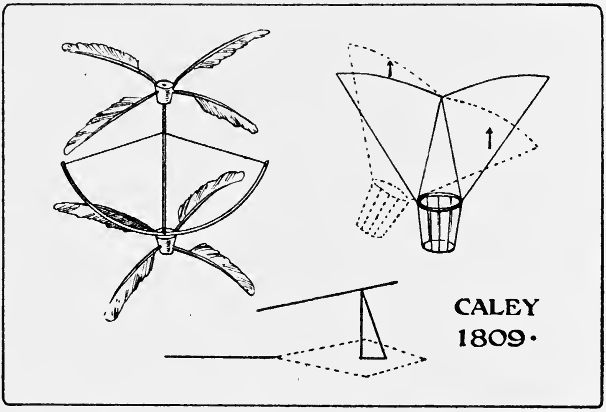
THE FOUNDING OF THE SCIENCE OF FLIGHT AND THE DEVELOPMENTS IN ENGLAND FROM 1809–1893

The toy helicopter—Sir George Cayley's calculations—Henson and Stringfellow's power-driven models—The Aeronautical Society of Great Britain—Phillips and the dipping front edge—Maxim's great machine.

THE invasion of the air by static means naturally reawakened interest in the dynamic side of the problem, and within a year of the first balloon ascent the French Academy of Scientists were invited, in 1784, to witness the ascent of a toy helicopter constructed by Launoy and Bienvenu. The device consisted of two propellers formed by feathers stuck into corks, which were rotated by means of a spindle operated by a string that was unwound by a bow.

An English scientist, Sir George Cayley, repeated this experiment in 1796 with a similar apparatus, a sketch of which was included in an article that he wrote on Aerial Navigation for *Nicholson's Journal* in 1809. It is interesting to observe that the helicopter or direct-lifting screw was, apparently, the first conception of a dynamic flying machine among most scientists of this period. As a toy it was successful from the first, but on a large scale it has been a failure, although there have not been wanting enthusiasts who have spent time and money on attempts at its perfection. It would be out of place here to enter into a technical examination of the causes that have been uppermost in preventing success, but there is one point that appears to have escaped the notice of advocates of the helicopter principle, which is that the difficulties of navigating the air would in all probability be as great, if not greater, with a machine of this type, even supposing the initial problem of effecting a vertical ascent into the air to have been satisfactorily solved.

Twelve years after these experiments, in 1808, a curious thing happened, which had a very important effect in bringing the subject of aviation to the fore in England, and incidentally in establishing Sir George Cayley as the founder of aerodynamic science. There was a certain Viennese watchmaker, named Degen, who decided to abandon his trade for the pursuit of aeronautics, and being imbued with the usual crude ideas of a flapping-wing machine, he attracted considerable attention at that time by appearing in public with a mechanism of this sort suspended beneath his balloon. Whatever may have been the effect of these attachments on the behaviour of the balloon, it is certain that he never succeeded in lifting himself off the ground by their aid alone. It happened, however, that a report to the effect that he had accomplished this feat became current, and was given publicity in *Nicholson's Journal* among other places. Among those who read and believed the account were Sir George Cayley and Thomas Walker, both Yorkshiremen, and both keenly interested in the subject of flight, although entirely unaware of each other's work.



"Flight" Copyright Sketches

Sketches used by Sir George Cayley to illustrate his articles in *Nicholson's Journal* in 1809. They represent a helicopter, a parachute, and an aeroplane with a tail.

Both were inspired by Degen's reported success to write treatises on the subject of aviation, but whereas Walker was mainly concerned with describing a man-operated flying machine of his own design, Cayley took a much broader and more scientific view of the whole subject.

Cayley lived in the era of steam. On his horizon the potency of the engine as the helpmate of man loomed large. Power-driven flying machines he considered to be theoretically possible so soon as an engine could be produced that would develop more power in proportion to its weight than man was capable of producing by muscular exertion. He considered that the steam plant of his day could be made, with certain modifications, to satisfy these requirements, and although in the light of present-day knowledge we are aware that it would have been practically impossible to have achieved success under the circumstances, this in no way destroys the merit of Cayley's own appreciation of the outlook. It is only by following chronologically and in detail man's attack on some specific problem, like flight, that we can properly appreciate the enormous importance of the more famous inventions. Everyone allows, of course, that the steam-engine revolutionized civilization, but such statements are regarded as mere platitudes nowadays, and so we tend to lack sympathy with earlier points of view. It is because the history of the conquest of the air throws so many interesting periods on to the screen that its study is thus full of fascination.

Cayley possessed a mind that would have tackled the problem of flight had he existed on earth a century before his time, and it is not difficult to realize with what avidity an intelligence of this order seized upon the possibilities of Messrs. Boulton and Watt's engine, nor to sympathize with the unique satisfaction Cayley must have felt in his realization that flight was theoretically possible with the means then available.

Not only did Cayley attempt to give a mathematical explanation of the action of the inclined flat plate in motion, but he also observed that birds' wings have cambered sections, and noted that in many instances the chord of a bird's wing in flight is horizontal, so that the front edge dips. From these data, crude though they were, Cayley made an estimate of the lift of a cambered plane for a specific speed; his figures were more or less in line with present-day values. He was the first to present aerodynamics in this well-ordered form, and there is no doubt whatever that he thoroughly deserves to be regarded as the father of the science.

Although a practical motor-driven, man-carrying aeroplane was an impossibility in Cayley's time, for mechanical reasons, there is little doubt, nevertheless, that had Cayley been urged by necessity he would have succeeded in demonstrating most of the principles of modern flight to the world at large, for it is, as was subsequently proved by later experimenters, possible to do this without the aid of an engine. Curiously enough, too, Cayley himself appears to have been on the threshold of gliding flight, but, like so many others who have been interested in aviation, he seems not to have recognized its entire significance. In his writings it is recorded that he built a large aeroplane, "large enough for aerial navigation," which would "sail majestically from the top of a hill to any given point of the plain below it with perfect steadiness and safety, according to the set of the rudder, merely by its own weight descending in an angle of about 8° with the horizon," and that "when any person ran forward in it with his full speed, taking advantage of a gentle breeze in front, it would bear upwards so strongly as scarcely to allow him to touch the ground, and would frequently lift him up and convey him several yards together."

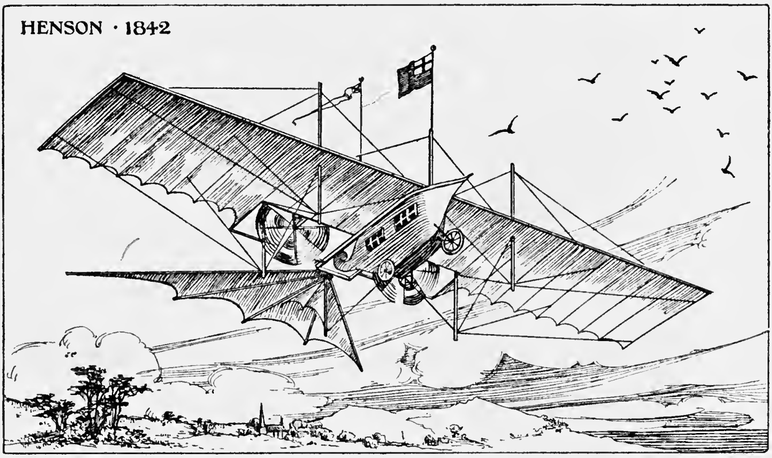
In Yorkshire the tradition is that it was either his gardener or his coachman who tried to pilot Cayley's flyer, and that he sustained a broken leg for his daring. From the above references it would scarcely appear as if any attempt was made to practise gliding as an art or as if the possibility of practising flying by means of a glider was realized. A gust may have occasionally lifted man and machine well clear of the ground, and one of the descents may, as seems to be believed in the county, have resulted in an accident, but it is very clear from Sir George Cayley's own writings that he regarded an engine as a *sine qua non* to the furtherance of useful experiments.

This was the point of view apparently of all pioneers up to the time of Montgomery and Lilienthal, and it is all the more interesting to reflect that just as in the case of the balloon, so in the development of the aeroplane would it have been possible to have constructed a successful glider at almost any period in the history of man.

Possibly motor-driven machines would have come to pass no sooner than they have done, but it is nevertheless instructive to reflect that aeroplane gliders might have been in use for centuries before any sort of engine was known. And if the braver spirits of those times had sought to emulate the soaring feats of birds, there is very little doubt that a man at the present day would be as much at home in the air as he is, for example, in water. Imagine for a moment what the present state of the art would have become if youths of preceding generations had been in the habit of varying their high-diving achievements into deep water with similarly bold attempts at launching themselves into the air from the same rocky eminence on the rigid pinions of a home-made glider. Very soon they would have become adepts in the art of control and manœuvring, and the more scientific would soon have learned the trick of making their machines naturally safe. By to-day we should all be flying as a matter of course.

Cayley himself found out many of these practical points in design. The rudder to which he refers was a movable horizontal tail plane, or what we should now call an "elevator," and he appreciated its use as a means of correcting the variations in the centre of pressure on the main planes. He also believed that dihedral wings (wings that slope upwards from the body) and an underhung load constituted features of natural stability. It would appear, therefore, as if Cayley was possessed of adequate theoretical and practical knowledge to build a successful man-carrying glider, and it is a profound pity that he did not fully realize the enormous importance of developing his machine along these lines. His own regret was that his machine was accidentally broken before there was an opportunity of trying the effect of any propelling apparatus, for, like every beginner, he had that intense desire to run before he could walk. In his case, however, this was more excusable, inasmuch as he was the first to have any plausible reason for even trying to run at all.

Even as it was, however, Cayley obtained such a thorough insight into the practical side of the subject as to have invented almost every leading feature that characterizes the modern aeroplane now in use over a century later. He suggested the cambered plane, the elevator tail, dihedral wings, and the ascentric position of the centre of gravity, which latter, however, is in little favour. Almost the only important features of the present-day machine that he did not discuss are the principles of superposed planes, high aspect ratio, and wing warping.



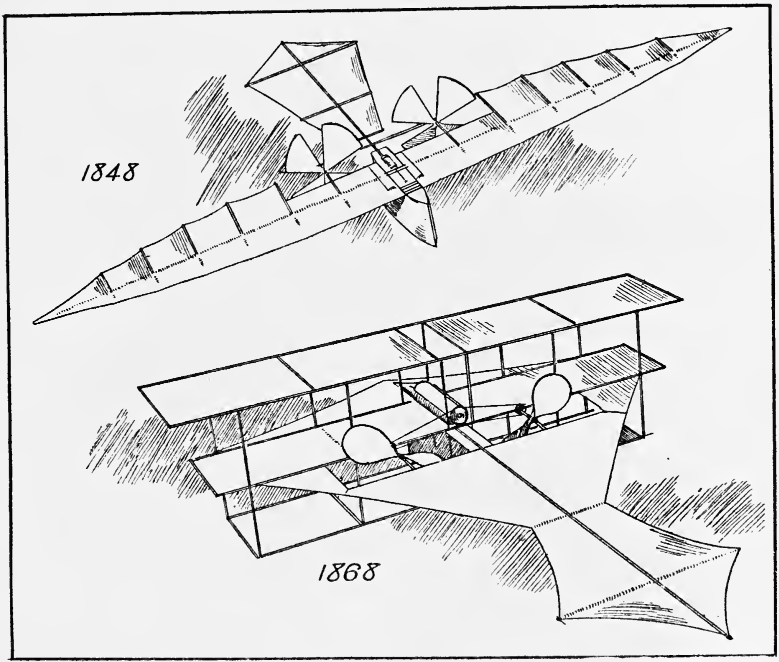
"Flight" Copyright Sketch from an old print

Sketch of the aeroplane proposed by Henson in 1842. There are many old prints still in existence showing this machine on its way to China and the like. It is interesting to compare the wing bracing with that used in what is generally known as the Antoinette type aeroplane.

From Cayley's time, the still undiscovered art of flying takes on an entirely different aspect, for Cayley's articles once and for all removed any further excuse for vague and visionary ideas. He laid down some very workable theories, and gave sufficient evidence of their practical value to make them most decidedly the proper lines for future development. There was an interval of over thirty years, however, before anything was done, but in 1842 another Englishman, W. S. Henson, filed a patent specification for "the aerial steam carriage," which contained designs for a monoplane of 4500 sq. ft. surface, and in March, 1843, Mr. Roebuck moved for leave to bring in a Parliamentary Bill to incorporate the Aerial Steam Transit Co. It was from Henson's patent drawings that the well-known old print, representing a monoplane in full flight to China, was prepared.

Henson was a resident of Chard, in Somersetshire, and in 1843 he joined J. Stringfellow, also a resident in the same place, and together they built models for experimental purposes. The first was one designed to be operated by a spring, and the second was a larger model of 20 ft. span, which was equipped with a small steam plant. In 1847 this large model was taken out on to Bala Downs for a trial, but proved unsuccessful. A copy of this machine can be seen at the South Kensington Museum, London, and it is worthy of inspection, owing to the remarkable similarity of its appearance with a typical monoplane of the present day.

In 1848 Henson left England for America, but J. Stringfellow continued to work alone, and early in the same year produced a model of his own design. This machine differed from the Henson design in having tapered wings of cambered section. Trials were made with it in a large empty hall measuring 22 yards in length, and the launching was effected by allowing the model to run along a horizontal wire. In this way free flights of about half the length of the room were frequently accomplished, many of them taking place in the presence of spectators. They are of the greatest historical importance, being the first actual demonstration of dynamic support with a power-propelled aeroplane, but the technical interest of Stringfellow's model lies principally in the lightness of the steam plant with which it was equipped, this in itself being quite a remarkable engineering feat. Thus was demonstrated the principle that Cayley had been the first to present to the public in the form of a logical argument, and a sustained flight on the part of a power-propelled aeroplane having been accomplished, it only remained to develop the same type of machine on a sufficiently large scale to carry a pilot. The successful achievement of this end occupied a period of many years.



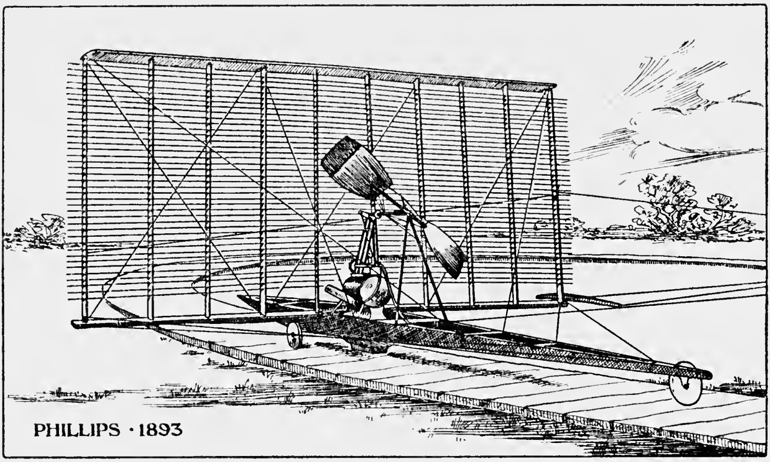
"Flight" Copyright Sketch

The upper sketch shows a model monoplane constructed by Stringfellow in 1848, after collaboration with Henson. It was fitted with a small steam-engine, and was the first power-driven model to make a free flight. It is now exhibited in the Victoria and Albert Museum. The lower sketch is an illustration of a model triplane built by Stringfellow and exhibited at the Crystal Palace in 1868. It was fitted with a light steam-engine, and demonstrations were made in the presence of King Edward VII, then Prince of Wales. Its flights were restricted by a suspension wire track, along which it travelled. Having been bought by Prof. Langley in 1889, it was removed to America, and is now exhibited in the Smithsonian Museum at Washington, D.C.

Eighteen years after Stringfellow's success, which of itself failed to arouse any very marked enthusiasm, presumably because those who were aware of it were unable to appreciate its importance, a definite movement was made toward the encouragement of aeronautics by the foundation of the Aeronautical Society of Great Britain in 1866. At this time there was considerable interest in the subject of ballooning for scientific purposes, due mainly to the work of James Glaisher, who had made several ascents in order to investigate the higher atmosphere. He and a few others were instrumental in founding the Society, of which he became the treasurer. The Duke of Argyll was about to publish his book, *The Reign of Law*, in which the flight of birds and the possibility of artificial flight were studied, and it was only natural that he should be offered the first Presidency of the Society. Other leading men of the day who supported the movement and became first Vice-Presidents were the Duke of Sutherland, Lord Richard Grosvenor and Lord Dufferin. Hatton Turner, who had just published his famous work, *Astra Castra*, was elected to the Council, which included Sir Charles Bright, William Fairbairn, and several other well-known engineers. Frederick Brearey was the first Honorary Secretary.

Of the founder members, perhaps the most prominent was F. H. Wenham, who read an address on Aerial Locomotion at the opening meeting of the Society held at the Society of Arts on 27 June, 1866. Wenham was an engineer by profession, and obtained his inspiration to study flight during a trip up the Nile seven years earlier. It was immediately on the return from this trip, that is to say in 1859, that he really wrote the paper for which he is principally famous. It can scarcely be said that Wenham really added much that was original to the knowledge of his time, but he did what is often more useful in laying emphasis on points that were apt to escape attention. In particular, he urged the importance of recognizing the advantages of high aspect ratio and superposed planes, both of which ideas had already found expression in the Henson and Stringfellow models, but had been ignored in Sir George Cayley's writings. Wenham's active work was mainly associated with the carrying out of certain early experiments on the lift and resistance of planes, under the auspices of the Aeronautical Society.

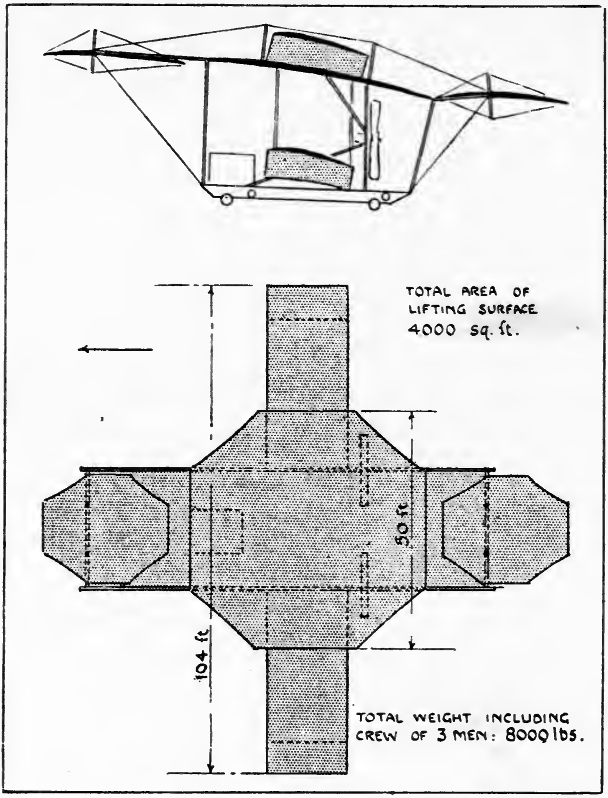
Among those whom the mere foundation of the Aeronautical Society inspired to energetic research in aviation was Horatio Phillips, then a youth who had just attained his majority, and had already been making model flyers for a couple of years or so. As is often the case, however, the effect of this public enterprise by others tended at first to induce a desire for secrecy in the mind of this young pioneer, who in 1870 fondly imagined that he was about to electrify the world with a successful flying machine in the form of a helicopter. The roseate hue of these earlier visions gradually faded in the inventor's mind as failure took the place of success in this particular direction, and when, having reverted to experiments with model aeroplanes, he was finally led to investigate experimentally the qualities of cambered sections, he likewise decided to give the world at large the benefit of his research. His first effort in this direction was the publication of an article



"Flight" Copyright Sketch from a photograph

Philips's multiplane, which was tested on a circular track at Harrow in 1893. It had numerous very thin planes arranged somewhat in the appearance of a venetian blind.

in *Engineering* on 14 August, 1885. From that day until the year 1900 Mr. Phillips kept up a regular correspondence with the journal in question, and nothing that he deemed of importance was withheld from those who might, but seldom did, make better use of the knowledge than himself.



"*Flight*" *Copyright Drawing*

Elevation and plan of Sir Hiram Maxim's aeroplane which was tried in Baldwin's Park, Kent, in 1893.

It will be remembered that Sir George Cayley was the first to draw public attention to the advantage of cambered sections, and to notice that they could be used with a horizontal chord, or in other words with a dipping front edge. It remained for Horatio Phillips, however, definitely to put this question on a scientific footing by means of his experiments, and it is certainly with his name that this feature of modern aeroplane wings ought to be associated, more particularly as he was distinctly the first to point out the advantage of having the maximum camber situated toward the forward edge of the plane instead of in the centre. Another point that showed how carefully Phillips had studied his subject was his advocacy of extremely high aspect ratios.

Putting these various principles into practice, he proceeded to build a large model multiplane somewhat resembling a venetian blind in appearance, with which experiments were conducted on a prepared circular track at Harrow in the early part of 1893. A report of a successful flight of this model, unmanned, appeared in *Engineering* of 10 March, 1893, and a still more successful experiment, resulting in a circular flight of 1000 ft., is recorded in the same journal of 19 May, 1893.

In the same year Sir Hiram Maxim carried out experiments at Baldwin's Park, in Kent, with a very large machine of 4000 sq. ft. surface, and on one occasion it broke away from its guide rails and made a short accidental flight with two of his mechanics on board. It is interesting to note that this machine was much the same size as that proposed by Henson in his original patent, and it is also instructive to observe that the characteristic arrangement of its surfaces is diametrically opposed to that of Phillips's machine, for whereas Phillips used a great number of planes, Maxim used very few. Sir Hiram Maxim also carried out independent experiments on lift and resistance of different sections, including cambered planes, and had generally studied various aspects of the problem of flight for several years before he commenced the construction of his large machine in 1889.

CHAPTER XXI

SOME PIONEERS ABROAD

THE INVENTION OF THE GLIDER

In France: Penaud—Tatin—Mouillard—Ader—In America: Langley—Montgomery—In Australia: Hargrave—In Germany: Lilienthal—The coming of the glider—Pilcher—Chanute—Herring.

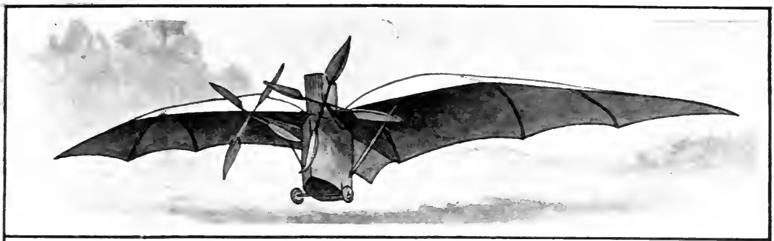
AT this stage we must transfer our attention once more to France, but it is a change of scene that can be made with the less regret inasmuch as practically the whole of the progress recorded in the previous chapter was originated and developed in England, and it represents without doubt the foundation of the science of flight.

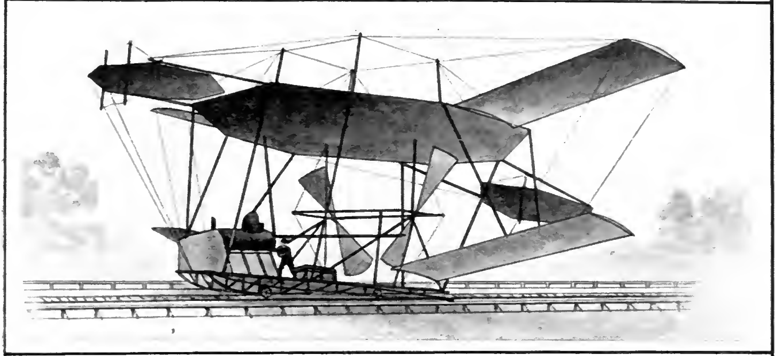
England, having viewed the enthusiasm of France over the balloon with almost unnatural apathy, seized hold of the problem of aviation with a characteristically tenacious grip, and for three-quarters of a century made the subject her own. Not that France had ignored the art; on the contrary, there were those across the Channel who had done excellent work, but in reviewing the history of a development like this it is always essential to temper strict chronological sequence with due regard to place as well as time. In these days the effect of distance has been eliminated so much by the telegraph that a man can scarcely walk backwards in his own garden but the Press hear of it, and give the news of his experiment to the world the next day. Twenty or thirty years ago, however, daily journalism was of an entirely different character from what it is at the present time, and there is at any rate very little evidence that the flight experiments in one country were in any way widely known to the pioneers of the same art in another. The contemporary influence of individual research is seldom very widespread until the subject in question has taken sufficient hold upon popular fancy to ensure a regular dissemination of such news in the periodicals of the time. And, even when flying became the talk of the day, it was sufficiently difficult to glean any sort of intelligent technical information from the majority of news that appeared in the general Press.

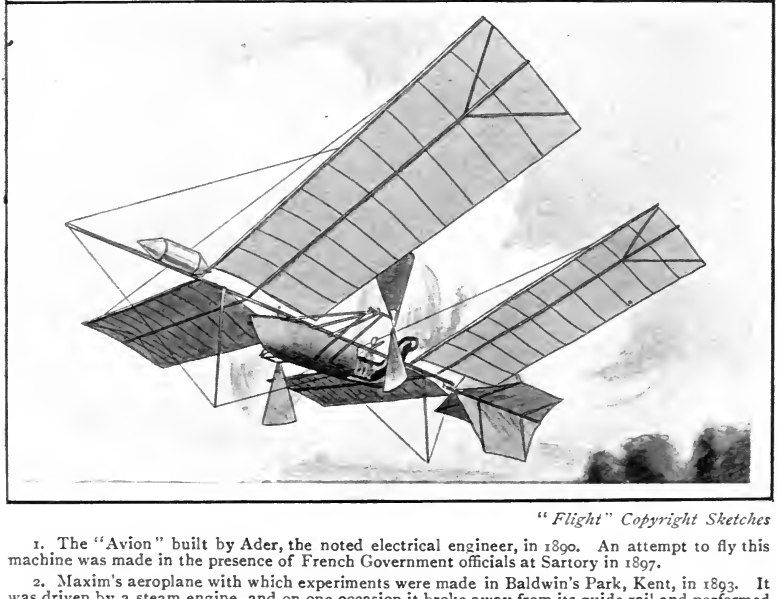
Much that is of undoubted importance took place in France during the period under review. In 1871 Penaud hit upon the idea of employing twisted elastic as a motor for small models, and his ingenious model monoplane of that date is the prototype of the toys that are so popular to-day. Merely as a toy, Penaud's invention has been of real service to the movement, but his models were also of great value to scientists who wished to make investigations on a small scale. A little later, in 1879, Victor Tatin drew public attention to the subject of aviation by making some experiments with a model aeroplane on a circular track in the Chalais Meudon riding school, and also about this time L. P. Mouillard was engaged on a somewhat similar line of research. These latter pioneers, however, mainly take their place on the roll of fame for their contributions to aeronautical literature, rather than for their practical work in the construction of flying machines.

The practical side of the subject is better revealed in the work of Ader, who experimented in comparative obscurity behind his fame as an electrical engineer. Ader built a very remarkable bat-like man-carrying monoplane, and with this he is said to have achieved, on 9 October, 1890, in the grounds of the Château d'Armainvilliers, a glorified jump of about 50 metres. In itself this was apparently a performance of somewhat the same order of importance as that achieved later by Maxim.

There is, however, one thing in particular that must always stand out prominently in connection with Ader's experiments, to the credit of the inventor and to the credit of France. The French Government of that day, true to the characteristics of the race as a society of encouragement, subsidized Ader in the furtherance of his work.







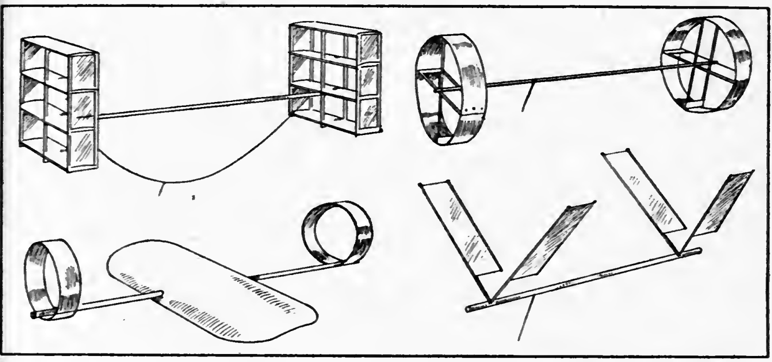
"Flight" Copyright Sketches

1. The "Avion" built by Ader, the noted electrical engineer, in 1890. An attempt to fly this machine was made in the presence of French Government officials at Sartory in 1897.

2. Maxim's aeroplane with which experiments were made in Baldwin's Park, Kent, in 1893. It was driven by a steam engine, and on one occasion it broke away from its guide rail and performed a short free flight.

3. S. P. Langley's No. 5 model tandem-type monoplane, which was flown with a small steam engine over the Potomac River, U.S.A., in 1896. A man-carrying machine of somewhat similar design was built for the American Government in 1903. It was twice disabled on launching, and the trials were abandoned. The second trial took place at Arsenal Point, near Washington, on December 8th. On December 17th of that year the Wrights made their first motor-driven flights.

Thus assisted, Ader built two more machines, with the second of which he made an official demonstration before a committee of army officers at Sartory on 14 October, 1897. The test was to fly round a circular track, and it is scarcely surprising that the inventor was unable to fulfil such a severe undertaking. On the other hand, Ader's machine is said to have risen from the ground and flown a distance of 300 metres, more or less in a straight line, before coming to earth. The delegates of the Government failed to take the broader view that the situation demanded, and their gloomy reports deprived Ader of further financial aid. It was a severe blow to the patriotic and enthusiastic Frenchman, who had from boyhood spent his leisure studying flight in nature and in pondering over the possibilities of the conquest of the air by artificial means. Moreover, as is unfortunately often true in such cases, the well-meaning caution of the authorities who decided Ader's fate exercised a damping influence on progress generally, for there is a marked hiatus in the development of flying in France after Ader's experiments came to an end.



"Flight" Copyright Sketches

Sketches of some of the experimental kites used by Hargrave in Australia. Lawrence Hargrave invented the "box-kite" in 1893, and advocated the principle as a means of stabilizing aeroplanes. The early Voisin biplanes of 1907 were built on box-kite lines.

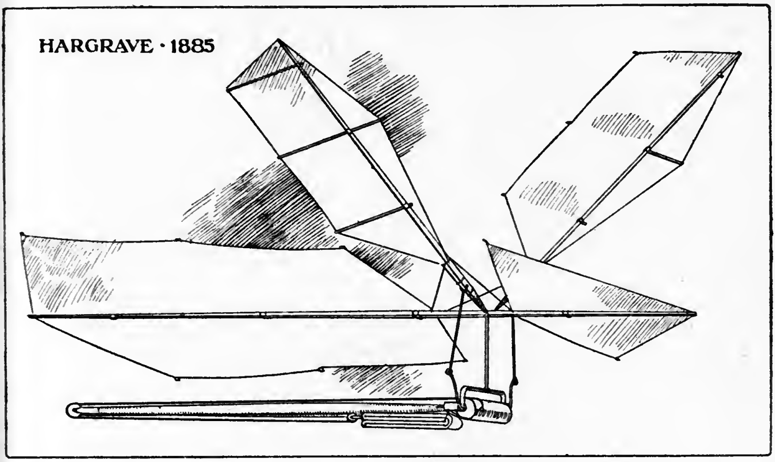
Among the pioneers in the science of aviation it would be extremely improper not to give Lawrence Hargrave a prominent place for the work that he accomplished in

Australia. His name is best known for his introduction of the "box-kite" in 1893, but, in spite of the undoubted practical importance of this invention, which has been most usefully developed, his earlier experiments in propulsion are even more interesting.

Once a year, from 1884, if not at more frequent intervals, Hargrave read a paper, embodying the results of his investigations, before the Royal Society of New South Wales, and it is perhaps in part due to the fact that the proceedings of scientific societies attract relatively little outside attention that Lawrence Hargrave's remarkable contributions to knowledge have been so little known.

His first paper of the series bore the unattractive title "The Trochoided Plane," and its context, at first reading, is inclined to seem abstruse to a degree. Closer investigation, however, reveals a remarkably able thesis on the principles of wave and vortex motion, together with a consideration of various mechanical means for producing this kind of disturbance in fluids. The point brought out in this paper was that the action in question—examples of which are to be found in nature in the sinuous flexing of the body of a swimming eel and the flapping of a bird's wing—produces a propulsive force of high efficiency.

Applying his theory to practice Hargrave constructed a number of very interesting mechanical models, and ultimately devoted his attention more particularly to model flapping-wing flying machines. On 3 June, 1885, he read another paper before the Royal Society of New South Wales, in which he described and demonstrated several flapping-wing models driven by elastic, which made successful flights. These models were extremely simple in construction and operation. The wings were pivoted to a fore-and-aft boom carrying a fixed horizontal plane in end on aspect. About one-third of this plane was forward of the wings. The wings were operated by connecting-rods from cranks, and the essential feature of the connection, which made the wings "trochoided planes," was the attachment of the connecting-rods to the wing spars by a fork and pin. By this means the plane of the wings remained at right angles to the connecting-rod, and consequently varied its attitude in space according to the position of the crank. In other words, a kind of "feathering" action was produced whereby the chord of the wing obtained a negative angle during the downstrokes and a positive angle during the upstrokes, being horizontal at each dead centre of the crank. The crank shaft was rotated by the unwinding of a cord from a drum under the tension of an elastic spring.



"Flight" Copyright Sketch

A model built by Hargrave and successfully flown before the Royal Society of New South Wales in 1885. It was supported by a fixed aeroplane surface, and propelled by flapping wings. The crank motion controlling the wings was driven by a stretched elastic band unwinding a cord from a drum. The longest flights were about 200 ft. Subsequently, models driven by compressed-air engines were built and flown.

Subsequently, Hargrave built other and more elaborate models equipped with compressed-air and steam-engines, and, like other investigators who experienced difficulty in obtaining a sufficiently light motive power, he spent much valuable time in the design and construction of suitable plant.

Fair success attended his efforts, however, for with the two compressed-air flapping-wing machines he obtained flights exceeding 350 ft. The longest flight with the elastic-driven models was a little over 200 ft.

In all cases the wings of his models were forward of the centre of gravity, and were used for propulsion, not for support.

In the middle of his experiments with steam-engines in 1893, Hargrave decided that it would be advisable to see whether a better disposition of the planes could be arranged, and also as to whether there was any foundation for the assertion that birds utilized the wind in soaring. He decided that the expense of constructing a large whirling table similar to those used by Langley and Maxim was too great, and thereupon determined that the use of kites would serve the best means of acquiring the desired data. It was in this way that the well-known box-kite associated with Hargrave's name came to be invented, and it is interesting and instructive to note that in making these kites Hargrave was merely putting into practice the principle of using superposed planes advocated so strongly by Wenham, with whose work he was acquainted.

As a result of his experiments with kites, Hargrave was led to the conclusion that in the construction of a flying machine the cellular or box-kite formation would afford the stability and support of a dihedral monoplane of twice the span in which the dihedral (rise of the wing tip above the centre) is equal to the gap. This principle Hargrave communicated to the Royal Society of New South Wales in a paper read on 5 August, 1896. The idea found practical expression in the first commercial Voisin biplane used by Farman and Delagrange eleven years later in 1907. The Voisin biplane at that date was characterized by its cellular formation, the main planes being joined by vertical planes in the gap.

From Australia, it will be convenient to transfer our attention to America, where one of the most interesting figures in the whole history of the science was working slowly and laboriously, but with infinite pains and skill, to accomplish a definite and very useful task. Samuel Pierpont Langley was the founder of the science of flight in America, and the early publication of the results of his experiments, by the Smithsonian Institute in 1891, gave the world at large its first real treatise on aerodynamics, and Langley in particular an undisputed claim to universal prestige. Others had experimented before on the lift and resistance of inclined plates, but no one had ever approached the subject with the same regard to the scientific accuracy of working that characterized Langley's research. When he had found out all he could by means of his whirling table, he set himself to finish his self-imposed task, which was to demonstrate on a small scale that a power-propelled model could be built that would fly. This had already, to a rather limited extent, been achieved by Stringfellow in England, but there is reason to suppose from Langley's writings that he was unaware of the fact, for he was scrupulously honourable in referring to the work of others whenever he had any knowledge of their accomplishments. Langley, however, was essentially a type that would work on in uninterrupted seclusion, and although he mentions several names of other pioneers, yet their work does not appear to have greatly influenced him, and it is even questionable if it was ever known to him in detail.

The record of Langley's endeavours to build a practical self-propelled model forms one of the most fascinating pages in the history of the art, and when at last, on 6 May, 1896, he achieved success, he had indeed accomplished a great deal for one man. The story of his many intermediate failures is in itself quite a remarkable example of undaunted endeavour. Langley's model was a tandem monoplane, and although this type has not since been popular, the fact that it was successfully flown must be borne in mind against the possibility of future development along these lines. At this point Langley considered that he had finished his task, but later on he was induced to build a full-sized machine under the auspices of the American Government, and had not the two attempts to launch this apparatus been attended by mishaps to the launching gear, it is quite possible that the Langley aeroplane would have been the first to make a really successful flight.

Both efforts to launch the machine, the first on 7 October, 1903, and the second on 8 December, resulted in failure.

On both occasions the launching apparatus tripped up the aeroplane as it left the rail on the top of a large houseboat, and precipitated it into the water. Although evidently no fault in the machine, the American Government withdrew their support, and the aeroplane was never repaired.

On 17 December of that year the Wrights made their historic flights with their first motor-driven biplane.

There was another pioneer in America, Professor J. J. Montgomery, whose work is apt to be forgotten, and which even at the time was very little known or appreciated. Having commenced experiments in California in 1883 with a flapping-wing machine, which was unsuccessful, he built in 1884 three gliders, with one of which he accomplished a glide of 600 feet. Desiring more particularly to investigate the principles of equilibrium and control, he constructed a series of large models, which were tested by dropping them from a cable stretched between two mountain-tops. It was the success of these models, which invariably glided safely to earth, that led him to construct a large machine, which he took down to the mountains near San Juan for trial. These experiments were made somewhat on the same lines as those of Lilienthal, and came to a conclusion when Montgomery injured his leg by tripping up in a squirrel hole. As a result of this accident three pilots, J. M. Maloney, Wilkie, and Defolto, were engaged to ride the new machines which were put in hand, and with which exhibition glides were given about the year 1905 in Santa Cruz, San José, Santa Clara, Oakland, and Sacramento. So much confidence had Montgomery in his machines that he had consented to make the tests by launching them, with the pilot on board, from balloons.

At first the adjustments were so arranged that the pilot had very little control, and the machines merely settled down in the air. With increasing experience, however, the pilot's powers to manœuvre the glide were extended. Unfortunately one of these trials resulted disastrously, although through no fault of the machine or the pilot. During the ascent in the balloon a guy rope caught in the framework of the machine and broke an important member.

The pilot, Maloney, failed to observe the accident: he launched the machine, which turned turtle and settled a little faster than a parachute. Maloney was picked up unconscious, and died half an hour afterwards, although the only mark of any kind on him was a scratch from a wire on the side of his neck. He had descended from an altitude of 2000 ft., and his death was, therefore, presumably due to heart failure. It was not this mishap that interfered with the continuation of Montgomery's experiments, but one of far more serious importance, for the San Francisco earthquake occurred just as he was arranging to make some far from elaborate tests, and naturally distracted public attention, and particularly public support, from an undertaking that was so little allied to the immediate needs of that plucky community.

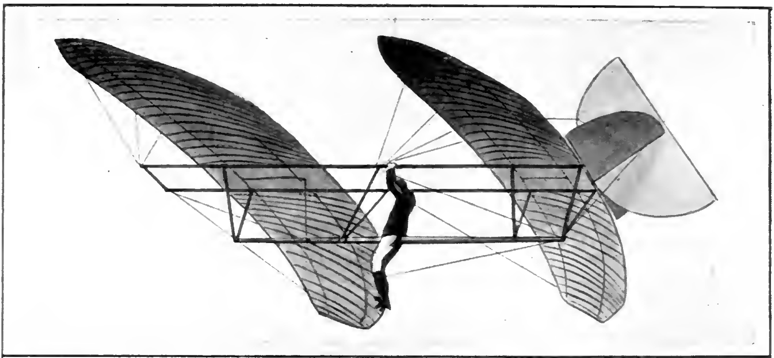
Apart from his practical experiments, Montgomery also devoted much thought to the science of aerodynamics, and in particular to the mathematics of the cambered plane. At the Aeronautical Congress of 1893 he drew attention to the cyclic up-current in the vicinity of the leading edge of a plane in flight by making the following statement: "A current of air approaching an inclined surface is deflected far in advance of the surface and approaching it in a gradually increased curve, reached it at a very abrupt angle."

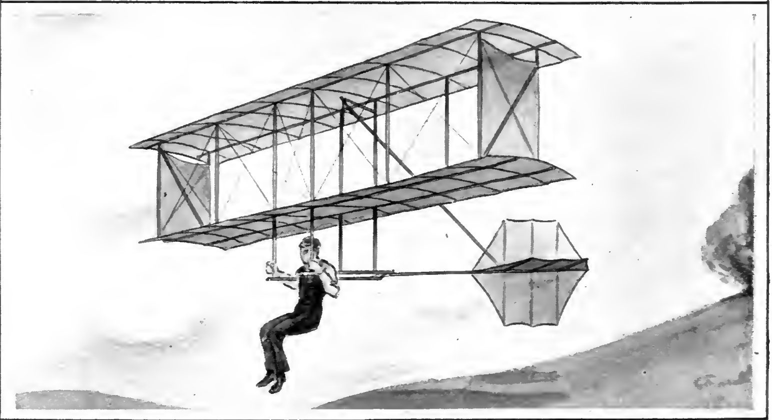
Gliding, as a recognized branch of flight, originated, from the point of view of its contemporary influence, in Germany, where the art was commenced in 1891 by that brilliant exponent, Otto Lilienthal, whose experiments are recorded in another chapter. Where Lilienthal's method of procedure differed so essentially from that of other experimenters, and that wherein he performed such a valuable service to the cause, was his early realization of the necessity of gaining some sort of practical experience in the air without the use of either complicated or expensive apparatus. He was, it would seem, practically the first pioneer to appreciate that the real problem of flight lay far more in learning to control the machine than in the designing apparatus that should be capable of dynamic self-support.

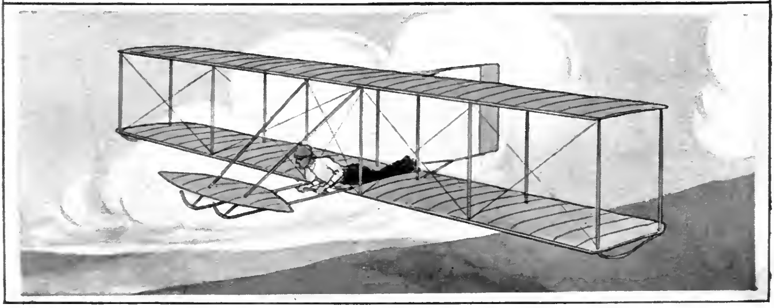
With his machine adjusted like a life-buoy under his arms, Lilienthal would launch himself into the air by running downhill against a head wind, and giving a final leap from the ground when he felt a sufficient supporting effect of the wind under the wings. In this way he accomplished from the year 1891 actual gliding flights through the air of several hundred feet in length, and during the course of his experiments he made thousands of successful trials of this nature. It is important to remember, in order to appreciate the significance of Lilienthal's experiments, that such glides are true flights in principle, and the only reason they take place in a downward direction instead of along a horizontal path is because the earth's attraction is employed, in lieu of a mechanical engine, as the prime moving force. Lilienthal thus demonstrated a means of experiencing and investigating the problem of flight that was within the reach of all who had the little means but enough leisure to devote to its pursuit. It is significant that the solution in question might have been discovered at a much earlier period in the history of man, yet no one before Lilienthal had apparently realized that gliding constituted the real front door to the practice of flying.

Otto Lilienthal was a scientist as well as an engineer, and his researches on the lift:resistance ratios of cambered planes are classic. He was an enthusiast for popularizing flight, and always tried to inspire youthful minds to take up the subject by describing how exhilarating the pastime of gliding is for those who practise it. It was evidently one of his cherished ideas that the art in question might be generally taken up by the youth of the country, for he recognized that nothing would be more likely to further the progress of flying than to have the rising generation intimately acquainted with a very pleasing phase of its technique.

Unfortunately, Otto Lilienthal lost his life in 1896 during one of his experiments, just at the time when his work was about to take a turn in a still more interesting direction, for he had already made some few experiments in power propulsion when the end came. It has since been recog-







"Flight" Copyright Sketches

1. A tandem-type monoplane glider, designed by Prof. J. J. Montgomery, and successfully flown by D. Maloney at California in 1905. The initial altitude for gliding was obtained by ascending in a balloon.

2. The biplane glider designed by Octave Chanute and flown by A. M. Herring in 1896 over the shores of Lake Michigan, U.S.A. This machine is the prototype of the modern biplane construction in respect to the bracing of the main planes.

3. The Wright biplane glider as used on the Kill Devil Sand-hills at Kitty Hawk, North Carolina, U.S.A. Gliding experiments commenced in 1900, and continued until 1903.

Observe the pilots' attitudes in the above photographs. In the upper photograph the pilot is seated on the longitudinal boom.

nized that Lilienthal's method of using his machine is fraught with some danger in gusty weather, and it is commonly admitted that previous accidents were only avoided by his gymnastic skill in the control of his machine. The vast number of flights that he did accomplish, however, were of immense value as an encouragement to others, for if his death damped the ardour of some, the sterling quality of his work inspired others to continue his work, among them Pilcher, Chanute, and the Wrights.

The former, a young English engineer, at that time attached to the experimental department of Hiram S. Maxim, took up the subject in 1895, and built a machine of his own design, but somewhat on Lilienthal lines. On two or three occasions he met Lilienthal in Germany, and made glides in Lilienthal's own machine. Unfortunately, however, he, too, met with a fatal accident at an early stage of his career, although not before he had drawn attention to several matters of great practical importance, among them the disadvantages of a big dihedral angle in side winds, the difficulty of controlling a machine with an unduly low centre of gravity, the possibility of towing a glider as a kite, and the advantage of a wheeled chassis as a means of relieving the pilot of the weight of his machine when landing.

Octave Chanute, who, like Lilienthal, was an engineer by profession, had already retired from the more active path of railroad construction, in which he had risen to become one of the leading men of his day, before he seriously interested himself in the study of aviation. Like Lilienthal, too, he grasped the importance of gliding flight, and, having published an article strongly recommending others to pursue the art, he decided to institute practical experiments, if not exactly personally, at any rate at his own expense. He therefore secured the services of A. M. Herring, a much younger enthusiast than himself, who had previously made some gliding flights of his own on a Lilienthal apparatus in 1894. This machine Herring rebuilt, and also another on very different lines, suggested by Chanute himself.

The apparatus was completed in June, 1896, and transferred to a suitable site on the shores of Lake Michigan, near St. Joseph, for trial.

Chanute's experiments lasted until September of that year (1896), when the camping party broke up for the winter, and were not afterwards renewed, for Chanute was even then sixty-four years of age, and although attracted to flight with all the fervour of youth, he doubtless deemed it wise to moderate his personal participation in such experiences. Moreover, the trials had served their purpose so far as Chanute was concerned, and their results coming from such an authority in the engineering world induced a widespread interest in the subject.

CHAPTER XXII

THE CONQUEST OF THE AIR

Early work of the Wrights—The first long flight—Santos Dumont's tail-first aeroplane—Henry Farman wins the first Grand Prix—The American Army contract.

LILIENTHAL'S death, regrettable as it was in itself, had one most significant effect that in some measure may be said to have placed the coping stone on his labours. Among those who read the brief announcement of the fatal accident were Wilbur Wright and his brother Orville, whose work is described in detail in another chapter.

They fully recognized the enormous advantages of gliding as a means of obtaining effective experience with a minimum of trouble and expense, but they had an idea that by using a larger machine than Lilienthal's, capable of being supported at a speed of about 18 miles per hour, and by selecting a site where winds of this order were frequent, if not regular, they would be able to vary their free glides by the use of the machine as a kite. Before actually drawing out designs, they took very carefully into consideration the features of the Lilienthal, Pilcher, and Chanute machines, the result of which was that they evolved a type of their own that embodied from the first the principal characteristics of the Wright biplane with which Wilbur Wright subsequently electrified the world by his wonderful flights.

Like Chanute, the Wrights went into camp in order to make their experiments, the site chosen being Kitty Hawk, North Carolina, a little settlement located on the strip of land that separates Albemarle Sound from the Atlantic Ocean. Here they commenced their practical trials in the summer of 1900, and Chanute himself, who was one of their first visitors, stayed a week with them. Their experiments were most successful and highly instructive, but being carried on well away from the madding crowd, little reliable information of the work done was brought to light until Wilbur Wright himself read a paper before the American Western Society of Engineers, published in their Journal for December, 1901. In 1902 their gliding experiments were resumed, and some modifications made in the machine. So long as they were actually engaged on their experiments, they very properly resented intrusion by the general public, and consequently they took every reasonable precaution to work in seclusion. It thus happened that their ultimate success, which was to achieve sustained flight with a power-driven machine, took place under conditions that gave rise to all sorts of rumours and doubts affecting the truth of this momentous event in the world's history. It was on 17 December, 1903, a little more than three years after the commencement of their original gliding flights, that, having equipped a biplane with a petrol engine of their own design and construction, they succeeded in making four free flights from level ground against the wind. The experiments were resumed in 1904 with great success, over one hundred flights being made. Further progress was achieved in 1905, and in that year they brought the control of their machine to such a pitch of perfection that they could legitimately claim to have definitely achieved the conquest of the air, and to have commenced upon the second phase of aviation, which may be better described as the development of flight. The following is an interesting letter from Orville Wright to Patrick Y. Alexander, who communicated it to the Aeronautical Society of Great Britain on 15 December, 1905. The letter itself is dated 17 November of that year:

"We have finished our experiments for this year after a season of gratifying success. Our field of experiment, which is situated eight miles east of Dayton, has been very unfavourable for experiment a great part of the time, owing to the nature of the soil and the frequent rains of the past summer. Up to the 6th September we had the machine out on but eight different days testing a number of changes that we had made since 1904; as a result the flights on these days were not so long as our own of last year. During the month of September we gradually improved our practice, and on the 26th made a flight of a little over 11 miles. On the 30th we increased this to 12⅕ miles, on 3rd October to 15⅓, on 4th October to 20¾ miles, and on the 5th to 24¼ miles. All of these flights were made at about 38 miles an hour, the flight on 5th October occupying 30 minutes 3 seconds. Landings were caused by the exhaustion of the supply of fuel in the flight of 26th and 30th September and 8th October, and in those of 3rd and 4th October by the heating of bearings in the transmission, of which oil cups had been omitted. But before the flight of 5th October oil cups had been fitted to bearings and the small gasoline can had been replaced with one that carried enough fuel for an hour's flight. Unfortunately, we neglected to refill the reservoir, and as a result the flight was limited to 38 minutes. We had intended to place the record above the hour, but the attention the flights were beginning to attract compelled us to suddenly discontinue our experiments in order to prevent the construction of the machine from becoming public.

"The machine passed through all of these flights without the slightest damage. In each of these flights we returned frequently to the starting-point, passing high over the heads of the spectators. ORVILLE WRIGHT."

Thus was the air finally subjected to the motive power of man's invention by two Americans, very nearly a century after Cayley had logically demonstrated the plausibility of such an achievement, and had accurately forecast many of the features of the machine wherewith it was actually accomplished. Owing to the desire of the Wrights to keep certain details of their machine from public knowledge, in order that they might negotiate for the sale of their patents to Governments, their accomplishments at first met with none of that general appreciation and public enthusiasm that they deserved and subsequently received. Many were altogether sceptical of engine-propelled flight having been accomplished at all, overlooking or being ignorant of the *bona fides* of their integrity that Wilbur Wright had already given by his addresses to the American Western Society of Engineers. Again and again did articles appear in the Press urging the Wrights to come out of their shell, but they remained firm in their original decision, and the mystery of silence grew more intense during a subsequent period of two and a half years that they were engaged in various negotiations.

In this interval, the star of aviation suddenly moved once more to France, where Santos Dumont, a Brazilian long resident in Paris, achieved the first officially observed flight recorded by the Aero Club of France on 23 October, 1906. This achievement, small though it was in itself—for the flight was really only a long jump of 164 ft.—nevertheless had a most important effect in firing enthusiasm all over the country, where, as a matter of fact, active experiment had been in progress for some time.

Captain Ferber, of the French Army, was the first to take up the subject after the unfortunate termination of Ader's work in 1890, and his inspiration came, as did so much that resulted in good work, from the pioneer Lilienthal. Ferber commenced his own gliding experiments in 1898, but lack of suitable ground at first prevented very successful results. Later, in 1901, Ferber obtained new ideas from Chanute, and commenced experiments with a biplane, which resulted more satisfactorily. Another enthusiast in France, interested in the work of Chanute, was Ernest Archdeacon, who did perhaps more than anyone to encourage the early stages of flight by founding a fund in 1903, and in offering the Archdeacon Cup as a prize for the first officially recorded flight exceeding 25 metres. It was this prize that Santos Dumont won, on 23 October, 1906, by successfully performing a prearranged flight under the observation of duly appointed representatives of the Aero Club of France.

Apart from his financial encouragement, which at all times has been most generous, Archdeacon deserves also to be remembered for his personal association with the practical side of experimental work. He had several gliders constructed, commencing with the first in 1904, and in 1905 put into practice an original idea for performing experiments over water by having the machine towed as a kite by a motor-boat on the Seine. In these experiments Gabriel Voisin performed the duties of pilot. Contemporary with these tests, others of a similar character were conducted by another pilot, who was ultimately to achieve great fame—Louis Bleriot, the hero of the first cross-Channel flight.

These experiments took place in 1905; in October, 1906, Santos Dumont set the ball rolling by winning the first prize, as already mentioned; in November the *Daily Mail* offered its famous £10,000 prize for a flight from London to Manchester; and early in 1907 Voisin, who with his brother decided to go in for aeroplane construction on a commercial scale, had already built two machines of his own design with which Leon Delagrange and Henry Farman were diligently experimenting at Bagatelle and Issy. Although Delagrange was the first in the field by several months, it was Henry Farman who was the first to make the flight for which everyone was hoping. It was fully recognized by all who followed these early experiments in detail, that while straight-ahead flights were likely to become more and more general and relatively easy of accomplishment, the real test of machine and pilot lay in turning about and in going in all directions through the wind; in other words, in the performance of a flight over a closed course. So important was this achievement deemed to be that MM. Deutsch and Archdeacon put up a prize of 50,000 frs. for its accomplishment over a course of one kilometre in length. This prize Henry Farman won with his Voisin biplane on 13 January, 1908, and the following is a translation of the historical official notice issued by the Aero Club of France:

"The Grand Prix d'Aviation of 50,000 francs offered by M. Deutsch de la Meurthe and M. Ernest Archdeacon to the Aero Club de France, to be awarded to the inventor of a flying machine who shall first accomplish a flight of one kilometre in a closed circuit without touching ground, has been officially won to-day, Monday, 13 January, 1908, at Issy-les-Moulineaux, by Mr. Henry Farman, in his first and single flight made at 10.15 this morning.

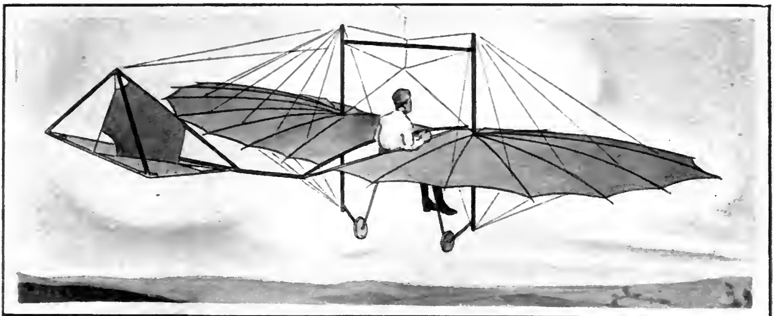
"The trial was officially controlled by the delegates of the Committee of Aviation of the Aero Club de France, Comte Henry de la Vaulx, M. Henry Kapferer, and M. Louis Bleriot. The duration of the flight, according to the time officially taken by M. H. Kapferer, was 1 min. 28 sec., and the average elevation was between four and six metres from the ground.

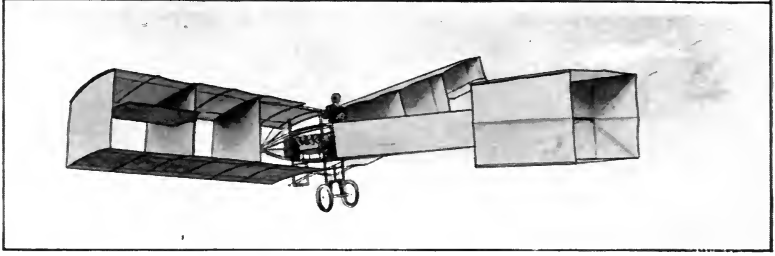
"The Committee of Aviation met on the same day, at 4.30 in the afternoon, to enter an official record of the result in the books of the Aero Club.

"The board of directors of the Aero Club, represented by M. Deutsch de la Meurthe, Comte Henry de la Vaulx and M. Georges Bosançon, has resolved to give a banquet in honour of Mr. Henry Farman in the salons of the Automobile Club de France on Thursday next, 16 January. At this banquet the grand gold medal of the Aero Club de France will be handed to Mr. Farman, and silver-gilt medals to his co-operators, the firms of Voisin Frères and of Antoinette. In addition to this prize the firm of Antoinette wins the gold medal offered by M. Albert Triaca to the builders of the motor which won the Grand Prix d'Aviation."

It is important to bear in mind, in order properly to appreciate the relative significance of progress in France at this date, that the successful flights of the Wrights had altogether faded from the public's horizon. Two years had elapsed since the accounts of their great flights had appeared in the Press, and it requires something more substantial than memory to last through any such length of time as this in modern history. The Wrights themselves kept quiet, although every now and again the Press would ask them point blank what they thought of the trend of affairs in the flying world, and even when they did once again occupy the stage, their acts still took place behind the curtain.

On 23 December, 1907, the American Army Signal

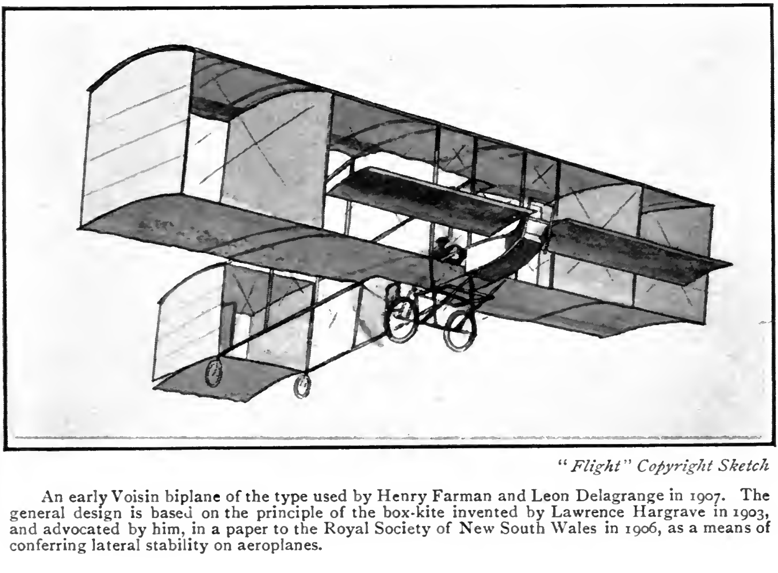




"Flight" Copyright Sketches

1. Sketch from a photograph illustrating Pilcher's glider "The Hawk" with which he experimented in England in 1896. The above illustration should be compared with that of the Lilienthal glider.

2. Santos Dumont's tail-first type biplane with which he won the first flight prize (Archdeacon Cup) on October 23rd, 1906. The prize was for the first officially observed flight exceeding 25 metres.



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An early Voisin biplane of the type used by Henry Farman and Leon Delagrange in 1907. The general design is based on the principle of the box-kite invented by Lawrence Hargrave in 1903, and advocated by him, in a paper to the Royal Society of New South Wales in 1906, as a means of conferring lateral stability on aeroplanes.

Corps invited tenders for army aeroplanes, the purchase to take place conditionally upon certain tests that were then regarded, by those whose actual knowledge of what had been accomplished was limited to the public achievements in France, as so severe as to be preposterous. The more interesting and important clauses of this famous document are as follows: [1]

(3) The flying machine must be designed to carry two persons having a combined weight of about 350 lb., also sufficient fuel for a flight of 125 miles.

(4) The flying machine should be designed to have a speed of at least 40 miles per hour in still air, but bidders must submit quotations in their proposals for costs depending upon the speed attained during the trial flight, according to the following scale: 40 m.p.h., 100%; 39 m.p.h., 90%; 38 m.p.h., 80%; 37 m.p.h., 70%; 36 m.p.h., 60%; less than 36 m.p.h. rejected; 41 m.p.h., 110%; 42 m.p.h., 120%; 43 m.p.h., 130%; 44 m.p.h., 140%.

(6) Before acceptance a trial endurance flight will be required of at least one hour, during which time the flying machine must remain continuously in the air without landing. It shall return to the starting-point, and land without any damage that would prevent it immediately starting upon another flight. During this trial flight of one hour it must be steered in all directions without difficulty, and at all times under perfect control and equilibrium.

(10) It should be sufficiently simple in construction and operation to permit of an intelligent man to become proficient in its use within a reasonable length of time.

(12) Bidders will be required to furnish with their proposal a certified cheque amounting to 10% of the price

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[1] For full text of this historic document readers are referred to *Flight*, p. 651, of 14 June, 1913, where also will be found an interesting personal statement by Lieutenant-Colonel G. O. Squier, who was intimately associated with its preparation.

For detail aviation history prior to January, 1909—in which year *Flight* was founded—readers should consult the *Automotor Journal*. This motoring periodical contained a section devoted to aeronautics for many years and published the first account of the Wrights' success that appeared in any English newspaper. The *Auto* was the parent journal of *Flight*, and both papers are still published from the same offices at 44 St. Martin's Lane, W.C.

stated for the 40 miles speed. Upon making the award for this flying machine these certified cheques will be returned to the bidders, and the successful bidder will be required to furnish a bond, according to Army Regulations, of the amount equal to the price stated for 40 miles speed.

CHAPTER XXIII

THE FAMOUS YEAR

The Wrights in France—An hour in the air—Generosity and prizes—The first pupils—The restart in England—Cody and Roe—The first certificates—The first Aero Show.

IN the summer of 1908 Wilbur Wright came to France, his brother Orville remaining in America in order to attend to the construction and testing of a machine for the Army contract. There began, when Wilbur Wright first came to France, a period of almost ludicrous suspense. Everyone was so keenly impatient to see this wonderful man fly that the suppressed excitement often reached fever heat, as day after day was passed in his methodically careful preparations.

The chosen site for the experiments was the Hunaudieres Race-course near Le Mans, and early in August everything was apparently in readiness. The aviation world was all expectancy, everyone was waiting to see—they knew not quite what. It would be difficult indeed, too, to exactly analyse the mixed feelings induced by Wilbur Wright's first public flight, which lasted exactly 1 min. 47 sec., and covered a distance of a mile and a quarter!

This took place on 8 August, 1908, which day, being a Saturday, gave the public time to discuss the performance at leisure over the ensuing week-end. On Tuesday, however, Wilbur Wright made another little flight, but this time with a difference. He rose in the air, and repeatedly executed figures of eight and other manœuvres, showing the utmost control over his machine. The trial lasted less than four minutes, but M. Delagrange, who witnessed it, thus succinctly summed up the situation, "Eh bien. Nous n'existons pas. Nous sommes battus."

Few people knew, nor is it even generally known to-day, that Wilbur Wright was himself to all intents and purposes learning on his own machine. Although surpassing all others in his experience of riding the air, nevertheless, it happened that he was strange to the precise system of control embodied on his own aeroplane. When, after their gliding experiments, the two brothers built their motor-driven aeroplane, they arrived at a point at which their opinions differed. Each preferred a different arrangement of levers for manipulating the same system of control, and just before Wilbur Wright packed up his machine, which thereafter remained in its crate during the long period of negotiations in foreign countries, he had introduced the universally pivoted warping and rudder lever that characterized all the early Wright biplanes. This control he considered to be best suited to his requirements, but he had not had time to become expert in its use, which very simple explanation accounts for a great deal that was often mystifying to the good spectators of Le Mans.

Presently, the scene of operations was, for convenience, changed to Auvours, and again the progress was slow. Newspaper correspondents kicked their heels with impatience, and to pass the time would hum the following refrain :

> " C'est difficile de voir voler Orville,
> C'est bien plus dur de voir voler Wilbur."

It was part of Wilbur Wright's contract with the French syndicate, of which Lazare Weiller was the head, to make two flights of 50 kiloms. in one week, with a second person as passenger or a bag of sand equivalent to a man's weight, the flights to be made in a wind of at least eleven metres per second. In consideration of this performance, the transference of the French patents to the syndicate, and the building of a certain number of machines, Wilbur Wright was to receive £20,000.

Each day saw an increase in the length of his flight by two or three minutes, but even by 5 September his longest flight was only 20 mins. in duration. Then, like a bolt from the blue, there suddenly came the news, on 9 September, that Orville Wright had flown for over an hour at Fort Myer in America. The next news that Wilbur Wright received was that his brother had met with an accident on 17 September, and, worse still, that the accident in question had resulted in the death of Lieut. Selfridge, who was a passenger on the machine. This naturally cast a gloom over matters aeronautical, for since the untimely disasters to Lilienthal and Pilcher, flyers of every degree had seemed to be in charge of a special Providence. Frequent accounts of machines toppling over during the inexperienced efforts of embryo pilots were to be heard on all sides, but so far no one had been killed, or even, apparently, seriously hurt. Louis Bleriot, for example, who was most perseveringly trying to develop a monoplane of his own design, used frequently to break up his machine, yet he himself always came through unscarred. Orville Wright, although badly hurt, was reported to be not seriously in danger of losing his life.

It was after this incident that Wilbur Wright began to increase the rate of his progress. He had, in fact, only been waiting for Orville to make the first flight of an hour, in order that America might have the honour of its performance within her shores. On 21 September he remained in the air for 1 hr. 31 min. 25⅘ sec., during which time he covered a distance of nearly 61 miles. This was followed by other flights of equal importance, and on several ascents he carried passengers. On two of these latter occasions he succeeded in completing his contract with the Weiller Syndicate, for on 6 October he flew for 1 hr. 4 min. 26 sec. with Mr. Arnold Fordyce, and on 11 October carried M. Painleve for 1 hr. 9 min. 45⅖ sec., thus making two flights exceeding 50 kiloms. each in the same week. Shortly afterwards Wilbur Wright also carried as passengers four members of the Royal Aero Club, the late Hon. C. S. Rolls, Mr. F. Hedges Butler, Major Baden-Powell, and Mr. Griffith Brewer.

Whilst Wilbur Wright was making these fine performances at Le Mans, Henry Farman and Leon Delagrange, inspired by what they had seen, gained confidence to surpass themselves on their own machines. Very soon they, too, were making flights of appreciable duration, far exceeding anything that they had accomplished prior to Wilbur Wright's appearance in France. Progress in the art during the first nine months of 1908 was phenomenal, for whereas the year had opened with a circular flight of one kilometre as a great effort, by the end of September the following principal flights had been accomplished :

List of principal flights up to 30 September, 1908.

			Time.		Date.
Order.	Aviator.	h.	m.	s.	1908.
1.	Wilbur Wright	1	31	$25\frac{4}{5}$	21 Sept.
2.	Orville Wright	1	14	20	12 Sept.
3.	Orville Wright	1	10	0	11 Sept.
4.	Wilbur Wright	1	7	24	28 Sept.
5.	Orville Wright	1	5	52	10 Sept.
6.	Orville Wright	1	2	30	—
7.	Orville Wright	0	57	31	9 Sept.
8.	Wilbur Wright	0	54	$3\frac{1}{5}$	24 Sept.
9.	Henry Farman	0	43	0	29 Sept.
10.	Wilbur Wright	0	39	19	16 Sept.
11.	Wilbur Wright	0	36	$14\frac{3}{5}$	5 Sept.
12.	Henry Farman	0	35	36	30 Sept.
13.	Leon Delagrange	0	29	$53\frac{4}{5}$	5 Sept.
14.	Leon Delagrange	0	28	0	6 Sept.
15.	Wilbur Wright	0	21	$43\frac{2}{5}$	10 Sept.
16.	Henry Farman	0	20	20	6 July
17.	Wilbur Wright	0	19	$48\frac{2}{5}$	5 Sept.
18.	Leon Delagrange	0	16	30	22 June
19.	Leon Delagrange	0	15	$26\frac{4}{5}$	30 May

Other flyers in the field at this time included Louis Bleriot, who was, as mentioned above, diligently pioneering the monoplane, of which type of machine there was also another good example, that was originally known as the Gastambide-Mengin, but subsequently became more famous as the Antoinette. Esnault Pelterie, who had been so interested in the Wrights' gliding experiments as to make certain tests of his own with a view to checking their figures, had also come to the conclusion that the monoplane was a more desirable type of machine than the biplane, and, like Bleriot, he was at that time endeavouring to achieve success.

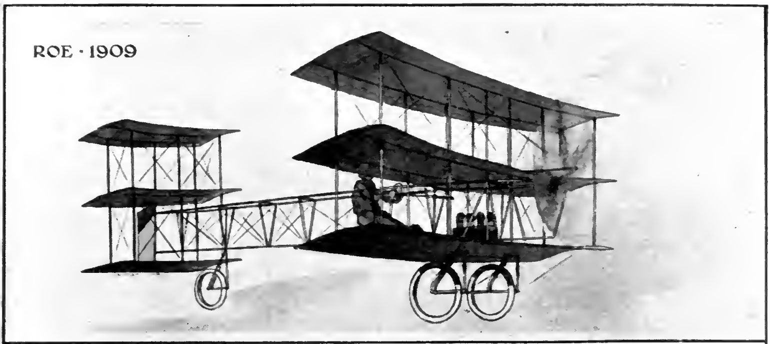
Much encouragement from all quarters was being given to aviation by the creation of valuable prizes, the most notable of which was a very generous offer by a large tyre firm, Messrs. Michelin, involving an aggregate sum of £10,000. Of this £600 per annum was to be available in the form of an annual prize, during a period of ten years, for the flight of longest duration, provided that in each year the flight in question should last twice as long as that accomplished by the previous winner of the prize. A sum of £4000 was also set aside as a special prize for a passenger flight to the summit of the Puy-de-Dôme. With prizes like this to be won, it was little wonder that flying should grow apace. Almost every available open space in France was called into requisition as an aerodrome, and machines of all kinds and descriptions were to be seen "rolling" about the ground in the initial attempts of their pilots to ascend. An art that was almost non-existent in January became the topic of the hour in September, and the end of the year saw Wilbur Wright, who was easily the winner of the first Michelin prize, with a flight of 1 hr. 53 min. 59$\frac{2}{5}$ sec. on 18 December, carefully training three Frenchmen—Paul Tissandier, Count de Lambert, and Lucas Gerardville—to fly his machine in the balmy air of Pau. Wilbur Wright's first Italian pupil was Mario Calderara, a lieutenant in the Royal Italian Navy.

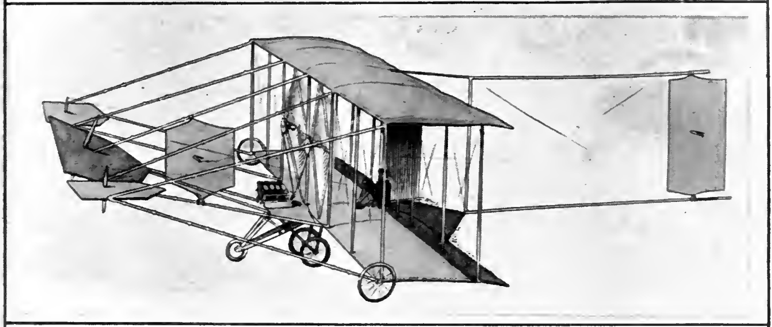
Chilly days ushered in the new year 1909, and although possibly propitious enough so far as the absence of wind was concerned, they were not conducive to increased enthusiasm at the various flight grounds, for flying is a cold pastime at any time, therefore especially so in winter. January passed uneventfully, but saw much perseverance on the part of those who meant to see the thing through, and in February one of the most determined students at that time, J. T. C. Moore-Brabazon, made some short flights with a Voisin biplane at Chalons in France. Putting aside the question of Henry Farman's English descent, Moore-Brabazon thus obtained the honour of being the first Englishman to fly. Before the month was out, however, signs of success began to manifest themselves within our own shores; S. F. Cody, flying some 400 yards at Aldershot on 21 February, with the British Army biplane. Great credit is also due to the plucky perseverance of A. V. Roe, who for a year or more past had been trying with varying success to fly his low-powered triplane.

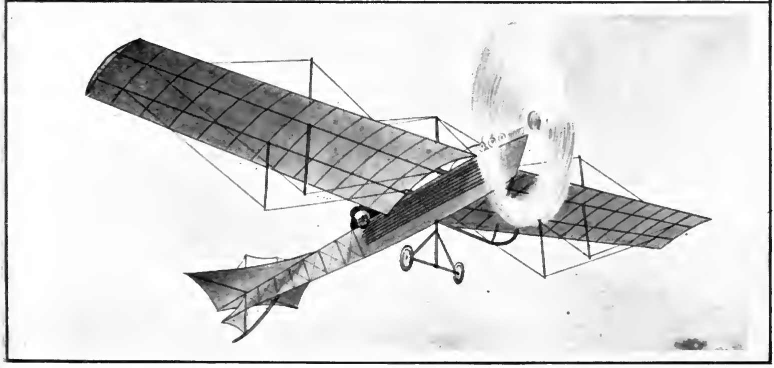
In preparation for the various proposed flight meetings the C.A.M. (Commission Aerienne Mixte) published their general competition rules about this time, and early in March the Aero Club of France issued their first list of pilots' certificates (dated 7 January, 1909) to the following pioneers: L. Delagrange, Santos Dumont, R. Esnault Pelterie, Henry Farman, Wilbur Wrigth (*sic*), Orville Wright Capt. Ferber, L. Bleriot. Truly do the names of these famous eight deserve to go down to posterity, not alone because of the curiosity that almost always attaches to the first in things of this sort, but because these men thoroughly deserve the distinction of being the real pioneers of the practical side of the movement. Capt. Ferber, who stands out less prominently than some of the others as a pilot, was a leading exponent of the science.

At this point in the history of the movement the Aero Club of the United Kingdom made their first important practical move towards the furtherance of aviation, as distinct from ballooning, by the acquisition of an aerodrome at Shellbeach, in the Isle of Sheppey. Here Short Bros. immediately commenced to erect a factory for building aeroplanes, in their capacity of official engineers of the Club. Subsequently, this firm acquired a concession to construct the Wright biplanes in England.

At Pau, the Wright School in France, the pupils continued to make rapid progress, and considerable encouragement resulted from two royal visits; one on the part of King Edward VII and the other from King Alfonso of Spain. Shortly afterwards Wilbur Wright, having by this time trained some of his pupils to fly by themselves, left the school in charge of Count de Lambert, in order that he might attend personally to the manufacture of his biplane. The absence of Wilbur Wright from the arena thus served to divide attention more evenly among the different aviation grounds in France, where almost every day found a new-







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1. The British-built Roe triplane of 1909.
2. The British-built Cody biplane of 1909.
3. The French-built Antoinette monoplane of 1909.

comer with a new machine. Few of these would-be pilots had yet learned to fly, and as a matter of fact the first to do anything sensational during this interim was Santos Dumont, who succeeded in flying his miniature monoplane "Demoiselle," which had a span of only 17 ft., a distance of 2·5 kilom. across country on 8 April, 1909.

It can never be said against this generation that it failed to encourage aviation once flying had been demonstrated as an accomplished fact, and not the least pleasing feature of this particular period was the manner in which the English branch of the Michelin Tyre Company came forward with the offer of an English Michelin cup valued at £500, together with a prize of £500, to be given annually for five years, solely for the encouragement of British pilots and British constructors. The announcement was made at the end of March, which month closed with the holding of the first British Aero Show at Olympia, London.

This exhibition naturally aroused a great deal of interest among the general public, the majority of whom had naturally never previously seen an aeroplane, and many of whom were not a little astonished to find what curious great machines they were at close quarters.

Early in April, the *Daily Mail* again came forward with the offer of £1000 for the first circular mile flight to take place in Britain by a British subject flying a British machine. This was the third prize that the *Daily Mail* had offered, the first being the famous £10,000 London to Manchester prize, which few people supposed would ever be won, and the second was a prize of £500 for the first cross-Channel flight, which, being initially only open for the year 1908, had been re-established as a £1000 prize for the year 1909.

In April, 1909, there must have been well over 100 prizes of one kind and another that had been definitely offered for specific events. They did not all run into four figures in English sovereigns, but very often they represented five figures in francs, and there is no doubt whatever that this generosity on the part of wealthy private people, no less than the enterprise on the part of some progressive companies who saw the prospect of a little advertisement for their outlay, was of the very greatest service in encouraging the movement. Many of the more enthusiastic spirits among would-be flyers were but poorly endowed with this world's goods, and in this country especially it was almost impossible to raise funds for private experiments. Fired by the chance of a substantial reward, however, many pioneers spent their time and their money freely in their efforts to achieve success.

CHAPTER XXIV

THE CHANNEL FLIGHT

Latham's splendid failure—Bleriot's great success—The Royal Aero Club's first aerodrome—The first British flight meeting—The end of 1909.

JULY, 1909, was the greatest month of the history of aviation, for it witnessed the crossing of the Channel by Bleriot on Sunday morning, 25 July. The event was not only one of epoch-making importance in itself, but the incidents associated therewith are of unique interest. Early in the month much excitement was aroused by definite announcements on the part of various more or less proficient pilots, that they would compete for the *Daily Mail* prize. Principal attention, however, centred around the preparations of Hubert Latham, who was the first to make any actual move. Having taken his Antoinette monoplane to Sangatte during the second week of the month, he patiently awaited a favourable day, which did not arrive for more than a week.

His famous first attempt took place on Monday, 19 July, the start being made at 6.20 a.m. When from 6 to 8 miles out from the French coast, however, the engine began to miss-fire, and ultimately stopped, so that the pilot was faced with no other alternative than that of descending on to the water, which, fortunately, was calm. A well-executed glide terminated in very gentle contact with the sea and the peculiar construction of the machine, which was built with very thick wings and a boat-like body, enabled it to float when partly submerged. Latham himself did not even get his feet wet, and when rescued by a French torpedo destroyer, told off for his escort, he was calmly smoking his inevitable cigarette.

It was a splendid failure, but before it had even ceased to be the topic of public conversation, Bleriot suddenly arrived on the scene, and without delay made his historic flight. A few days previously he had completed a very successful cross-country journey of 25 miles between Etampes and Orléans, and it was probably this achievement that determined him to try for the great event while fortune wore a smiling face—for it is not always that the Fates are favourable to the flyer. He chose Baraques as a starting-point, and left the French shore at half-past four on Sunday morning, 25 July, arriving in England at 12 min. past 5, where he landed in the Northfall meadow behind Dover Castle. Allowing for the difference between French and English time, the journey occupied approximately 40 min., and as the course followed was far from straight, it is estimated that the speed was at least 45 miles an hour. One of the interesting minor points about the flight was that Bleriot lost his way, and did not land on the spot that he had previously selected for the purpose; in consequence, the crowd awaiting his arrival was disappointed, and the only actual witness of his arrival was, so far as is known, Police Constable Stanford, who happened to be on duty in the vicinity.

Hardly had Bleriot achieved success when Latham made another bid for fortune, and again met with failure; once more also was he rescued safely from the waters of the Channel.

The foregoing events naturally placed all other achievements in the shade, but the month of July saw the advent of many new stars in the firmament of flight whose subsequent brilliancy in turn attracted the eyes of the world. It was in July, for instance, that a young French mechanic, Louis Paulhan, first appeared at Issy with a Voisin biplane that he had won as a prize in a competition for models. His first attempts were very modest little jumps, but before the end of the month he flew from Douai to Arras, a distance of 13 miles across country, which he accomplished in 22 min. As the result of this achievement he formally entered his name as a competitor for the London to Manchester flight—and this after less than four weeks' experience!

One of the first English pupils in France, G. B. Cockburn, also attracted attention at this time by flying his Farman biplane at Chalons; while M. Delagrange, who was, of course, already famous as a pioneer, commenced at this period to take lessons from Count de Lambert in the art of flying a Wright biplane. In England, S. F. Cody accomplished a flight of about 4 miles, and there were signs of future success in the trials made by A. V. Roe with his triplane on Lea Marshes.

About this time news from America announced the acceptance by the U.S.A. Government of the Wright biplane in respect to the Army contracts. In this matter the Wrights received the sum of $30,000, inclusive of a bonus of $5000. The tests of the machine were carried out at Fort Myer drill ground near Washington, D.C. Towards the latter end of August came the much-anticipated Rheims Aviation Week, the Grand Semaine de Champagne, as it was called in France, of which the most important event was the first contest for the Gordon-Bennett Aviation trophy. Among the competitors was one representative of Great Britain, G. B. Cockburn, whose longest flight up to that time had been about a quarter of an hour in duration. Altogether 36 machines were entered, several, of course, being of the same type, the Wright, Farman, and Voisin biplanes with the Bleriot, Antoinette and R.E.P. monoplanes predominating. One machine came from America, the Curtiss biplane, and with this Glenn Curtiss succeeded in winning the principal event, which resulted in placing the custody of the Gordon-Bennett trophy in the hands of America for the ensuing year. During this meeting Paulhan came still more prominently to the fore, and Hubert Latham accomplished what was then regarded as a wonderful altitude flight of 508 ft.

During September, Alec Ogilvie and T. P. Seawright took delivery of a Wright glider, which had been constructed for them by T. W. K. Clarke, a pioneer in the British industry, and with this machine they went down to some hills behind Eastbourne in order to make preliminary experiments, pending the arrival of their power-driven machine. The month closed with some rather sensational flights by Santos Dumont on his miniature monoplane "La Demoiselle," and, sad to relate, also with the death of Capt. Ferber, who was perhaps the most scientific of those actively associated with the practical side of the movement.

October was an important month from the point of view of aviation in England, for it marked the beginning of active proceedings at the Aero Club ground at Shellbeach, where J. T. C. Moore-Brabazon and the Hon. C. S. Rolls both made successful flights; the former on his all-British Short biplane, with which he entered for and subsequently won the *Daily Mail* prize of £1000 offered to the first British aviator who should fly an all-British machine over a circular mile. Quite the most sensational event of this period, however, was again provided in France, where Count de Lambert flew his Wright biplane from Juvisy round the Eiffel Tower in Paris one fine Monday afternoon.

Notwithstanding all this extraordinary progress in flying, few people in England at this time had actually seen a machine fly, and the greatest possible interest thus centred in the first aviation meetings to be held in this country, which took place simultaneously at Blackpool and Doncaster during October. The Blackpool meeting was held under the auspices of the Aero Club, and among the famous pilots who attended were Henry Farman, Hubert Latham, and Louis Paulhan. Farman's flying was impressive from its very monotony; indeed, nothing could have been better calculated at that time to inspire public confidence in the stability of aeroplanes than Farman's regular circuits of the course. They were accomplished at quite a low altitude, the machine being often barely 8 ft. off the ground. Paulhan exhibited far more versatility in the handling of the same machine, which was flown alternatively by these two pilots, but the sensation of the meeting was Hubert Latham's marvellous flight in a wind that fluctuated, according to the official anemometer, between 15 and 30 miles an hour.

It was an enthralling performance that held every spectator spellbound in suspense, for it seemed hardly possible that the pilot and his machine could continue to fight a wind so violent. Unfortunately, the Blackpool meeting, and also the Doncaster meeting, where Sommer, Delagrange, and Le Blon were the principal pilots, were largely marred by persistent bad weather, so that the less experienced pilots were unable to come out of their sheds.

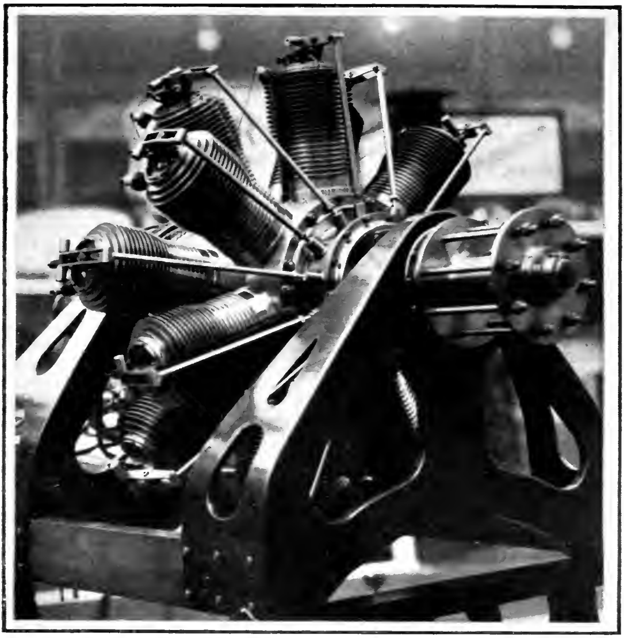
Subsequent to the Blackpool meeting, Louis Paulhan was engaged to give a series of demonstration flights over the Brooklands motor race-course at Weybridge, where thousands of people in the London district, who had been unable to attend at Blackpool, took the opportunity of obtaining their first ocular demonstration of flight from this already great master of the art. The month of October closed with J. T. C. Moore-Brabazon winning the *Daily Mail* £1000 prize for the first circular mile flight on a British machine, with C. S. Rolls making a very successful mile and a half flight, also at the Aero Club's ground at Shellbeach, on a Wright biplane, and with the appearance of the first lady flyer, Baroness La Roche, in France.

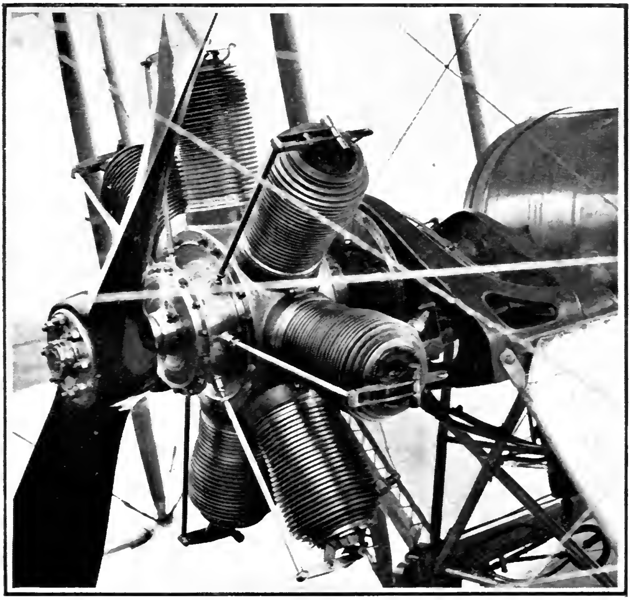
During November J. T. C. Moore-Brabazon and C. S. Rolls continued to make progress, and Alec Ogilvie commenced a series of successful flights with his Wright biplane over the Camber sands near Rye. In the middle of this month the Commission Aerienne Mixte officially passed the following records as having been established in accordance with their regulations :

Altitude. Count de Lambert, 300 metres.
Speed. Henry Farman, 200 kiloms. in 3 hr. 42 min. 34 sec.
Distance. Henry Farman, 234·212 kilom.
Duration. Henry Farman, 4 hr. 17 min. 53$\frac{2}{5}$ sec.

December saw F. K. McClean, another member of the Aero Club, successfully flying a Short-Wright biplane at Eastchurch in the Isle of Sheppey, which ground Mr. McClean acquired in the vicinity of the Club ground at Shellbeach, and which subsequently became, through his generous action, the official Club ground when unexpected inconveniences rendered it necessary to quit the Shellbeach aerodrome.

More British pupils practising in France came to the fore in this month, among them being Mortimer Singer and Claude Grahame-White. In England, as the result of Paulhan's successful demonstration, the ground enclosed by the Brooklands race-track was converted into an aerodrome, and a few aeroplanes began to take up residence in the sheds that were there erected.





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1. The fourteen-cylinder Gnome with its fore-and-aft supporting bracket.
2. The seven-cylinder Gnome as mounted on an aeroplane.

CHAPTER XXV

LATTER-DAY PROGRESS

The London-Manchester flight—The second Channel flight—The Bournemouth meeting—The deaths of C. S. Rolls and Cecil Grace—The coming of the military flyer.

ALL other events in the early part of 1910 were utterly eclipsed by the winning of the *Daily Mail* £10,000 prize, for a flight from London to Manchester, by Louis Paulhan on Wednesday and Thursday, 27 and 28 April. The victory was sensational to a degree, for an earlier competitor in the field was Claude Grahame-White, who made an unsuccessful attempt on the preceding Saturday, when he flew his Henry Farman biplane from Park Royal, on the outskirts of London, to a place near Lichfield, where he was forced to descend, on account of engine trouble.

During the night an increasing wind damaged his machine, and necessitated an immediate return to London for repairs, which were only just completed on the same Wednesday afternoon that saw Louis Paulhan's biplane of the same type, which had arrived at Hendon that morning, finally assembled.

Somewhere about five o'clock in the afternoon, therefore, both competitors were more or less ready to make an immediate start, but the weather was so unsatisfactory as to render it a matter of doubt if any attempt would be made that day. So firmly, indeed, were Grahame-White's advisers of this opinion, that they allowed him to go to bed, in order that he might be fresh and fit in the morning. No sooner had Paulhan put the finishing touches to his own machine, however, than he decided to make a trial flight, and having once ascended into the air, he came to the conclusion that he would start for the journey to Manchester forthwith.

It was at 5.21 p.m. when he first rose from the ground, and he flew straight over to the L. and N.W. main line, which he followed as far as Rugby. Passing over this town at 7.20 p.m., he flew on as far as Lichfield, where he descended in a field by the Trent Valley station at ten minutes past eight. He had thus accomplished 117 miles of his journey. The landing at Lichfield was one of the finest features of this most remarkable flight.

Flying, as he was, in windy weather, in the dark and in a strange country, Paulhan suddenly realized that he had come to the end of his petrol, and that the ground beneath him was more or less impossible for descent. He had just passed over a small field, which seemed to the pilot to be the only clear space in the neighbourhood, so, without a hesitation, he turned about and glided down into this one safe retreat. Many pilots, who might conceivably have achieved the landing, would have been forced to finish their journey there and then, for the problem of reascent called for the exercise of still more skill, the field being so small, and telegraph wires being in the line of flight.

At four o'clock the next morning, however, Paulhan was safely in the air, and by 4.25 a.m. he had reached Rugeley. Less than an hour later he was passing over Crewe, and at 5.32 a.m. he alighted at his destination, in a field at Didsbury, two miles from Manchester, amid an enthusiastically applauding multitude. Thus was the *Daily Mail* prize won at his first attempt, by a man who was only " rolling " his machine at Issy in the previous July.

When Paulhan started, Grahame-White was asleep, but as soon as his camp heard the news he was awakened, and thereupon decided to make an immediate start. Without waiting to test the repairs of his machine, he set off just before half-past six, when the evening was already fast drawing in towards darkness. An hour later it was already too dark to see the way clearly, and at five minutes to eight he had to descend at Roade, after a journey of 60 miles. Before three o'clock the next morning he was aloft again, but his ill luck with the engine did not desert him, and he had to come down at Polesworth when only 107 miles of the total journey had been accomplished. Before he was able to make the necessary adjustments he heard the news of his defeat, and nothing remained for him but to conclude his own plucky attempt with a call for "three cheers for Paulhan" from the surrounding crowd.

With the successful accomplishment of the London-Manchester flight, aviation had been deprived of its most valuable prize, and it was, therefore, an event of no little moment when the *Daily Mail* announced, at the end of June, that they would offer another £10,000 for an event to take place in July, 1911. Full details of this event were not published at the time, beyond stating that it would take the form of a thousand miles circular tour extending over the greater part of England and Scotland and would occupy a period of about a week.

Prior to the Manchester flight, the event of chief importance in England was the award of the British Michelin Cup, together with a cash prize of £500, to J. T. C. Moore-Brabazon, for his flight of 19 miles, which he accomplished on an all-British Short biplane on Tuesday, 1 March. The Hon. C. S. Rolls, who had achieved a somewhat longer flight within the same period, did not at this time own a British-built machine.

When Bleriot entered for the cross-Channel prize, which he won on 25 July, 1909, he omitted to make formal entry for the Reuinart Prize of £500 that was also available for the same event. This sum, therefore, coupled with the further £100 cup offered by the *Daily Mail* for the second Channel crossing, rendered it well worth while making another attempt. To Jacques de Lesseps, the youngest son of the famous engineer of the Suez Canal, therefore, is the honour of having won these prizes by a cross-Channel flight on Saturday, 21 May. He flew from Les Barraques to a large meadow some distance inland from the South Forelands Lighthouse. His machine was a Bleriot fitted with a Gnome rotary engine, and his time for the journey was 37 min. Another entrant for the Reuinart Prize was the Hon. C. S. Rolls, who, however, was in no way deterred by the prior success of de Lesseps from his ambition to be the first Britisher to cross the Channel. Bad weather prevented his attempt for several days, and some delays were also caused through engine trouble. A satisfactory day at last dawned on 2 June, and at half-past six in the evening Rolls left the British coast on his French-built Wright biplane. He crossed the French shore about one and a half miles east of Sangatte at about a quarter-past seven, and returned to British soil just after eight o'clock, without alighting in France. Before starting on his homeward journey, he successfully "posted" a letter addressed to the Aero Club of France.

Also at the end of June there was held at Wolverhampton the first meeting confined entirely to British flyers, but the interest and importance of this event was overshadowed by the Bournemouth meeting, which took place early in July. At Bournemouth, the pick of modern pilots competed for a very valuable prize fund, and their achievements showed what extraordinary advance had been made as compared with the accomplishments at Blackpool in the preceding year.

The long-distance flights, as such, were not specially remarkable, but a sea flight, which consisted of a journey from the aerodrome to the Needles and back, was an important feature of the meeting, and the prize offered in connection therewith was won by Morane. J. A. Drexel and Grahame-White also successfully accomplished this flight, while Robert Loraine, well known as an actor, but then flying under the name of "Jones," made a plucky if ill-judged start in stormy weather, and was forced to descend on the Isle of Wight. Much anxiety was naturally felt at his absence, but news of his safety was received in due course, and at a later date, and in more favourable weather, he flew back again to the mainland.

Special events, such as a slow-speed test, which was won by the Hon. C. S. Rolls at 25·3 m.p.h., a weight-carrying contest, a starting prize and a prize for alighting, were also included in the programme. The latter event, which took place on the second day of the meeting, was so ill-fated as to result in the death of C. S. Rolls, whose absence from the arena of flight none have since ceased to regret.

After the Bournemouth meeting a flight of considerable interest was carried out by J. A. Drexel, who flew his Bleriot from the aerodrome to the Drexel-McArdle aviation school in the New Forest. He was accompanied by H. Delacombe, who made manuscript notes of his observations *en route*. Apart from its general interest, this experiment was in the main performed in order to prove that such a record would be legible, and that useful observations of the surrounding country might be made from such a position by a military officer.

In August, another international meeting took place at Lanark, in Scotland, which many of the Bournemouth competitors attended, but as competitions were held simultaneously at Blackpool, the interest and importance of these events was divided. Among the outstanding features of the Blackpool meeting were the ascent of Chavez on a Bleriot monoplane to an altitude of 5887 ft., and the coast flights of Robert Loraine and Grahame-White. Some weeks afterwards, on Sunday, 11 September, Loraine flew the Irish Channel, but failed to make a landing on Irish soil by a matter of yards: both he and his machine, however, were safely rescued from the water.

The most important Continental event in August was the Circuit de l'Est, an aerial tour organized by *Le Matin*, and comprising a series of cross-country flights forming a circuit from Paris via Troyes, Nancy, Mézières, Douai, and Amiens. Eight competitors started and two finished, Leblanc and Aubrun. Both flew Bleriot monoplanes fitted with Gnome engines, and Leblanc, the winner, who secured the £4000 prize, with, in addition, several special prizes for flights made at the various stopping-places, occupied 12 hr. 1 min. 1 sec. for the journey of 500 miles. Aubrun's time was 13 hr. 31 min. 9 sec.

The realm of flight has been remarkable for the rapid development of individual pilots, but even the most progressive were surpassed in boldness by J. B. Moissant, who, after a phenomenally short apprenticeship, set out with his mechanic to fly from Paris to London on his Bleriot monoplane. He left the Issy aerodrome on Tuesday afternoon, 16 August, 1910, halted at Amiens at 7.30 p.m., where he remained overnight, and flew to Calais early the next morning. Before noon he had crossed the Channel and made a safe descent near Tilmanstone, about seven miles from Dover. The next day he got as far as Sittingbourne, where a forced descent was made, owing to a broken valve rod, and after this was repaired a short flight as far as Rainham was all that could be accomplished before the engine again gave trouble. Persistent ill fortune then dogged his attempts to finish his journey, and other descents were made at Gillingham, Wrotham, and Kemsing, near Sevenoaks, before he finally reached the Beckenham Cricket Ground on Tuesday, 6 September, after an interval of exactly three weeks !

During September, 1910, the Army manœuvres in France gave an opportunity for demonstrating an aspect of the utility of flight that was always regarded as one of the most important of its probable fields of definite development. The aeroplane in war introduced an unknown quantity in military operations, and great interest naturally attached to the possibilities and limitations of the " new arm." In France they were not slow to take advantage of the occasion, and very good work was done of a kind that certainly aroused favourable comment from others besides French military experts.

Late in the same month another milestone in the history of the development of flight was erected, but unfortunately, over the grave of Chavez, who lost his life while landing after crossing the Alps. On 29 September, Chavez started from Brigue to fly across the Alps by way of the Simplon Pass. In fifty minutes he had flown 35 miles from the starting-point, and was then above Domo D'Ossola, where he decided to alight. While effecting the landing he capsized the machine within a short distance of the ground, and was himself so badly hurt that he died of his injuries. Doubt enshrouds the cause of this, as of many other accidents, but it is at any rate plausible to believe that after an effort of this magnitude the plucky pilot was so exhausted as to have miscalculated the last act of his great achievement.

In October a new aerodrome was opened at Hendon, on the outskirts of London, and became the head-quarters of the Bleriot School in England, and also of the Aeronautical Syndicate, which thereupon commenced the commercial manufacture of an original design by H. Barber of an all-British monoplane known as the Valkyrie. During the year, Brooklands, which was first used as an aerodrome by Paulhan for demonstration flights subsequently to the Blackpool meeting of last year, was also developed into a well-equipped flight ground, and became the scene of constant practice on the part of many new-comers. Indeed, it was the activity at Brooklands that best showed the true spirit of the movement at this date.

Towards the end of the month three British pilots, Claude Grahame-White, J. Radley, and Alec Ogilvie, left for America, in order to compete for the Gordon-Bennett Cup, which had been won by Curtiss last year. This event Grahame-White turned into a British victory.

Activity in England then began to centre round the events for the British Michelin Cup and the Baron de Forest £4000 prize for the longest flight from England to any place on the Continent. These events brought forward with startling suddenness a new pilot in T. O. M. Sopwith, who after a very short pupilage obtained his certificate, and put up a flight of over 100 miles on the Brooklands aerodrome. Almost immediately afterwards he seized a favourable opportunity to fly into Belgium, thereby temporarily holding the records for both the Michelin and de Forest prizes at one and the same time. S. F. Cody, who had previously flown nearly 100 miles for the British Michelin Cup, regained his position in the interim, but four days before the end of the year Alec Ogilvie flew 142 miles over the Camber sands near Rye. This achievement, notable in itself, was the more interesting inasmuch as the engine employed on this occasion was a new two-stroke N.E.C. motor, on the development of which a great deal of time and money had been spent by the manufacturers. Fate made great sport with chance on the Michelin Cup flights of 1910, for on the last day of the year Sopwith, who had returned to Brooklands, flew 150 miles, and was himself beaten at the eleventh hour by Cody, who flew 185 miles 787 yards over Laffan's Plain. By this victory S. F. Cody won a well-merited success, for none had been more persevering than he in his development of the aeroplane in England.

The French Michelin Cup, which also closed at the end of the year, was won by Tabuteau, who flew his Farman biplane for an approximate distance of 365 miles in 7 hr. 48 min.

Bad weather prevented competition for the de Forest prize being as keen as it might have been, and indeed the gales were so severe that some machines were wrecked in their sheds at Dover. Another was subsequently destroyed by fire. Cecil Grace, however, at last managed to make a start, but when he had crossed the Channel he was forced to descend, owing to the increasing wind. An improvement during the afternoon decided him to try to fly back to England, but during the return passage he lost his way in the fog and was drowned. In him England lost another of her best men, whose interest in the movement extended well into the science as well as the art of flight.

Many others, too, lost their lives this year, often, it is to be feared, through an over-ambitious anxiety to do great deeds with a little experience. Few remembered the example of the Wrights, who progressed slowly that they might be sure.

In America especially many phenomenal performances took place, often on Wright machines, for the Syndicate controlling the patents at this time decided that their immediate field of public activity should be concentrated on demonstration flights rather than manufacture. Among the pilots retained for this purpose two, who unfortunately lost their lives, were in the habit of electrifying sightseers with sensational airmanship of an extraordinary order. Descending, nay, almost dropping from great heights to get sufficient velocity, these pilots would execute spiral turns by banking their machines to an excessive angle, and one came to grief by actually turning over sideways in mid-air.

In 1911 the great event of the year was the Circuit of Britain for the second £10,000 prize offered by the *Daily Mail.* It was won by Lieut. Conneau, of the French Army, flying under the name of "Beaumont," after a close and exciting race with Vedrines, who was also from France. Many wonderful performances had been made before, but this was certainly the most wonderful of all, for these competitors flew daily stages of their circuit in all sorts of weather, that taxed not only the skill of the pilot, but the physical and mental endurance of the man. It was, in fact, a feat comprising so many difficulties, that all who followed its progress and realized its import recognized that they were witnessing an effort of altogether exceptional character. S. F. Cody and J. Valentine also completed this difficult course within the stipulated time limit. In so far as its general interest expelled some of the characteristic apathy of the Englishman to new developments, it accomplished a good purpose, but so much did it point to the extraordinary qualities of the pilots as the main cause of their success, that there was a tendency in some quarters to regard flying as more than ever a trick at which the few might excel, but the majority never learn.

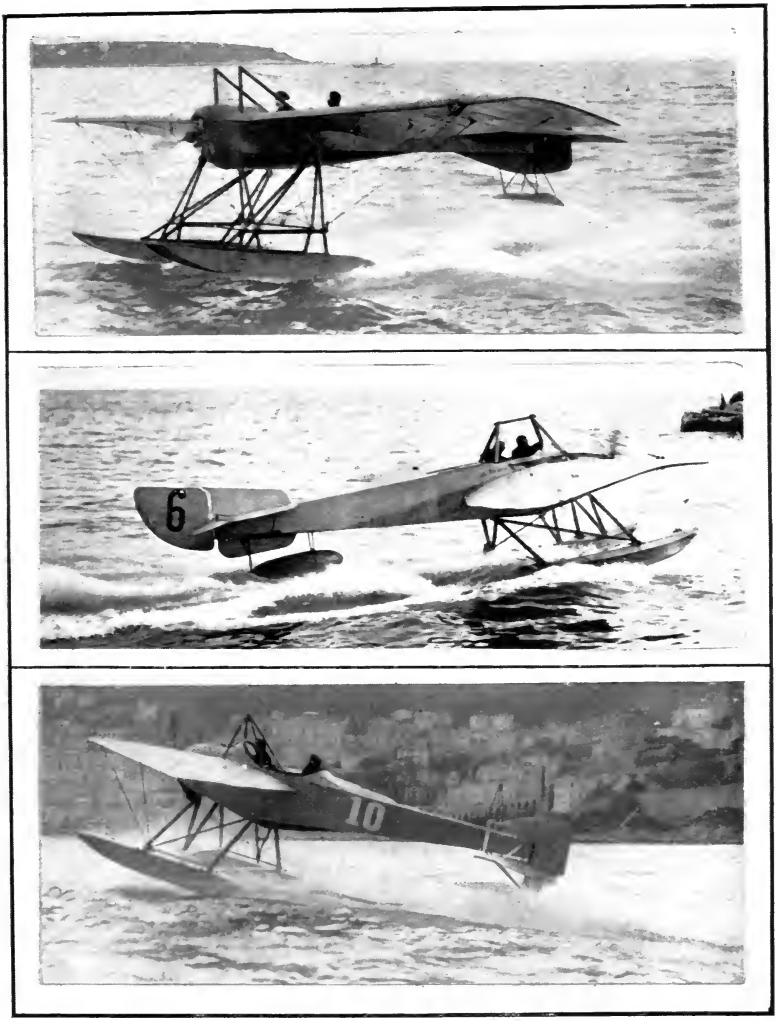
From this time, however, the centre of interest gradually transferred itself from private flying to the military use of aeroplanes, and in England the chief consideration of those engaged in the far from prosperous industry was how soon the Government would undertake the proper equipment of the Army with British-built machines. The first step to this end was the establishment of the Royal Flying Corps in the place of the Air Battalion, and the acquisition of a large piece of ground at Upavon, on Salisbury Plain, where was subsequently established a Central Flying School for the final training of naval, military, and civilian pilots who, having already taken their certificates privately, were desirous of joining the R.F.C.

Preparations were also started for holding a competition for military aeroplanes, which thus became the central feature of the subsequent year, and afforded incidentally a considerable amount of reliable technical data that hitherto had not been available.

The Army manœuvres followed the trials, and afforded an opportunity for a further important display of military aeronautics. Unfortunately, two serious accidents to service monoplanes marred the occasion, and gave rise to an inquiry by a departmental committee, the report of which suggested various minor alterations to existing machines, but in no way condemned the type.

A most valuable technical report was also published at the end of 1912 by the Government Advisory Committee for Aeronautics, which was established in April, 1909, under the Presidency of Lord Rayleigh, O.M., F.R.S., with Dr. R. T. Glazebrook, C.B., F.R.S., as Chairman. Two previous reports had been issued, but neither possessed quite the same direct interest to the practical constructor as that issued at the end of 1912. The Advisory Committee is responsible for the initiation of the scale model research conducted at the National Physical Laboratory, and for the sanction of the full scale experiments carried out at the Royal Aircraft Factory now under the superintendence of Mr. Mervyn O'Gorman, C.B.

During the summer of 1912 a new phase of flying suddenly assumed importance through the successful operation of several hydro-aeroplanes designed to arise and alight on the water. With the introduction of flying into the Navy, the hydro-aeroplane was naturally a *sine qua non* from the first, and its importance from the manufacturer's standpoint was soon to be demonstrated by the prevalence of such machines at the third British Aero Show organized by the Society of Motor Manufacturers, with the assistance of the Royal Aero Club, which was held at Olympia during a week in February, 1913.



Reproduced from "Flight"

Hydro-monoplanes getting up speed on the water preparatory to becoming "unstuck." The upper picture shows a Deperdussin, and the middle view is of a Nieuport, the floats of which have a triple-stepped keel about twelve inches wide; the lower photograph shows a Borel, which, like the "Dep.," has flat floats.

PART IV

INTRODUCTION

IN this part of the book will be found a collection of memoranda that could not properly have been included in the body of the text. Certain matters of technical interest have been dealt with in greater detail than would have been in keeping with the introductory nature of the other parts; also, numerical examples of an elementary character have been added for the benefit of those who desire to pursue the study of the subject in this direction.

Tables and formulae have been compiled to more than cover the requirements of those making such calculations, but they will doubtless be found of general utility to the technical student.

Needless to say, the assistance of readers who are kind enough to point out errors and to suggest useful additions will be very much appreciated by the author.

TERMINOLOGY

EVERY specialized subject has its own terminology, and even when the chosen words are commonplace their usage is necessarily of a technical character. Although I have endeavoured to make this book self-explanatory in the text, it will perhaps be as well if those who now approach the subject of aviation for the first time familiarize themselves in advance with certain of the more usual words.

Many French words are at present in common use for things that might just as well be described in English, and in the text I have avoided foreign terms as far as possible. Some of them are given below, however, for general convenience of reference.

As often happens in the early stages of a new science, the seeds of future confusion are sown by pioneers who choose words without considering all their current usages. Thus, the term *drift* is a term much used in aerodynamics to express resistance. That it harmonizes with *lift* (e.g. the lift and drift of a wing) is the most that can be said for it in this connection. On other and more serious grounds it should be abandoned in this sense, for it already possesses a nautical significance implying drifting with the stream. In this latter meaning also it is much needed in aeronautical terminology.

The word *plane* seems beyond salvation ; its usage as a term descriptive of the main supporting members of an aeroplane is too deep-rooted to be changed. In the text I have used, as much as possible, the word *wing* instead of plane. As the wings of aeroplanes are not flat but cambered, it is necessary to speak sometimes of a cambered plane.

The term *aerofoil* is used instead of cambered plane by some writers, but is not generally popular. The word *aeroplane* essentially belongs to the machine as a whole : it is descriptive of a class of flying machine that supports itself by its motion in flight.

Monoplanes and *biplanes* are merely types in the aeroplane class. The monoplane has a single pair of wings, like a bird ; the biplane has two superposed planes. The difference is merely a question of the arrangement of the supporting surface : when the wing area is very large it is more usual to dispose it in two layers, and such a machine therefore becomes a biplane.

A *glider* is an aeroplane without an engine. It flies downhill, like an aerial toboggan.

In speaking of the subject of aerial navigation at large it is preferable to use the word *aeronautics* to imply the entire science. *Aviation* relates to the art of flying, and *aerodynamics* is the science of the forces created by relative motion in air. It is thus the science of the aeroplane: which kind of aircraft is the only machine that is thus far successful in flight.

It is important to distinguish between the aeroplane and the *airship*; the latter floats by the aid of its balloon. The airship is a dirigible balloon, being able to navigate against the wind: it is often called a *dirigible* for short. The present volume does not deal with this side of aeronautics.

A ground set apart for aircraft is called an *aerodrome*, but some early writers have used this term to mean an aeroplane. Sheds for aircraft are sometimes called by the French word *hangars*.

Another French word at present in common use is *fuselage*, meaning the girder-like backbone employed in modern aeroplane design. This member also forms the *body* of the machine. The term *chassis* has such a well-known reference to the motor-car that it may be said to be an adopted English word. Used in connection with aeroplanes, it means the *undercarriage* that supports the machine on the ground.

French terms that are used in connection with the flight of an aeroplane include such expressions as *vol plane*, meaning a *gliding* descent with the engine shut off, and *vol piqué*, meaning a *dive*, or descent at a very steep angle. When a machine flies with its tail abnormally low in respect to the head of the machine it is said to be *cabré*. The tail of the machine itself is, in French, the *empennage*. Monoplanes usually have a pyramid-like *mast* over the pilot's cockpit; it is called in French a *cabane*. Biplanes sometimes have flaps called *ailerons* attached to their main planes for balancing purposes.

The above are the more frequently heard French words relating to aeroplanes and flying generally, and although they are avoided as far as possible in the text this reference to them is made for general convenience of those who may find them elsewhere.

There is one technical word in particular to which it seems well to call special attention—*efficiency*. This term has but one meaning to the engineer, to whom it represents the ratio of the useful work done to the energy expended in doing it. Thus, technically, the only justifiable use of the word is in the form of a percentage, e.g. 80% efficiency, etc. The sole criterion as to the technical justification of the use of the word in any particular case is, therefore, determined by whether or no it is possible to define 100% efficiency. When there is obviously no such theoretical limit to the relationship to which the term *efficiency* has been applied, its use, technically speaking, is improper.

But the ramparts of this exclusiveness have been much battered. The lay public uses the term in an indefinite sense, implying a vague merit. Technical writers, and I one of them, are sometimes guilty of making a convenience of the expression in connection with the ratios that are not efficiencies in the true technical sense of the term; but in this book I have endeavoured to avoid its use wherever it is not properly justified by the above definition.

"Flight" Copyright Photo

DUAL CONTROL

The above photograph illustrates a Deperdussin monoplane fitted with dual control so that two pilots can alternately take charge while in flight. Marcel Prevost is seated in front, with Capt. G. Dawes, R.F.C., behind.

CLUBS AND INSTITUTIONS

THE *Royal Aero Club* (166 Piccadilly) is the representative of Great Britain on the International Aeronautic Federation, which exercises jurisdiction over all matters of sport, records, etc. It is open to all who are interested and eligible to join, on the same lines as any other sporting club.

Pilots' certificates are issued by the R.Ae.C., and all who wish to fly in public must first obtain this certificate. It is recognized by all other clubs affiliated to the F.A.I.

The R.Ae.C. is also the authority to whom to apply for official observation of special performances for which it is desired to obtain a certificate.

The official notices of the R.Ae.C. appear in *Flight,* which is sent to members every week.

The Public Safety and Accidents Investigation Committee was formed by the Royal Aero Club. Representatives of the Aeronautical Society sit on this committee by invitation of the R.Ae.C. Communications should be addressed to the Secretary, Mr. H. E. Perrin, at 166 Piccadilly.

The Aeronautical Society (11 Adam Street, Adelphi) is devoted more particularly to the scientific side of the movement, to the encouragement of experimental research, and to the organization of lectures and discussions. These latter take place once a fortnight during the session.

Membership is open to all who are interested in the subject, and ladies are admitted to membership. For those qualified technically, there is a Fellowship Grade within the membership of the Society to which members can be transferred, subject to the approval of the council and the membership generally. The object of the Fellowship Grade is to confer a technical status on those elected thereto, in the same way that membership of certain technical institutions is solely reserved for technically qualified persons.

The National Aerial Defence Association (11 Victoria Street) was founded in 1913 by the Navy League as a non-party organization for influencing public opinion in favour of adequate British aerial defence. Its object is to support any Government in power that has a vigorous programme laid down for that purpose, and to work harmoniously with the R.Ae.C. and Aeronautical

Society in the promotion of public interest in matters relating to aeronautics generally. Its policy excludes the purchase of aeroplanes for the Government on the principle that the provision of armament is a parliamentary duty.

The Aerial League (104 High Holborn). General propaganda and, in particular, the organization of popular lectures.

The British Woman's Patriotic League (65 Sinclair Road, Kensington). General propaganda and the collection of funds for the development of National Aeronautics.

The Woman's Patriotic Aerial League (25 Denison House, Vauxhall Bridge Road). General propaganda and the collection of funds for the development of National Aeronautics.

The Imperial Air Fleet Committee (104 Shoe Lane, E.C.). Founded mainly for the purpose of obtaining subscriptions for the purpose of presenting aeroplanes to the Governments of our overseas dominions. The first such aeroplane was presented to New Zealand.

The Society of Motor Manufacturers and Traders (Maxwell House, Arundel Street, W.C.), representing the Automobile Industry, organizes and defrays the cost of the Annual Aero Show, which is held in conjunction with the R.Ae.C. There is a permanent sub-committee of the S.M.M.T. representing aeronautical interests.

BIBLIOGRAPHY

THE following are a few of the books that should be included in any aeronautical library:

Technical Report of the Advisory Committee for Aeronautics. Published yearly (commencing 1909) by H.M. Stationery Office and sold by Wyman & Sons, Fetter Lane, E.C. Contains particulars of the experimental work conducted at the National Physical Laboratory and at the Royal Aircraft Factory.

Eiffel's *La Résistance de l'Air et l'Aviation.* Published with the complement in 1911, by H. Dunod et E. Pinat, 47 Quai des Grands-Augustins, Paris. Contains particulars of Eiffel's experiments at his laboratories in the Champ de Mars and at Auteuil. English Edition, translated by J. C. Hunsaker, published by Constable & Co., London, and Houghton Mifflin Co., New York.

Bulletin de l'Institut Aerotechnique de l'Universite de Paris. Published by H. Dunod et Pinat, 47 Quai des Grands-Augustins, Paris.

Rendiconti delle esperienza e degli studi eseguiti nello stabilimento de esperienze e construzioni aeronautiche del genio. Published by Cav. V. Salviucci, Viale Giulio Caesare N. 2, Roma.

Bulletin de l'Institut Aerodynamique de Koutchino. Published by the Institution in 1906, 1909, 1911, and 1912. Contains the records of the researches conducted under the direction of D. Riabouchinsky.

Stanton's *Resistance of Plane Surfaces in a Uniform Current of Air,* and *Experiments on Wind Pressure.* Published in 1907 and 1908 by the National Physical Laboratory, Bushy House, Teddington.

Langley's *Experiments in Aerodynamics,* and *The Internal Work of the Wind.* Published in 1891 and 1893 by the Smithsonian Institution, Washington, U.S.A.

Alexander See's *Les Lois Experimentales de l'Aviation.* Published in 1911 by Libraire Aeronautique, 32 Rue Madame, Paris.

Lanchester's *Aerial Flight.* Published in 1907 by Constable and Co., Orange Street, Leicester Square. In two volumes. The first volume, entitled *Aerodynamics,* is a treatise on the theory of motion in air, the lift and resistance of aerofoils, etc. The

second volume, entitled *Aerodonetics*, relates more particularly to experiments with models.

Greenhill's *Dynamics of Mechanical Flight*. Published in 1912 by Constable & Co., 10 Orange Street, Leicester Square. A mathematical treatise on the subject, originally delivered in the form of lectures at the Imperial College of Science and Technology, in March, 1911.

Bryan's *Stability in Aviation*. Published in 1911 by Macmillan & Co., St. Martin's Street, London. A treatise giving the form for the mathematical treatment of problems relating to equilibrium in air.

Duchene's *Mechanics of the Aeroplane*. Translated by J. H. Ledeboer and T. O'B. Hubbard. Published in 1912 by Longmans, Green, & Co., 39 Paternoster Row. An up-to-date, straightforward, and well-arranged introduction to the practical science of aviation.

Marey's *Vol des Oisseaux*. Published in 1890 by G. Masson, 120 Boulevard St. Germain, Paris. An investigation of the movements of birds in flight

Mouillard's *L'Empire de l'Air*. Published in 1881 by G. Masson, 120 Boulevard St. Germain, Paris.

Lilienthal's *Bird Flight as the Basis of Aviation*. Published in German in 1891. Translated by A. W. Isenthal in 1911. Published by Longmans, Green, & Co., 39 Paternoster Row, London.

The Aeronautical Classics. A series of six small books published by the Aeronautical Society, 11 Adam Street, Adelphi. Edited for the Council by T. O'B. Hubbard and J. H. Ledeboer. The object of their publication was to preserve in a convenient form the writings of Sir George Cayley, F. H. Wenham, Thomas Walker, Francesco Lana, Percy S. Pilcher, John Stringfellow, and Giovanni Borelli.

Means' *Epitome of the Aeronautical Annual*. Published in 1910 by W. B. Clarke & Co., 23 Tremont Street, Boston, Mass., U.S.A. This volume forms a collection of the more important articles originally printed in the three volumes of the *Aeronautical Annual* published in 1895, 1896, and 1897. Edited by James Means. It contains Lilienthal's own account of his experiments, also articles by Octave Chanute, Sir Hiram Maxim, Pilcher, and Langley.

Henry De La Vaulx' *Triomphe de la Navigation Aerienne*. Published in 1912 by Jules Tallandier, 75 Rue Dareau, Paris. A review of all phases of aeronautics, including ballooning, by one who played an intimate part in their development.

Hildebrandt's *Airships, Past and Present*. Translated by W. H. Story. Published in 1908 by Constable & Co., 10 Orange Street, Leicester Square. Captain Hildebrandt was instructor in the Prussian Balloon Corps, and his work affords an interesting résumé of the progress in military ballooning and the use of dirigibles up to that date.

Moedebeck's *Pocket-book of Aeronautics.* Translated by W. M. Varley. Published in 1907 by Whittaker & Co. A concise collection of aeronautical data, more particularly relating to ballooning.

The results of the researches at the Göttingen Model Testing Institution, under the direction of Professor G. Prandtl, are published in the German periodical *Zeit für Flugtechnic und Motorluftschiffahrt.* Abstracts of the more important foreign memoranda of this kind are to be found in the Appendices to the Technical Reports.

Index to certain special articles in *Flight* that may be needed for reference in respect to subjects mentioned in this book :—

Vol. V

1913 "Stability and Control" (A. E. Berriman), p. 34 *et seq.*
"Negative Wing Tips" (J. H. Hume Rothery), p. 64 *et seq.*
"Hydro Aeroplanes" (V. E. Johnson), p. 72 *et seq.*
"Notes on Machines" (Lieut. Parke), p. 69.
"Flying Experiences" (G. M. Dyott), p. 58, p. 138.
"Stability Devices"* (Mervyn O'Gorman), p. 161 *et seq.*
"Monoplane Committee's Report, p. 154.
"Military Aviation"* (Maj. F. H. Sykes), p. 277.
"Wright Patent Decision," p. 300.
"Flying Fish," p. 302.
"Teaching Flying" (L. W. F. Turner), p. 326.
"Aerial Navigation Act," p. 284.
"Laws of Similitude"* (L. Bairstow), p. 330.
"Bird Flight" (E. F. Andrews), p. 334.
1912 "Germany and France, their Air Fleets," p. 1160.
"Engines"* (A. Graham Clark), p. 1178.
"Aviation in India" (C. E. Esdaile), p. 1018.
"Military Trials. Judges' Report," p. 986.
"Elevator Action of Rudder" (Maj. Brocklehurst), p. 853.
"Army Manoeuvres (Official)," p. 851.
"Parke's Dive," p. 787.
"Measurement of Gliding Angle," p. 746.
"Royal Flying Corps," p. 346, p. 371, p. 510.
"Bleriot Control" (E. L. Ovington, pilot), p. 494.
"Wilbur Wright," p. 458.
"The Magnetic Compass" (E. H. Clift), p. 163 *et seq.*
"Soaring Flight,"* p. 123.
1911 "Observations on Bird Flight" (Dr. E. H. Hankin).

* Indicates a paper contributed to the Aeronautical Society or some other technical institution.

PRINCIPAL JOURNALS IN THE FOREIGN AERONAUTICAL PRESS

FRANCE

L'Aerophile. Official organ of the Aero Club de France. Fortnightly. Subscription 18 fr. per annum. 35 Rue Francois 1er, Paris (VIII^{e}).

L'Aero. Daily. 35 fr. per annum. 23 Bvd. des Italiens, Paris.

GERMANY

Zeit. für Flugtechnic und Motorluftschiffahrt. Official organ of the Imperial Flying Club. Fortnightly. 15 marks per annum. Publishers: Verlag von R. Oldenbourg, Munich. General Editor: Ing. Ausbert Vorreiter, Berlin, W. 57, Bülowstrasse 73.

Deutsche Luftfahrer Zeitschrift. Fortnightly. 16 marks per annum. Publishers: Verlag Klasing and Co., G.m.b.H., Berlin, W. 9, Linkstrasse 38. General Editor: H. W. L. Moedebeck. Berlin W. 30, Nollendorfplatz 3.

AMERICA

Aero Club of America Bulletin. Monthly. 3.50 dollars per annum. 420 W. 13th Street, New York City.

Aeronautics. Monthly. 25 cents per copy. 250 W. 54th Street, New York City.

Aircraft. Monthly. 2 dollars per annum. 37 E. 28th Street, New York City.

Aero and Hydro. Weekly. 4 dollars per year. 537 S. Dearborn Street, Chicago.

CHRONOLOGY

1452–1519 Leonardo da Vinci invented the ornithopter (flapping-wing type), the helicopter (lifting-screw type), and the parachute.

1670 Francesco Lana designed an airship supported by vacuum globes.

1782 Montgolfier invented the hot-air balloon.

1783 Rozier made the first balloon ascent.
Robert built a hydrogen gas balloon.

1785 Blanchard crossed the Channel in a balloon with Dr. Jeffries (7 January).

1804 Laplace recommended French Government to find funds for balloon research, and Gay Lussac and Biot were selected to give this recommendation effect.

1809–10 Cayley wrote his articles on flight and aeroplane design in *Nicholson's Journal.*

1821 Green used coal gas in balloons.

1842 Henson and Stringfellow began their investigations.

1848 Stringfellow succeeded in making his large model aeroplane to fly with a small steam-engine.

1852 Giffard built a dirigible fitted with a steam-engine.

1859 Goddard in charge of French war balloons used in the campaign against Italy.

1862 Glaisher selected by the British Association to carry out scientific balloon experiments.

1866 Aeronautical Society founded (12 January).

1868 Aeronautical Society's First Exhibition at the Crystal Palace.

1874 Pénaud introduced the elastic-driven toy aeroplane for experimental purposes.
British military balloon school established at Chatham.

1884 Renard built "La France," an electrically propelled dirigible, and the first to manœuvre in a figure of eight.

1885 Aeronautical Society's Second Exhibition at the Alexandra Palace.

1890 Ader began his flying experiments.

1891 Langley's experiments in aerodynamics published by the Smithsonian Institute, Washington.

Lilienthal commenced his gliding experiments in Germany.

1893 Hargrave invented the box-kite in Australia.

Maxim made an accidental free flight with his captive aeroplane.

1895 Pilcher commenced his gliding experiments in England.

1896 Chanute introduced gliding in America.

1900 Wright and his brother built their first glider.

1902 Lebaudy built the first practical military dirigible for the French Government.

1903 The Wrights made their first free flight with a motor-driven aeroplane (17 December).

1906 Santos Dumont won the first flight prize (23 October).

1907 The American Army Signal Corps invited tenders for army aeroplanes (23 December).

1908 Henry Farman won the Grand Prix with his Voisin biplane (13 January).

Wilbur Wright commenced flying in France (August).

Flight, first aero weekly in the world, founded (5 Nov.).

First Aero Salon, Paris (December).

1909 Cody began to make successful flights with the British Army biplane.

First British Aero Show at Olympia (March).

Hubert Latham alighted in the Channel while trying to fly from France.

Bleriot flew the Channel (Sunday, 25 July).

First Gordon-Bennett race at Rheims won by Curtiss for America (August).

First British flight meeting at Blackpool (October).

Paulhan gave demonstration flights at Brooklands over motor track, the ground enclosed by which was subsequently prepared as an aerodrome (October).

J. T. C. Moore-Brabazon won the *Daily Mail* £1,000 for a circular mile flight, with a Short biplane (October).

1910 Aero Club of the United Kingdom receives the Royal prefix (February).

Meeting at Heliopolis, Egypt (February).

J. T. C. Moore-Brabazon won the first British Michelin Cup, for longest distance, with a flight of nineteen miles on a Short biplane (March).

1910 Second British Aero Show (March).

London to Manchester flight won by Paulhan (27–28 April).

Jacques de Lesseps flew the Channel (May).

C. S. Rolls flew across to France and returned without alighting (June).

Bournemouth meeting (July).

Circuit de L'Est (August.)

Robert Lorraine flew the Irish Channel and alighted in the sea (September).

Aeroplanes at the French Army Manœuvres (September).

Chavez crossed the Alps, and was killed while alighting (September).

Hendon aerodrome opened (October).

Second Gordon-Bennett race in America won by Claude Grahame-White for Britain (November).

T. O. M. Sopwith flew into Belgium.

S. F. Cody won the second British Michelin Cup with a flight of 185 miles 787 yards on a Cody biplane, with a Green engine (December).

Cecil Grace drowned in the Channel, having flown into a fog while returning from France (December).

1911 Capt. Bellenger flew from Paris to Bordeaux (90 kiloms. in 5 hr. 10 min. net time) (February).

Aeroplane first used in war by Hamilton, who flew over Ciudad Juarez, while fighting was in progress between the Mexican rebels and the Royalist troops, and reported the situation to the latter (February).

Prier flew from Hendon to Paris, non-stop (April).

Paris-Madrid race won by Vedrines (May).

Aerial Navigation Act (June).

European Circuit won by Lieut. Conneau (" Beaumont ") (June).

Third Gordon-Bennett race held at Eastchurch, and won by Weymann for America (July).

Circuit of Britain for the *Daily Mail* £1,000, won by Lieut. Conneau (" Beaumont "), with Vedrines a close second. Cody and Valentine also finished the course within the stipulated time-limit (July).

Fourny flew 720 kiloms. in eleven consecutive hours (September).

Garros attained 13,943 feet altitude (September).

French Military Aeroplane Trials (October).

The Wrights practise soaring flight in America (October).

1911 Cody won the third long-distance British Michelin Cup (now known as Cup No. 1, there having been introduced a second cup by the Michelin firm which is known as Cup No. 2, for the quickest time over a given course (October). Cody won the British Michelin Cup No. 2 (October).

1912 British Army Estimates provided a vote of £308,000 for the Aerial Services (February).

French Army Estimates provided a vote of £880,000 to be spent on aircraft (February).

Formation of the Royal Flying Corps (March).

Tabuteau flew from Pau to Paris in a single day (March).

Vedrines conducted an electioneering campaign by aeroplane in France (March).

French Army temporarily suspended the use of monoplanes on a report by Bleriot respecting top bracing (March).

Mr. Roger Wallace, K.C., retired from Chairmanship of the Royal Aero Club and succeeded by Sir C. D. Rose, Bart. (March).

Appointment of a Public Safety and Accident Investigation Committee by the R.Ae.C. and the Aeronautical Society invited to nominate representatives (March).

Miss Harriet Quimby flew the Channel (April).

Corbett Wilson flew the Irish Channel and was the first to land on the Irish soil (April).

The French Minister of War reviewed twenty-six fully equipped aeronautical units (April).

Daily Mail inaugurated an expansive scheme of aeroplane tours about the country in order to arouse popular interest in flying (May).

Wilbur Wright died from typhoid fever in America (May).

Garros won the Grand Prix of the French Aero Club, which was flown over the Anjou circuit.

T. O. M. Sopwith won the Aerial Derby, consisting of a flight round London, organized by the *Daily Mail* (June).

H.M. King George V became the patron of the Royal Aero Club (June).

Hubert Latham killed by a buffalo while big-game shooting on the Congo (July).

Military Aeroplane Trials on Salisbury Plain (August).

G. de Havilland made a British height record of 9500 ft. with the Royal Aircraft Factory's biplane B.E. 2.

Paris-Berlin flight by Audemars (August).

Provisional ban on Army monoplanes following fatal accidents during the Army manœuvres. A committee of inquiry appointed to investigate (September).

1912 Aeroplanes and small dirigibles played an important part in the military manœuvres (September).
Fourth Gordon-Bennett race held in America and won by Vedrines for France (September).
Paris Aero Salon (November).
Aeroplanes in the Balkan War (November).

1913 Bieolvucie flew across the Alps (January).
Bider flew from Pau to Madrid (January).
Report on Army monoplanes issued (February).
Fourth Aero Show at Olympia (February).
R.F.C. squadron at Montrose established (March).
Decision of foreign courts in the Wright patent litigation (March).
Monaco Hydro-aeroplane meeting (April).
Death of Sir C. D. Rose, M.P., Chairman of the Royal Aero Club (April).
Election of the Marquess of Tullibardine, M.V.O., D.S.O., M.P., to the Chairmanship of the Royal Aero Club (May).
Mansion House meeting for Aerial Defence organised by the Navy League (May).
M. Brindejonc des Moulinais prosecuted under the Aerial Navigation Acts for flying into England without giving notice (May).
The British Government offers £5000 as a prize for British engines (June).
Robert Slack flew from Paris to London (July).
Mr. Joynson-Hicks, M.P., and Mr. Sandys, M.P., disclose to Parliament the unfavourable result of their investigations into the state and number of aeroplanes possessed by the R.F.C. (August).
Cody killed by a fall during a flight on his new biplane (August).
Commander Felix flies a Dunne biplane from England to France.
First start of the *Daily Mail* waterplane race round Britain (August).
On a second attempt, H. G. Hawker flew from Southampton via Yarmouth, Scarborough, Aberdeen, Cromarty, the Caledonian Canal, Oban, and Larne to within about 18 miles of Dublin, where he met with an accident that disabled his Sopwith biplane. He was flying with a six-cylinder Green engine of about 100 h.-p. Starting at half-past five on Monday morning, he arrived at Oban on Tuesday afternoon. He was awarded a consolation prize of £1000.

WORLD'S RECORDS CERTIFIED BY

I. Time for a given distance on a closed circuit :

	Pilot Alone.				With One Passenger.				With Two Passengers.			
Kiloms.	Pilot.	Time.			Pilot.	Time.			Pilot.	Time.		
		h.	m.	s.		h.	m.	s.		h.	m.	s.
5	J. Vedrines	0	1	43⅖	H. Bier	0	2	58	Ch. Nieuport	0	2	52
10	J. Vedrines	0	3	28	Legagneux	0	4	24⅘	Ch. Nieuport	0	5	45
20	J. Vedrines	0	6	56	Legagneux	0	8	51	Ed. Nieuport	0	11	59⅖
30	J. Vedrines	0	10	32⅗	Legagneux	0	13	18⅗	Ed. Nieuport	0	17	52⅗
40	J. Vedrines	0	14	3⅗	Legagneux	0	17	44⅘	Ed. Nieuport	0	22	44⅖
50	J. Vedrines	0	17	35	Legagneux	0	23	13	Ed. Nieuport	0	29	37⅖
100	J. Vedrines	0	35	16⅘	Legagneux	0	44	36⅗	Ed. Nieuport	0	59	8
150	J. Vedrines	0	52	52⅘	Legagneux	1	7	10	—		—	
200	J. Vedrines	1	10	55	H. Bier	2	3	49	—		—	
250	M. Tabuteau	2	7	54	H. Bier	2	39	37	—		—	
300	M. Gobioni	2	49	0	—		—		—		—	
350	Gilbert	3	26	16	—		—		—		—	
400	Gilbert	3	55	27⅗	—		—		—		—	
450	Gilbert	4	24	44⅖	—		—		—		—	
500	Gilbert	4	54	6⅕	—		—		—		—	
600	Gilbert	5	52	38	—		—		—		—	
700	Fourny	9	34	1	—		—		—		—	
800	Fourny	10	44	45⅘	—		—		—		—	
900	Fourny	11	59	9⅗	—		—		—		—	
1000	Fourny	13	1	12	—		—		—		—	

II. Absolute fastest speed for a distance of 5 kiloms. during a closed circuit flight

		Speed. k.p.h.		Speed. k.p.h.		Speed. k.p.h.
5	J. Vedrines	174·100	G. Legagneux	135·952	Ed. Nieuport	102·855

III. Absolute greatest distance in a closed circuit :

	Distance. kiloms.		Distance. kiloms.		Distance. kiloms.
Fourny	1010·900	Lt. Barrington-Kennett	401·500	Bier	112·000

IV. Absolute longest duration in a closed circuit :

	Duration. h. m. s.		Duration. h. m. s.		Duration. h. m. s.
Fourny	13 17 57⅕	Souvelack	4 35 0	H. Oeterich	2 41 0

V. Absolute greatest altitude :

	Altitude. metres.		Altitude. metres.		Altitude. metres.
Garros	5610	v. Blaschke	4630	v. Blaschke	3580

VI. Distance in a given time :

Hours.		Distance. kiloms.		Distance. kiloms.		
¼	J. Vedrines	45·664	Legagneux	31·020	—	—
½	J. Vedrines	84·665	Legagneux	66·639	—	—
1	J. Vedrines	168·244	Legagneux	133·469	—	—
2	Tabuteau	234·431	P. Mandelli	190·858	—	—
3	Tabuteau	310·281	Leoel	224·850	—	—
4	Gilbert	410·900	—	—	—	—
5	Gilbert	510·000	—	—	—	—
6	P. M. Bournique	490·000	—	—	—	—
7	Tabuteau	522·935	—	—	—	—
8	Fourny	585·200	—	—	—	—
9	Fourny	661·200	—	—	—	—
10	Fourny	744·800	—	—	—	—
11	Fourny	820·800	—	—	—	—
12	Fourny	904·400	—	—	—	—
13	Fourny	980·400	—	—	—	—

HE F.A.I. UP TO 31 DEC., 1912

With Three Passengers.		With Four Passengers.		With Five Passengers.	
Pilot.	Time.	Pilot.	Time.	Pilot.	Time.
	h. m. s.		h. m. s.		h. m. s.
P. Mandelli	0 3 48	Busson	0 3 34	—	—
Busson	0 6 16$\frac{3}{5}$	Busson	0 7 8	—	—
P. Mandelli	0 12 3	Busson	0 14 0$\frac{3}{5}$	—	—
P. Mandelli	0 17 37	—	—	—	—
P. Mandelli	0 23 11	—	—	—	—
P. Mandelli	0 29 47	—	—	—	—
P. Mandelli	0 56 33	—	—	—	—
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—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
	Speed. k.p.h.		Speed. k.p.h.		
P. Mandelli	106·029	Busson	87·251	—	—
	Distance. kiloms.		Distance. kiloms.		
P. Mandelli	110·000	Busson	25·740	—	—
	Duration. h. m. s.		Duration. h. m. s.		Duration. h. m. s.
Grolich	1 35 0	A. Faller	1 18 0	Molla	1 6 48$\frac{1}{5}$
	Altitude. metres.		Altitude. metres.		
Sablatnig	1120	Verschaeve	596	—	—
	Distance. kiloms.				
—	—	—	—	—	—
—	—	—	—	—	—
P. Mandelli	106·029	—	—	—	—
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THE ROYAL FLYING CORPS

THE development of aeronautics for service purposes in England commenced with experiments with captive balloons at Aldershot in 1862. Military ballooning was formally introduced into the Army in 1879, a balloon school being established at Chatham. In the next year the 24th Company of Royal Engineers was selected for special instruction in aeronautics.

The Royal Flying Corps was formed in 1912 and absorbed the Air Battalion that formerly represented military aviation in England. While the Royal Flying Corps represents what is in some respects a distinct arm of the service, its administration comes partly under the War Office and partly under the Admiralty. Thus there are two wings, military and naval, but the personnel of both wings is supplied from a Central Flying School, which trains soldiers, sailors, and civilians in flying and in the mechanics of aviation. From the Central Flying School, officers and men are drafted into the Naval or Military Wing as the case may be.

Experimental scientific work is conducted under the general direction of the "Advisory Committee," which was appointed by the Prime Minister in 1909 and sits once a month. The research itself is partly carried out on a model scale at the National Physical Laboratory, and in part on a full scale at the Royal Aircraft Factory.

A standing sub-committee of the Committee of Imperial Defence and known as the "Air Committee" has been appointed by the Army Council to co-ordinate action in dealing with questions that arise in connection with the Royal Flying Corps. The present chairman of this committee is Brig.-Gen. D. Henderson, Director of Military Training.

The following abstracts from various official documents give the more important items of information that may be required for reference.

From the official memorandum on the formation of the Corps:

"The necessity for an efficient aeronautical service in this country not less urgent than in the case of the other Powers.

" The organization should be capable of absorbing and utilizing the whole of the aeronautical resources of the country.

" While it is admitted that the needs of the Navy and Army differ, and that each requires technical development peculiar to sea and land warfare respectively, the foundation of the requirements of each service is identical, viz. an adequate number of efficient flying men. Hence, though each service requires an establishment suitable to its own special needs, the aerial branch of one service should be regarded as a reserve to the aerial branch of the other. Thus in a purely naval war the whole of the Royal Flying Corps should be available for the Navy, and in a purely land war the whole corps should be available for the Army.

" At present no military requirements beyond those of the Expeditionary Force, which are of urgent importance, are being dealt with.

" The purposes for which aeroplanes will be required in land warfare are as follows :

(*a*) Reconnaissance.
(*b*) Prevention of enemy's reconnaissance.
(*c*) Intercommunication.
(*d*) Observation of artillery fire.
(*e*) Infliction of damage on the enemy.

" Having considered the organization of the aeronautical forces of other Powers, so far as information is available, the establishments laid down below would appear to provide a suitable organization for the Expeditionary Force of 6 divisions and 1 cavalry division, viz. :

" Head-quarters.

" 7 Aeroplane Squadrons, each providing 12 aeroplanes.

" 1 Airship and Kite Squadron, providing 2 airships and 2 flights of kites.

" 1 line of communication flying corps workshop.

" For the future, the Military Wing of the Royal Flying Corps comprises all branches of aeronautics, including aeroplanes, airships, and kites. All these are required for the same purpose, and should work in close co-operation.

" The total number of aeroplanes required for the seven squadrons of the military division will be eighty-four.

" To provide the war establishment for the seven Aeroplane Squadrons that are considered necessary for our Expeditionary Force, 182 officer flyers and 182 non-commissioned officer flyers are required.

" It is considered that the minimum number of trained flyers should be two per aeroplane. Of these one should be an officer, and, in the case of one-seated machines, both should be officers. For purposes of calculation, however, one officer and one non-commissioned officer flyer are allowed. The number of flyers required on this basis is shown below:

"7 Squadrons.—Officers: commanders, 7; 3 sections, 84; total, 91. Non-commissioned officers: sergeants, 7; 3 sections, 84; total, 91.

"In addition, it is necessary to provide a Reserve to meet casualties, and it is considered that this should be on a basis of 100 per cent for six months' wastage.

"The total number of flyers required will therefore be:

	Officers	N.C.O.'s
For war establishment and 7 squadrons ..	91	91
Reserve	91	91
Total	182	182

"*Conditions of Service.*—Entry to the Royal Flying Corps as officers will ultimately be confined to those who have graduated at the Central Flying School. These officers will be drawn from (*a*) officers of all branches of the naval and military services, and (*b*) civilians. The rank and file will consist of warrant officers, petty officers, non-commissioned officers and men transferred from the Royal Navy or the Army, and also of men enlisted directly into the Royal Flying Corps, either on a regular or a special reserve basis. At the conclusion of their training they should be eligible to be appointed either (*a*) for continuous service in the Naval or Military Wing of the Royal Flying Corps, or (*b*) to the permanent staff of the Flying School, or (*c*) to the Royal Flying Corps Reserve.

"The period of appointment in the case of officers, who elect for continuous service with the Naval or Military Wings of the Royal Flying Corps or at the Central Flying School, will normally be 4 years.

"Civilian candidates for appointment to the Royal Flying Corps as officers apply in the first instance to the Commandant of the Central Flying School, quoting the number of their Royal Aero Club certificate.

"Great importance is attached to the primary condition that every member of the Royal Flying Corps shall incur a definite obligation to serve in time of war either for naval or military purposes in any part of the world.

"It is essential that all combatant officers in the Royal Flying Corps should be practical flying men.

"For the present, military officers and civilians who are candidates for commissions in the Royal Flying Corps first have to obtain their Royal Aero Club certificate, and on being accepted as members of the Royal Flying Corps receive the sum of £75.

" *Naval Wing*.—The Naval Flying School at Eastchurch will, for administrative purposes only, be provisionally under the orders of the Captain of H.M. ship *Actæon*, and all officers and men will be borne on the books of the *Actæon*.

" *Central Flying School*.—The Central Flying School is established on Salisbury Plain, on ground south-east of Upavon.

" There are three courses at the Central Flying School during the year, each course lasts 4 months.

" The training includes:

(i) Progressive instruction in the art of flying.
(ii) Instruction in the general principles of mechanics and the construction of engines and aeroplanes.
(iii) Instruction in meteorology.
(iv) Training in observation from the air.
(v) Instruction in navigation and flying by compass.
(vi) Training in cross-country flights.
(vii) Photography from aircraft.
(viii) Signalling by all methods.
(ix) Instruction in types of warships of all nations.

" *The R.F.C. Reserve*.—The officers of the Reserve of the Royal Flying Corps are divided into two classes; the officers of the First Reserve are required to produce on the first day of each quarter satisfactory evidence that they have performed during the previous quarter flights amounting to an aggregate of nine hours in the air, and including one cross-country flight of not less than one hour's duration. These conditions are subject to modification in particular cases. Flyers of the Second Reserve need not be required to carry out any flights, but are available for service in the Royal Flying Corps in time of war.

" *Royal Aircraft Factory*.—The existing Army Aircraft Factory has been renamed the 'Royal Aircraft Factory.' It will be administered by the War Office. It should carry out the following functions:

(1) The higher training of mechanics for the Royal Flying Corps.
(2) Repairs and reconstruction for the Royal Flying Corps.
(3) Tests with British and foreign engines and aeroplanes.
(4) Experimental work.
(5) The existing work in the manufacture of hydrogen, and generally meeting the requirements of the Airship and Kite Squadron.
(6) General maintenance of the factory at present.

" *Pay.*—Abstracts from Army Order :

	Ordinary Pay	Flying Pay
Squadron Commander	25s.	8s.
Flight Commander	17s.	
Flying officer	12s.	

" The order continues that His Majesty the King's will and pleasure is that :

" Flying pay may be issued during leave on the same conditions as staff pay. Subject to this, flying pay may be issued continuously to officers serving in the aeroplane squadrons and to officers who are qualified aeroplane flyers serving in the airship and kite squadron. Officers serving in the airship and kite squadron who are not qualified aeroplane flyers shall receive flying pay at the above rate for each day on which they make an ascent by airship or kite.

" 2. The pay of other officers shall be as follows :

" Commanding Officer, Military Wing, £800 a year, with quarters. Medical Officer, pay and allowances of his rank.

" If the medical officer is required to fly, the Army Council shall decide what emoluments he shall receive with reference to the special circumstances of the case.

" 3. The pay of the Staff of the Central Flying School shall be as follows :

Commandant ..	£1,200 a year, with quarters.
Instructor.. ..	The emoluments laid down for a Squadron Commander in Article 1.
Quartermaster..	As laid down in Article 138 of the Pay Warrant.

" 4. Officers shall be seconded for service in Our Royal Flying Corps from the date they satisfactorily complete such period of instruction at the Central Flying School as Our Army Council may prescribe. Whilst undergoing this period of instruction they shall receive the regimental emoluments of which they were previously in receipt, and shall in addition receive flying pay at the rate of 4s. a day.

" 5. The period of an officer's service in Our Royal Flying Corps, shall, subject to his remaining fit for flying duties, be 4 years, but it may be prolonged at the discretion of Our Army Council.

" 6. Officers appointed from civil life to Our Special Reserve of Officers for service in Our Royal Flying Corps shall, whilst under instruction at the Central Flying School, be considered as on probation, and shall receive regimental pay at the rates appointed for infantry officers of Our Special Reserve of Officers, together with flying pay at the rate laid down in Article 4. Their period of service shall be as laid down in Article 5. On the satisfactory completion of the period of instruction prescribed by Our Army Council their commissions may be confirmed and they shall then be graded as flying officers. They shall thereafter be eligible to receive while employed on flying duties the emoluments laid down in Article 1, except when performing the quarterly flying test referred to in Articles 7 and 8. They shall also be eligible to receive an outfit allowance of £40 under the conditions prescribed for other officers of Our Special Reserve of Officers.

"7. Officers who are not serving continuously in Our Royal Flying Corps shall form the Reserve of Our Royal Flying Corps. The officers of this Reserve shall consist of two classes. Officers of the First Reserve shall be required to perform a quarterly flying test to be prescribed by Our Army Council. Officers who do not perform a quarterly flying test shall form the Second Reserve of Our Royal Flying Corps.

"8. Officers appointed to Our Special Reserve of Officers for service in Our Royal Flying Corps who are serving in the First Reserve shall in consideration of their holding themselves liable for service with Our Navy or Army at home or abroad, and of the performance of the quarterly test, receive in place of the gratuity of £20 issued to other officers of Our Special Reserve of Officers an annual gratuity of £50 payable under conditions to be prescribed by Our Army Council. Officers of Our Regular Army of the First Reserve of Our Royal Flying Corps shall receive for such number of days as may be found necessary (regard being had to weather conditions) for the proper performance of their test, the regimental emoluments of their rank, together with flying pay at the rate laid down in Article 1.

"9. Officers of the Second Reserve shall receive no special emoluments as such.

"*Warrant Officers, Non-commissioned Officers and Men*

"10. The daily rates of pay of men enlisted or transferred to serve in the Military Wing of Our Royal Flying Corps shall be as follows: Warrant officer, 9s.; sergeant, 6s.; first-class air mechanic, 4s.; second-class air mechanic, 2s.

"They shall in addition be eligible to receive flying pay at the rate of 4s. or 2s. a day, according to their flying proficiency under such conditions as may be laid down by Our Army Council. Warrant officers and others serving in the airship and kite squadron shall, unless they are qualified aeroplane flyers, receive flying pay at the rate of 2s. a day for each day on which they make an ascent by airship or kite.

"11. Warrant officers, non-commissioned officers and men of Our Royal Flying Corps Special Reserve shall receive pay and flying pay at the same rates and under the same conditions as under Article 10, when employed on Army duty. Whilst undergoing an enlistment instruction in flying at the Central Flying School, they shall draw the rates of pay laid down in Article 10, and in addition flying pay at the rate of 1s. a day.

" 12. Warrant officers, non-commissioned officers and men, other than those serving continuously in Our Royal Flying Corps, shall, if performing the quarterly tests to be prescribed by Our Army Council, be granted annual gratuities as follows:

" (*a*) Whilst serving with the colours, £10.

" (*b*) Whilst serving in Our Army Reserve, or in Our Special Reserve, £20.

" Warrant officers, non-commissioned officers and men serving in Our Army Reserve or Our Special Reserve who do not engage to perform the quarterly test to be prescribed by Our Army Council, shall be granted a gratuity of £10. The conditions and method of issue shall be determined by Our Army Council.

" 13. Army reservists shall not, in addition to the gratuities payable under Article 12, be entitled to pay under Article 1199 of the Pay Warrant, and warrant officers, non-commissioned officers and men of Our Royal Flying Corps Special Reserve shall not be eligible to receive recruits' bounty, training bounty, or non-training bounty.

" *Gratuities and Special Pensions*

" 14. Officers who are:

(*a*) Members of Our Royal Flying Corps,
(*b*) Members of Our Special Reserve of Officers (Royal Flying Corps),
(*c*) Undergoing a private course of instruction, having previously been selected by Our Army Council for military flying work,
(*d*) Undergoing a course of instruction at the Central Flying School,

shall if injured on flying duty, be eligible for gratuities and pensions under the conditions and at the rates laid down in the Pay Warrant for officers who have been wounded in action.

" In the event of death within 7 years as the result of injuries so received, pensions, etc., may be awarded to the officer's widow and children or other relatives, under the conditions applicable to the case of officers killed in action or dying of wounds received in action.

" 15. Warrant officers, non-commissioned officers and men of Our Royal Flying Corps, or of Our Royal Flying Corps Special Reserve, discharged in consequence of injuries received on flying duty shall be eligible for pensions under the conditions and at the rates laid down for their respective ranks in the Pay Warrant in the case of men discharged for wounds received in action.

“ In the event of death within 7 years as the result of injuries so received, pensions and compassionate allowances may similarly be awarded to the widow and children of a warrant officer, non-commissioned officer, or man.”

“ *Army Estimates, Aviation Vote*

“ The total provision for the above services made in the 1912–13 Estimates compares with that made in 1911–12, as follows :

	1912–13 £	1911–12 £
Establishment of Army personnel for aeronautical work	25,000	20,000
Premiums to officers gaining pilots' certificates	3,000	—
Staff of new school	5,000	—
Aeroplanes, stores, and materials for factory and school	161,000	85,000
Buildings, including Army share of school buildings	38,000	26,000
Land for school	90,000	—
	322,000	131,000
Less Admiralty contribution to general expenses of school	14,000	—
	308,000	131,000
Increased provision	£177,000 ”	

“ Excluding provision for land, the sums taken in 1913–14 compare with those taken in 1912–13 as follows :

	1913–14 £	1912–13 £
Establishment of Army personnel, including Special Reserve and premiums for pilots' certificates	150,500	28,000
Staff of school	18,500	5,000
Aeroplanes, mechanical transport, stores, and materials	285,000	161,000
Buildings, including Army share of school buildings	72,000	38,000
	526,000	232,000
Less Admiralty contribution towards school	25,000	14,000
Net provision	501,000	218,000
Increase	283,000 ”	

“ Provision (not included in the above figures) has also been made for guns for the attack of aircraft.”

MILITARY TRIALS, 1912

ABSTRACTS FROM THE OFFICIAL REPORT

"ORDER *of importance.*—The Judges' Committee placed the requirements called for in the competition in the following order of importance, and assigned value to them accordingly: Speed, including flexibility of speed, climbing, gliding, landing, view, starting; communication between passenger and pilot, and dual control; sound construction throughout, interchangeability of parts, and compactness and convenience of handling. No competing aeroplane had a silenced engine, and, therefore, the difficulty of measuring relative efficiency in this particular did not enter into the awards. The low position in the above list given to sound construction is due to the fact that those aeroplanes which were considered in the awards all complied generally with the broad requirements in this respect. The difficulty of judging accurately the capability of an aeroplane to face rough weather is so great that, in spite of its supreme importance, it was considered unwise to allot a high value to it. The Judges' Committee, however, included this kind of stability among other impressions of general excellence which they formed during the course of the trials, and to which due weight was given.

"*Order of Merit Obtained.*—Ten of the competing aeroplanes were placed by the Judges' Committee in order of merit as follows:

1. Cody biplane (British), No. 31.
2. Deperdussin monoplane (French), No. 26.
3. { Hanriot monoplane (French), No. 1 .. } Equal.
   { Maurice Farman biplane (French), No. 22 }
5. { Bleriot tandem monoplane (French), No. 4 } Equal.
   { Hanriot monoplane (French), No. 2 .. }
7. { Deperdussin monoplane (British), No. 21 .. }
   { Bristol monoplane (British), No. 14 .. } Equal.
   { Bristol monoplane (British), No. 15 .. }
10. Bleriot Sociable monoplane (French), No. 5.

"Certain of these aeroplanes did not fulfil some one of the requirements called for, but all were considered to be efficient machines. The standard of excellence attained by several of the competing aeroplanes brought them very close together in the final assignment of positions in the order of merit, although their particular merits were of a widely varying nature. The Judges' Committee were unanimous in the selection given above.

"*The Awards.*—The Army Council, on the recommendation of the Judges' Committee, have awarded the following prizes in connection with the Military Aeroplane Competition.

Prizes open to the world:

First prize, £4000, to S. F. Cody, for Cody biplane (British).
Second prize, £2000, to A. Deperdussin, for the Deperdussin monoplane (French), No. 26.

Prizes open to British subjects, for aeroplanes manufactured wholly (except the engine) in the United Kingdom:

First prize, £1000, to S. F. Cody.

"As no other British aeroplane completed all the tests, the two second prizes will be withheld, but the three third prizes of £500 each are awarded to:

British Deperdussin Co., for Dep., No. 21.
British and Colonial Co., for Bristol monoplane, No. 14.
British and Colonial Co., for Bristol monoplane, No. 15.

"The following entrants, whose aeroplanes were submitted to all the tests, will receive £100 in respect of each aeroplane:

M. Ducrocq, for Hanriot monoplanes (French), Nos. 1 and 2.
Aircraft Co., for Maurice Farman biplane (French), No. 22.
L. Bleriot, for Bleriot monoplanes (French), Nos. 4 and 5.
A. V. Roe, for Avro biplane (British), No. 7.

ANALYSIS OF THE PERFORMANCES

The accompanying tables contain data relating to the eleven machines that went through the Military Trials. A detailed report of the tests was published in *Flight* at the time of the event. The dimensions of the machines are approximate only, but an attempt has been made to include the more interesting figures. The supporting area includes the tail area where that member is of the lifting type. In the case of the Cody, which has a large load-carrying elevator in front and only a very small horizontal fin on each of the rudder plates behind, the elevator has been included. In other cases, the elevator area is not included in the supporting surface.

The rating of the engines sometimes varies considerably from the power they are known to develop and the calculations have thus been based on values that are believed to be approximately accurate. The engine powers are not, however, based on actual tests of the engines in question.

The machines were weighed during the trials and the weights stated in the tables are, therefore, accurate figures. The weight in flight comprises the weight of the pilot and passenger, which was in all cases made equal to a load of 350 lb. In addition, there is the weight of fuel and oil carried during the three hours' flight. This amount had to be adequate for a flight of 4½ hours' duration, in most cases it slightly exceeded that amount. The weight in flight given in these tables includes such surplus, and, therefore, differs by that amount from the figures given in the official report.

It is interesting to observe how uniformly the different machines work out to a common weight per unit of power when empty. It might be supposed that the structure could be regarded apart from the engine, but the figures tend to show that the aeroplane represents a complete unit in respect to weight for power, and that within the limits of common practice modern aeroplanes weigh about 15 lb. per h.p. available. Two comparatively heavy machines are the Avro biplane and the Maurice Farman biplane. The Cody biplane is about 1 lb. per h.p. heavier than the monoplanes. It had an engine of 120 h.p. as compared with the 60 h.p. engines on the Bleriot monoplanes. As the load carried in flight varied within narrow limits, the weight per h.p. in flight is thus also fairly constant, the Avro biplane and the Maurice Farman biplane again being the heaviest machines per unit of power.

The wing areas varied widely and the wing loading in the table is, of course, calculated on the total weight in flight. The gliding angle was measured by an apparatus carried on board the machine. This instrument simultaneously recorded the relative air speed and the rate of vertical descent, from which could be calculated the average slope. The gliding angle, which for the most part is better than 1 in 6, represents an inclusive measurement of all the resistances obtaining under the conditions of the glide. It is necessary to be cautious, however, about deducing too much from the figures in question as a great deal depends on what the actual conditions were at the time the test was made. A factor of importance, for example, is whether the propeller was rotating during the glide, as the propeller itself would offer considerably more resistance if stationary. The question of best speed also affects the result, as was very evident from the differences in the results of the first and the second attempts that each pilot made in this test. The gliding speeds at which the best gliding angles were measured appear in the tables.

The fastest speed was measured with and against the wind, and the value given is the mean of the values so obtained. The slowest speed, it should be remarked, depended much on the skill and daring of the pilot; in a few instances exceptionally slow speeds were obtained by switching on and off an engine that would not run slow enough when throttled down. The speed range is indicated by the percentage increase represented by the fastest speed over the slowest speed.

The rate of climbing is given in feet per minute and the equivalent power represented by raising the total weight at that rate is also shown. In another column this is expressed as a percentage of the engine power available, assuming 100 per cent efficiency. In general, less than one-fifth of the total engine power is demonstrated in the actual ascent, but allowing for the probable propeller efficiency, the proportion of power available for climbing may be regarded as nearly one-quarter.

Details of the petrol and oil consumption appear in another table and the cost per mile on the basis of petrol at 1s. 6d. per gal. and oil at 4s. 6d. per gal. has also been calculated. It will be observed that the rotary Gnome engine used in some cases one-third as much castor oil for lubrication as it consumed petrol for the development of power. The expense of their lubrication, owing to the higher cost of oil per gallon, is thus very nearly equal to that of the expense of the petrol per mile. Extravagance in oil for lubricating purposes is essentially due to lack of proper regulation in the oil feed and distribution. In the Gnome rotary engine, a quantity of oil escapes through the induction valve in the piston head and so through the exhaust valve in the cylinder head into the atmosphere, where it emerges as very pungent smoke.

Although aeroplanes fly against a resistance of approximately one-sixth of their weight, whereas a motor-car is opposed by no more than about one-fiftieth of its weight, the cost of fuel is comparatively little more in the case of the aeroplane than it is with the motor-car. Thus, even the Cody biplane with its 120 h.p. engine and its total weight of over a ton can be flown for a cost of 2¼d. a mile for petrol. Also, its economy of oil consumption brings the total cost of petrol plus oil to a figure only slightly in excess of 2½d. The Avro biplane with the 60 h.p. Green engine is another notable example of fuel and oil economy, the cost in this case being less than 1¾d. per mile. If speed is taken into consideration the cost per mile-per-hour for a journey of 100 miles on this machine may be represented by 2¾d., which is cheaper than the corresponding value given by any other machine.

The cost of fuel and oil required on an aeroplane is not only an interesting subject to study, but it bears an important relationship to the possible commercial future of aircraft. On first thoughts, the excessive resistance, which causes an aeroplane virtually to travel always uphill when compared with the resistance of such a vehicle as a motor-car, would seem to be all against its chances of utility from the commercial standpoint. It is, of course, a very serious limitation, but on the score of cost the figures in the table show that it suffers no very serious disadvantage provided the structure of the aeroplane is reasonably immune from damage. The straightforward nature of flight in the air and the high average speed thereby attained represent a very economical condition compared with the operation of a motor-car on the usual winding roads. Also, the tyre bill of the motor-car is a very serious item, and although tyres are used on aeroplanes there is no reason why they should seriously affect the expense. The wing fabric does not wear out by its motion through the air, and it can be made reasonably weatherproof. Thus, in the absence of breakages, the chief items in the upkeep of an aeroplane are fuel and oil, and although it is necessary to have a comparatively powerful engine there seems no reason why the expense under this head should not in future be brought down to a very low figure indeed.

One matter of great importance that it is, however, necessary to bear in mind in this connection, is that the motion of the aeroplane is relative to that of the air, and only incidentally relative to the earth. Thus, a machine may fly against the wind and occupy a very long time in reaching its destination. Alternatively it may fly with the wind and so traverse the distance at an abnormally high speed.

In the same table as that containing the cost of fuel, figures are also given showing the range of action on full tanks. The conditions of the Trial specified that the machines were to be capable of flying for 4½ hours without descent, and so the range is thus limited by the speed. It will be noticed, however, that in some cases the oil supply would run short before the fuel tank was empty. Lubrication is just as important to an engine as fuel, and such shortage might be very important in the case of an engine using a special lubricant, such as castor oil, which would not be available so readily as petrol if a forced descent were made in some chance locality for replenishments.

APPROXIMATE DIMENSIONS

Machine	Type	Engine	Span		Chord		Tail	Elevator	Rudder	Length o.a.	Angle of Incidence	Supporting Area
			ft.	in.	ft.	in.	sq. ft.	sq. ft.	sq. ft.	ft.	deg.	sq. ft.
Hanriot 1	Monoplanes	100 h.p. Gnome	41	9	7	6	33−	12	6	—	4°	300
Hanriot 2	Monoplanes	100 h.p. Gnome	41	9	7	6	33−	12	6	—	4°	300
Bleriot Tandem ..	Monoplanes	70 h.p. Gnome	31	6	7	4	31+	16	9	27·3	6° 50′	260
Bleriot Sociable ..	Monoplanes	70 h.p. Gnome	36	7	8	6	—	16	8	27·3	—	310
Avro	Biplane	60 h.p. Green[1]	35	3	4	9	20−	16	10	28·6	4° 30′	335
Bristol 14	Monoplane	80 h.p. Gnome	39	0	6	1	28−	16	19	28	2° 25′	210′
Bristol 15	Monoplane	80 h.p. Gnome	39	0	6	1	28−	16	19	28	2° 25′	210
British Dep. ..	Monoplane	100 h.p. Gnome	41	0	7	0	54+	21	—	24·6	6°	307
Maurice Farman ..	Biplane	70 h.p. Renault	51	8	4	7	130+	50	65	39·10	5° 45′	666
French Dep. ..	Monoplane	100 h.p. Gnome	41	0	7	0	54+	21	5	22·9	6°	307
Cody	Biplane	120 h.p. Austro-Daimler[2]	43	0	5	7	—	65	30	37·4	—	485

[1] Water-cooled.

[2] The span is measured across wing tips and includes body space. The chord is the approximate mean value for tapering wings. The supporting surface includes the tail area when that member is of the lifting type (+), but not when it is of the non-lifting type (−). The angle of incidence is that of the set of the wings to the longitudinal axis of the machine.

WEIGHTS

Machine	Weight empty	Weight in flight	Weight per h.p. empty	Weight per h.p. in flight	Weight per sq. ft.	Estimated Power	Gliding Angle
	lb.	lb.	lb.	lb.	lb.	h.p.	one in
Hanriot 1	1166	1921	14·7	24·0	6·4	80	6·6
Hanriot 2	1160	1898	14·6	23·7	6·34	80	5·9
Bleriot Tan. ..	885	1499	14·7	25·0	5·77	60	5·6
Bleriot Soc. ..	857	1481	14·2	24·7	4·8	60	5·3
Avro	1191	1762	18·4	27·2	5·28	65	6·5
Bristol Mon. 14 ..	1144	1839	15·3	24·5	8·75	75	6·5
Bristol Mon. 15 ..	1159	1871	15·4	25·0	8·9	75	—
British Dep. 21 ..	1226	2037	15·4	—	—	80	6·2
M. Farman ..	1318	1931	18·3	26·8	2·9	72	6·8
Fr. Dep.	1184	1868	14·7	23·4	6·1	80	5·4
Cody	1948	2680	16·2	23·8	5·55	120	6·2

SPEEDS

Machine	Fastest	Slowest	% Increase Fast, Slow	Gliding	Climbing	Equivalent Power of Climb	% of Engine Power
	m.p.h.	m.p.h.	%	m.p.h.	ft./min.	h.p.	%
Hanriot 1	75·2	59·9	25·6	61	365	21·2	26·5
Hanriot 2	75·4	66·6	13·2	68	333	19·1	24·0
Bleriot Tan. ..	60·8	51·0	17·5	—	250	11·3	17·7
Bleriot Soc. ..	58·9	40·0	47·3	52	236	10·6	16·6
Avro	61·8	49·3	25·4	—	105	5·6	8·6
Bristol Mon. 14 ..	70·5	68·3	3·2	64	200	11·1	14·9
Bristol Mon. 15 ..	72·9	58·1	26·0	—	218	12·4	16·6
British Dep. 21 ..	68·2	54·6	26·0	—	267	26·5	20·6
M. Farman ..	55·2	37·4	47·6	38	207	12·1	16·8
French Dep. ..	69·1	59·0	17·1	62	333	18·8	23·5
Cody	72·4	48·5	49·4	59	288	23·4	19·5

CONSUMPTION OF FUEL AND OIL

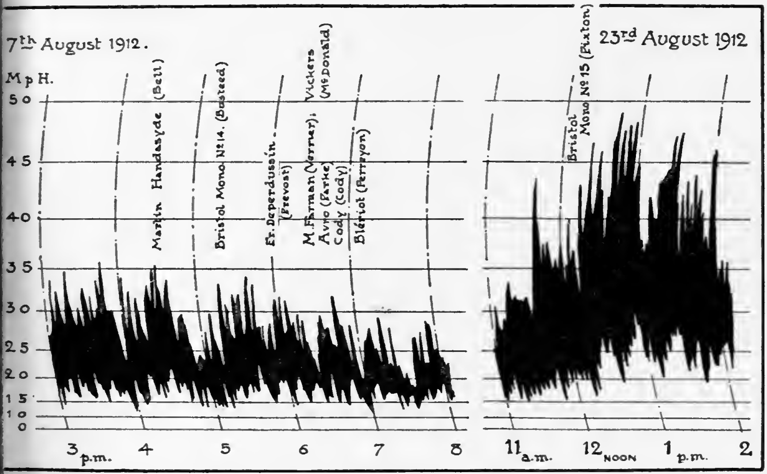
Machine	Engine	Estimated Power	Petrol			Oil		Ratio, Petrol : Oil	Petrol + Oil gals. per hour
			Gallons per hour	Miles per gallon	Ton miles per gallon	Gallons per hour	Miles per gallon		
Hanriot 1 ..	100 h.p. Gnome	80	8·0	9·6	8·16	2·4	33	3·3	10·4
Hanriot 2 ..	100 h.p. Gnome	80	8·6	8·8	7·5	2·1	36	4·2	10·7
Bleriot Tan. ..	70 h.p. Gnome	60	5·4	11·3	7·6	1·7	36	3·1	7·1
Bleriot Soc. ..	70 h.p. Gnome	60	6·3	9·3	5·5	1·7	36	3·7	8·0
Avro	60 h.p. Green	65	4·0	15·0	11·9	·5	120	8·1	4·5
Bristol Mon. 14 ..	80 h.p. Gnome	75	8·0	8·8	7·2	1·7	41	4·7	9·7
Bristol Mon. 15 ..	80 h.p. Gnome	75	7·0	10·4	8·6	1·5	48	4·6	8·5
British Dep. 21 ..	100 h.p. Gnome	80	9·8	6·9	6·3	1·8	38	5·5	11·6
M. Farman ..	70 h.p. Renault	72	7·0	7·9	6·8	·73	76	9·7	7·7
Fr. Dep.	100 h.p. Gnome	80	8·4	8·2	6·2	1·3	52	6·3	9·3
Cody	120 h.p. A.-D.	120	9·0	8·0	9·6	·42	172	21·4	9·4

COST OF FUEL AND OIL PER MILE

Machine	Petrol @ 1/6 gal.	Oil @ 4/6 gal.	Petrol+Oil	Max. Speed	Cost per 'mile per hour' for 100 miles	RANGE OF ACTION ON FULL TANKS		
						Petrol	Oil	Oil ÷ Petrol
	d.	*d.*	*d.*	m.p.h.	*d.*	Miles	Miles	
Hanriot 1	1·88	1·64	3·52	75	4·7	408	400	·98
Hanriot 2	2·05	1·5	3·55	75	4·7	361	406	1·12
Bleriot Tan.	1·59	1·5	3·09	61	5·0	305	295	·97
Bleriot Soc.	1·93	1·5	3·43	59	5·8	252	340	1·35
Avro	1·2	0·45	1·65	62	2·7	345	840	2·42
Bristol Mon. 14	2·05	1·32	3·37	70	4·8	343	328	·95
Bristol Mon. 15	1·73	1·12	2·85	73	3·9	421	420	1·00
British Dep. 21	2·59	1·42	4·01	68	5·9	320	590	1·84
M. Farman	2·38	0·71	3·09	55	5·6	276	266	·96
Fr. Dep. ..	2·2	1·04	3·24	69	4·7	315	379	1·2
Cody	2·25	0·31	2·56	72	3·6	336	740	2·2

WIND CHARTS

TO ignore meteorology in the study of aviation is to neglect the very foundations of the science. The scope of this book, however, does not pretend to do more than state the obvious importance of the connection.



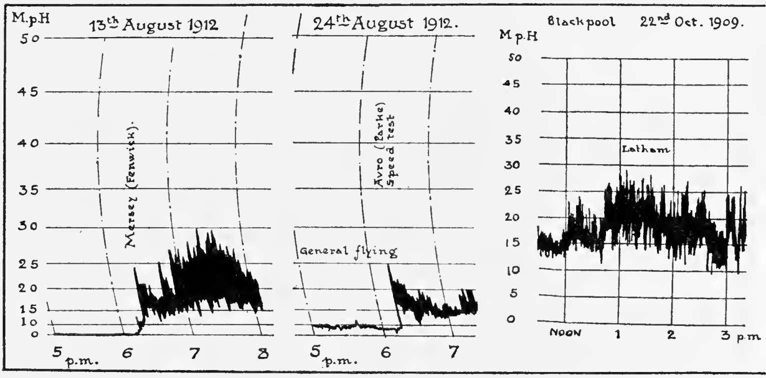
"Flight" Copyright Drawing

Wind charts showing the state of the weather when most of the competitors took their wind tests in the British Military Trials, 1912. On the right is the wind chart for the flight made by Pixton on a Bristol monoplane for a quarter of an hour just after noon on the 23rd August.

The wind charts above are given as a matter of interest and as a record of the state of the art of flying in winds at the period. They relate, with one exception, to the time of the Military Trials in August, 1912. The exception is Hubert Latham's famous flight at the first Blackpool meeting October, 1909. It was an altogether phenomenal performance, and the chart deserves to be recorded. His flight occurred between the hours of 1 and 2 p.m.

Each vertical line on the chart is a wind gust. A very remarkable chart is that showing the state of the air while Pixton flew the Bristol monoplane one noon over Salisbury Plain.

A special and sad interest attaches to the sudden rising of the wind after a dead calm about 20 min. past six on 12 August, 1912. The gust indicated upset the experimental Mersey monoplane, with fatal results. Just such a similar gust occurred at the same time of day and place eleven days later, whilst general flying was in progress. The state of the weather during the wind tests in the Military Trails is indicated in one of the charts, and shows the high general level of the security of the pilots and their machines. Gordon Bell, who led the way on the Martin Handasyde monoplane on that occasion, put up a particularly fine flight.



"*Flight*" *Copyright Drawing*

Wind charts illustrating a remarkable rise in the wind over Salisbury Plain on the 13th and 24th August, 1912. The former gust upset an experimental aeroplane and resulted in a fatal accident. General flying was in progress on the latter date, but there was no accident. On the right is the chart of the wind during the famous flight made by Latham at Blackpool on November 22nd, 1909. Latham's flight took place between 1 and 2 in the afternoon.

ACCIDENTS

THE following opinions and recommendations have been published by the Royal Aero Club, as the result of the investigations of the Accidents Committee into the specific cases to which they refer. The full reports on each case will be found in *Flight*.

" The Committee is of opinion that the cause of the accident was the pilot himself, who failed sufficiently to appreciate the dangerous conditions under which he was making the turn, when the aircraft was flying tail down, and in addition was not flying in a proper manner.

" A sideslip occurred, and the pilot lost control of the aircraft.

" It seems probable that his losing control was caused by his being thrown forward on to the elevating gear, thereby moving this forward involuntarily, which would have had the effect of still further turning the aircraft down. This would explain his being thrown out whilst in the air.

" In the opinion of the Committee it is possible that if the pilot had been suitably strapped into his seat he might have retained control of the aircraft.

" The Committee is of opinion that the cause of the accident was primarily due to the instability of the aircraft, which made it difficult to control in a disturbed atmosphere. That the point where the accident occurred is well known to be one where irregular disturbances of the air are prevalent under certain wind conditions. One of these disturbances must have struck the aircraft, and the pilot eventually lost control.

" The Committee draws the attention of manufacturers, designers, and pilots to the risk involved by want of provision against the consequences of possible failure of parts of the engine or its attachments to the aircraft, when such failure would lead to the breakage of other and vital parts of the structure.

" The Committee is of opinion that the ground in question was unsuitable for the sort of exhibition flights which the pilot was attempting. It was too narrow for a pilot to attempt sharp turns at a low altitude and between spectators on either side of the ground. The inevitable danger from this condition of affairs should be made known to promoters and aviators.

" The attention of manufacturers and pilots is specially drawn to this particular accident, which emphasizes the risk that is run in starting a cross-country flight with an aircraft which, from one cause or another, is under-powered at the time.

" The Committee again draws attention to the primary importance of a good field of view for the pilot.

" Seeing that this is not the first occasion on which wings of the 'Antoinette' type have collapsed in the air, the Committee recommends that the Royal Aero Club should vote a sum of money for the investigation of this design.

" In this particular instance the aircraft was removed by the local authorities almost immediately after the accident and any evidence which could have been obtained from the position or fractures of the parts was thereby lost. A good deal of the woodwork was burnt after the removal. The Committee has already made a recommendation that steps should be taken by the authorities to prevent similar destruction of evidence in future.

" In view of the above recommendation, the Committee unanimously voted a sum of £20 to cover the cost of the investigation.

" The risk that is run by a pilot in persevering in a flight with a faulty engine has already been drawn attention to, and this further accident adds additional emphasis to the danger. This flight, in that it was effected over water at a low altitude, demanded additional precaution.

" When flights over water are habitually attempted, precautionary measures should always be taken, either the aircraft itself should be capable of floating for a reasonable time, or, alternatively, the men should wear, or have available, some appliance for keeping them afloat until rescued."

MONOPLANE COMMITTEE'S REPORT

(ABSTRACTS)

" To the Secretary of State for War.

" The Committee appointed in the early part of October 'to inquire into and report upon the causes of the recent accidents to monoplanes of the Royal Flying Corps and upon the steps, if any, that should be taken to minimize the risk of flying this class of aeroplane,' submit the following report :

" *Chief Conclusions and Recommendations.*—The main conclusions arrived at by the Committee and their recommendations in connection therewith may be briefly summarized.

" (i.) The accidents to monoplanes specially investigated were not due to causes dependent on the class of machine to which they occurred, nor to conditions singular to the monoplane as such.

" (ii.) After consideration of general questions affecting the relative security of monoplanes and biplanes, the Committee have found no reason to recommend the prohibition of the use of monoplanes, provided that certain precautions are taken, some of which are applicable to both classes of aeroplane.

" (iii.) The wings of aeroplanes can, and should, be so designed as to have sufficient strength to resist drift without external bracing.

" (iv.) The main wires should not be brought to parts of the machine always liable to be severely strained on landing.

" (v.) Main wires and warping wires should be so secured as to minimize the risk of damage in getting off the ground, and should be protected from accidental injury.

" (vi.) Main wires and their attachments should be duplicated. The use of a tautness indicator, to avoid overstraining the wires in ' tuning up,' is recommended. Quick-release devices should be carefully considered and tested before their use is permitted.

" (vii.) In view of the grave consequences which may follow fracture of any part of the engine, especially in the case of a rotating engine, means should be taken to secure that a slight damage to the engine will not wreck the machine. Structural parts, the breakage of which may involve total collapse of the aeroplane, should, so far as possible, be kept clear of the engine.

" (viii.) The fabric, more especially in highly loaded machines, should be more securely fastened to the ribs. Devices which will have the effect of preventing tears from spreading should be considered. Makers should be advised that the top surface alone should be capable of supporting the full load.

" (ix.) The makers should be required to furnish satisfactory evidence as to the strength of construction and the factor of safety allowed. In this special attention should be paid to the manner in which the engine is secured to the frame.

" (x.) Engine breakages should be systematically investigated and reported on, and the reports should be submitted to the Advisory Committee for Aeronautics.

" (xi.) No machine should be taken into use until after examination and approved test, and all machines should be regularly inspected, especially after any serious damage or repair. Parts of machines in course of construction should be inspected and passed before being assembled.

" (xii.) Two or three skilled mechanics for each squadron should be specially engaged for a time to act as instructors and so set a standard of technical workmanship.

" (xiii.) In case of any serious accident, care should be taken to preserve and identify damaged portions of the machine which may help to account for the cause. It is desirable to obtain the assistance of the police authorities in this matter.

"56. The Committee also desire to recommend that the following questions be specially referred to the Advisory Committee for Aeronautics for further investigation and report:

"(*a*) The general question of stability of aeroplanes.

"(*b*) Detailed investigation of the strains and stresses in aeroplane wings, especially monoplane wings. Tests on the strength of wooden struts and beams as used in aeroplane work.

"(*c*) Aerodynamic investigation of aeroplane wings designed to have sufficient strength without external bracing.

"(*d*) Investigation into the strength of aeroplane fabrics, wounded and unwounded; and into the effect of the application of dopes and of exposure.

"(*e*) Investigation of engine breakages.

"(*f*) The methods of testing a complete machine and the test conditions to be fulfilled.

"(*g*) Investigation into the conditions of the *vol piqué* in respect to monoplanes and biplanes."

PILOT'S NOTES

I AM indebted to several pilots of great practical experience for the following notes:

To Steer due South.

1. Get into the air against the wind.
2. Look at the compass and steer south by its direction.
3. Look up and ahead quickly, and take note of any landmarks that happen to be in line with the compass course on the card. The objects thus seen will lie due south from the starting-point, for only an inappreciable amount of drift will have occurred during this preliminary manœuvre.
4. Without looking at the compass, proceed to steer the machine straight for the landmarks just chosen. Steer thus for a minute or so, until you *feel* you are progressing satisfactorily towards them. Take no heed of the direction in which the machine is pointing.
5. Without changing the attitude of the machine, glance down quickly at the compass, and set the lubber point against the needle. The lubber point being an adjustable part of the compass case, which is attached to the machine, serves to mark a certain attitude of the machine in respect to the needle of the compass, which is controlled by the earth's magnetism.
6. Continue to keep the needle on the lubber point. If the flight is of long duration, be sure to look out for changes in the wind by keeping a careful note of the direction in which the ground appears to move under the machine. If there is any evidence of a change in the wind it is necessary to reset the lubber point by repeating the original manœuvre.

Cross-country Journeys.

1. Never fly across strange country at less than 3000 feet.
2. Do not attempt cross-country journeys before your skill enables you to make the spiral glides and S-turns that may be necessary if you are to alight safely in a small space in emergency.
3. Ease your engine periodically by gliding down about 1000 feet, but be sure to regain the altitude afterwards.

Landing.

1. Beware of sea breezes and other diurnal changes of the wind that may cause the ground wind to blow in a diametrically

opposite direction to the upper air. Take note of flags, smoke, and other guides that may assist you properly to alight up-wind.

2. Beware of being deceived as to the slope of the ground; it is very difficult to see which way a field slopes when viewing it from above.

Rising.

1. When forcing a machine off a bad surface at a coarse angle and low-flying speed, ease off the elevator slowly once you are in the air. If the angle of the wings is reduced too quickly the machine will strike the surface again, because the acceleration will not yet have provided the necessary speed required to maintain the lift at the finer wing angle.

Banking.

1. Tie a piece of worsted or ribbon, about twelve inches long, to some part of the machine where it is in the line of sight and can fly freely like a flag in the wind. So long as the ribbon flies parallel to the axis of the machine, the aeroplane is properly banked. A sideslip is indicated immediately by the slewing of the ribbon into an oblique position. Most pilots, by underbanking, sideslip outward when turning. All pupils of the late Wilbur Wright use the ribbon; it will also work if tied to the mast of a tractor monoplane.

Gliding.

Fit the machine with an air-speed indicator clear of the propeller draught. Calibrate it by flying the machine level at its normal speed, note the position of the pointer, then set the index mark on the scale to correspond. Afterwards, in flight, the pointer will always be on this mark when the air speed is normal and the gliding slope can be adjusted accordingly. Most pilots who do not use an air-speed indicator descend at an unnecessarily steep angle.

THE WRIGHT PATENT LITIGATION

(From *Flight*, 15 March, 1913.)

“ IT is interesting to observe how the three years’ patent litigation in the United States, Germany and France, on which more than £50,000 has been spent, has now reached its final stage simultaneously in all three countries.

“ In the United States the action against Curtiss is now disposed of, the Court at Buffalo having upheld the validity of the Wright Brothers’ patent.

“ In Germany, the Supreme Court at Leipzig gave its decision orally on 26 February, to the effect that the Wright Brothers were the inventors of the warping *per se* and also of the warping and rudder control combined, but although it did not support the monopoly for the warping by itself, it confirmed the German patent as valid on amendment being made to exclude warping broadly *per se*. The German Court left the claim standing for the combined rudder and warping, without making any stipulation that these two mechanisms need be mechanically connected.

“ The French case has now been heard in Paris, and judgment will be delivered on 19th inst., and seeing that there is no official report of the oral judgment at Leipzig, those interested in France are discussing the German judgment and reading their hopes into the words of the judges. In view of the published opinions by those who were not present, it may be interesting to quote Mr. Orville Wright’s observations made to a representative of the *New York Herald* in Paris on the 7th inst., after his return from being present at the Trial at Leipzig:

“ Mr. Wright said that it is an error to suppose that the decision given by the Leipzig Court recently recognizes as valid or patentable only a mechanical combination, or rather coupling, of the warping wing movement with the aeroplane rudder. On the contrary, this verdict, he asserted, means that all aeroplanes with warping wings and a rudder, notwithstanding that the two be independent one of the other, constitute an infringement of the Wright patents.

“ ‘ The decision of the Supreme Court of Germany at Leipzig,’ continued Mr. Wright, ‘ was an oral one. The written decision will be made public later. After considering the patents of Mouillard, Boulton, Robitsch and Ader, the Court held that we were the inventors of warping, and that it was only on account of disclosures made by our friend Chanute and ourselves, prior to making our application for the patent, that the Court was compelled to reduce the claim so as to exclude warping *per se*. The Court then stated that the function of a rudder on a flying machine is not merely that of a ship's rudder, but that it is a necessity for maintaining balance on a flying machine having warping wings.

" ' It held further that we were the first to discover and use warping wings and rudder together, on the same machine. The Court did not say that the invention was restricted to the mechanical coupling of these two elements, as has been alleged.

" ' That our claim to the patent for the combined use of warping wings and a rudder is a broad one is shown by the fact that the director of a prominent German aeroplane factory called on me in Berlin after the Leipzig decision had been handed down to arrange for a licence to manufacture under the patent. He said : " According to the decision of the Supreme Court every machine built in Germany is an infringement." '

" British manufacturers will no doubt be interested in these foreign judgments, because up to the present, we believe, only one licence has been applied for to work under the Wright patents in England.

" In order to enable the patent situation in Germany to be clearly understood by readers of *Flight*, we have interviewed Mr. Griffith Brewer, who explained this somewhat complicated technical question as follows :

" ' There are two general methods of resisting a patent, one by proving the patent to be bad, and the other by proving the alleged infringement not to come within the scope of the patent. In cases where it is evident that escape by this second channel is not open, actions are brought by the infringers against the owners for the annulment of the patent, because if the patent can be declared void anyone may infringe with impunity.

" ' It was an action to annul the Wright patent which was brought in Germany, and the Supreme Court of Leipzig has now decided to uphold the patent on its scope being reduced to exclude the warping by itself. No other reduction is made in the patent, and, consequently, all aeroplanes which warp and have a vertical rudder, will still infringe the German patent in the same manner they did before the action.

" ' The judges at Leipzig, in giving their decision, expressed the view that the Wright Brothers were the inventors of the warping *per se*, and also of the combined warping and rudder, and they made no statement that the warping and rudder control had to be mechanically connected in order to come within the ambit of the claims. Statements to that limiting effect may therefore be disregarded, and seeing that the judges in an action for annulment are not called upon to interpret whether certain constructions come within the claims, it is obvious that they would not go outside their duties and decide whether or not aeroplanes of certain manufactures came within the claims.

" 'Warping on a machine which does not carry a rudder is thus free to all in Germany, but that is all the decision actually means.' "

Since the above account of the actions was published, the written decisions have been given. In Germany, the written decision differs from the oral one in so far as the breadth of the first claim is not declared, but in France the decision expressly says that the co-existence of rudder and warp on the same machine comes within the scope of the patent. It is now left to the experts to decide whether this broad claim is anticipated in any one of the alleged anticipations.

THE PETROL ENGINE

PETROL is a trade name given to a group of volatile fractions in the paraffin series of hydrocarbons. In America the commodity is known as gasolene; in France it is called *essence*. In the scale of densities and boiling points, the petrol group stands immediately above the lamp oils, which are misnamed in England by the generic title paraffin, and in France by the word *petrole*, but in America are called kerosene.

The chief source of petrol is natural petroleum, which is mined in all parts of the world. Great Britain now derives more than half her supply of petrol from Borneo, Sumatra, and Java, via the "Shell" route through Suez; the remainder, "Pratts," comes from the American fields.

In most natural petroleums the principal constituent is the paraffin series, the gaseous members of which serve to force the crude oil from the wells. Petrol and the other petroleum products are obtained by distillation. In natural petroleum there is commonly only a small percentage of the more volatile benzines that constitute commercial petrol. Owing to the demand for motor spirit increasing out of proportion to the demand for other petroleum products, the distillers have gradually included a small proportion of the heavier fractions, and petrol has steadily increased in density in consequence. At one time it was possible to buy spirit as light as 0.68 specific gravity; now the lower grade petrol is 0.76 sp. gr.

Petrol will ordinarily begin to boil at about 45° C.; about 90% will have distilled below 130° C. When sprayed into the atmosphere it evaporates and forms a combustible mixture that is highly explosive when compressed. In this state it is readily ignited by an electric spark.

The petrol engine works on this principle. One of its accessories is a carburettor, which consists of a simple spraying device, the flow of petrol being regulated by a needle valve controlled by a float. By means of a pipe the engine cylinder communicates with the mixing chamber containing the spray jet; this communication is intercepted at intervals by a valve that is usually opened and closed mechanically, but may operate by the suction of the engine itself.

Assuming the piston to be made to descend from the top of the cylinder, its effect will be to act like the plunger of a suction pump; if the above-mentioned inlet valve is open, it will draw into the cylinder a charge of the combustible mixture provided by the carburettor.

The inlet valve closes soon after the piston has reached the bottom of its stroke, and thereby imprisons the charge, which is subsequently compressed into the combustion space between the piston and the cylinder head as the piston returns to the top.

Just before the piston reaches the top of its stroke, an electric spark is caused to occur at the points of an ignition plug projecting through the cylinder walls. The explosive charge is fired, and the rapid rise in temperature within the cylinder causes a forcible expansion of the imprisoned gases, which press upon the piston, and cause it to perform the one working stroke of its cycle of operations.

Having completed this stroke, another valve in the cylinder head is mechanically opened to permit of the escape of the burnt gases to the atmosphere. The returning piston scavenges the cylinder of the products of combustion, the exhaust valve closes, and the simultaneous opening of the inlet valve is a signal for the cycle of operations to commence all over again.

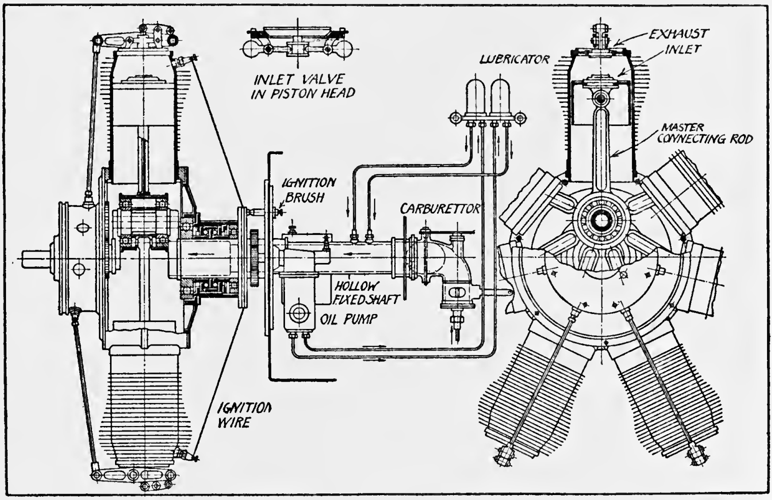
On this four-stroke cycle devised by Beau de Rochas in 1862 most modern petrol engines operate. There is, however, also a two-stroke cycle, in which a working stroke occurs once every revolution, instead of once every two revolutions. In this type of engine, of which the N.E.C. is an example, ports are cut in the cylinder walls, so as to be automatically uncovered by the piston as it approaches the bottom of its stroke. While completing its stroke these ports remain open, and means have to be devised for clearing away the burnt gases and introducing a fresh charge during this brief interval of time.

It is the momentum stored in the flywheel that keeps the engine running between the working strokes; the "rotary" engines serve as their own flywheels, for in such designs, of which the Gnome is an example, the cylinders and crank chamber revolve about the stationary crank shaft. Ordinarily, the cylinders are stationary and the crank shaft revolves.

In order to save weight, some engines, including the rotary engines, have their cylinders arranged radially about the crank chambers. Others have them set in V formation in two rows, and some follow orthodox motor-car practice in arranging the cylinders in line. When the cylinders are radial, one of the pistons is usually connected to a master connecting rod, the big end of which embraces the crank pin in the usual way. To this master big end the other connecting rods are hinged by pins similar to those used for the attachment of the pistons.

In the Gnome engine the inlet valves are situated in the piston heads and are opened by the suction in the cylinder. The mixture from the carburettor enters the crank chamber through the hollow stationary crank shaft that supports the engine, and so gains access to the cylinders through the valves in the piston.

Reverting to the subject of petrol, it is important to recognize that its evaporization, which is facilitated by spraying, is a process demanding heat. This heat is withdrawn from the atmosphere, and, under certain conditions, the lowering of the temperature will cause a deposit of snow and the consequent interruption of further carburation. It is necessary to avoid undue exposure of the carburettor to cold, and it is generally considered desirable to provide it with artificial heat by means of a hot-water jacket, or the proximity of an exhaust pipe when the circumstances are convenient.



"Flight" Copyright Drawing

Sectional drawing of a 50-h.p. Gnome rotary engine. Inset is a sketch of the inlet valve in the piston head; it is fitted with balance weights to compensate for the centrifugal force of rotation. The operating levers of the exhaust valve in the cylinder head are similarly balanced.

Other fuels that have been used with more or less success in motor-car engines comprise lamp oil, a mixture of lamp oil and petrol, benzol, "synthetic petrol," and alcohol. Lamp oil, lacking the volatile fractions, is difficult to start from the cold, but mixed with petrol it serves as a reasonable fuel.

Benzol is a by-product recovered from those coke ovens that are fitted with appropriate apparatus. It is chemically quite different from petrol, being the trade term for a group of the benzene series. Its lowest boiling point is 80° C., so that it, too, is sometimes difficult to start from the cold; it may, however, be mixed with petrol in order to remove this difficulty. It is essentially a by-product, for the benzene series is formed only when coal is distilled at a high temperature (1200° C.), and a high temperature is used only in the production of an illuminating gas and metallurgical coke. Were coal to be distilled commercially for the production of motor spirit, a low temperature (450° C.) would afford a larger yield, and the tar product would belong to the paraffin series, and so yield petrol. The Del Monte process operates on this principle.

"Synthetic petrol" is petrol manufactured out of crude oil that has had all its natural petrol removed by distillation. The crude oil is passed with water through a retort at about 600° C., containing a metallic catalyst in the form of iron turnings or nickel. Having been dissociated with the water in the presence of the catalyst, the elements reform as spirit having the qualities of petrol. The process is also applicable to the treatment of the tar produced by the low temperature distillation of coal. At the moment, it is in the experimental stage.

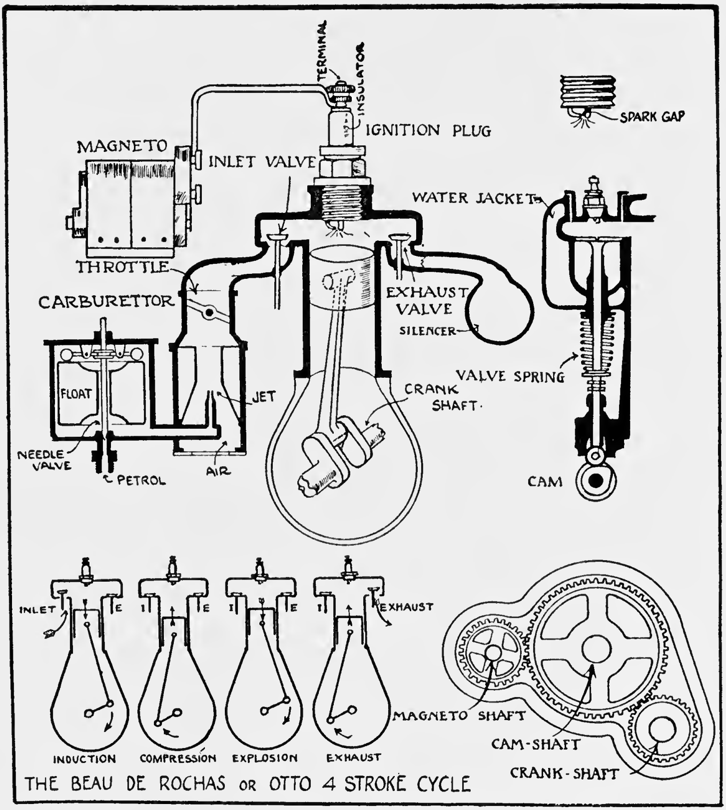
When a paraffin is heated to a temperature above its boiling point it becomes "cracked" into spirit, apparently of the olefine series. To a limited extent "cracking" is adopted in the usual process of distillation, as conducted commercially.

Alcohol, which may be produced by the fermentation of starchy substances like potatoes and grain, has only about one half the thermal value of petrol, and so cannot produce the same amount of power from a given-sized engine. Unless facilities were accorded by the Government, its industrial use as a motor spirit in this country is virtually rendered impossible on account of the expense involved in its methylation to conform with the law. Moreover, methylated spirits is not very suitable for use in a petrol engine.

The heat value of a pound of petrol is, roughly speaking, 20,000 British Thermal Units, and an engine consuming 0.7 lb. of petrol per h.p. hour will thus be supplied with about 14,000 B.Th.U. per hour per h.p. The relationship between heat and work is given by Joules equivalent, which is 772 ft. lb. per B.Th.U. Thus, the energy supplied to the engine in the form of latent heat is $772 \times 14{,}000$ ft. lb. per hour, which is 5.6 h.p. Thus the engine is being supplied with 5.6 h.p. in the form of latent heat in the fuel, and is producing 1 h.p. in the form of mechanical work; the thermal efficiency plus the mechanical efficiency of the engine, therefore, amounts to 18 per cent.

As the work done on internal friction in the engine is work actually accomplished by the heat of the fuel, the pure thermal efficiency is perhaps in the order of 23%. Thus, 77% of the heat is wasted, being in part absorbed by the cylinder walls, and in part discharged with the exhaust.

If the specific heat of the exhaust gas be taken as 0.2, its temperature of ejection as 1000° Fahr. above the atmosphere, and the original mixture to be such that 18 pounds of air is carburetted by 1 lb. of petrol, then the heat lost in the exhaust is in the order of 19%.



"Auto" Copyright Drawing

Diagram illustrating the fundamental component parts of a petrol engine. Petrol enters the carburettor through a needle-valve controlled by a float. It is sucked from the jet by the air entering the cylinder during the induction stroke. When compressed, this explosive mixture is ignited by the spark. The working stroke of the cycle ensues, and is followed by the exhaust.

THE HIGH TENSION MAGNETO

SUMMARY OF A LECTURE DELIVERED BY THE AUTHOR TO THE NATIONAL SOCIETY OF CHAUFFEURS

ELECTRICITY exists in Nature. Several ways are known of making its presence felt. For instance, if a piece of sealing-wax is rubbed with flannel it becomes electrified and will pick up little bits of paper. Again, if you attach a piece of carbon and a piece of zinc to opposite ends of a wire and dip them into a solution of sal-ammoniac in water, a current of electricity will flow in the wire in consequence of the chemical reaction in the cell. A battery of accumulators is charged by the chemical change caused to take place in its plates when a current of electricity passes through them. In return, it supplies its own electricity after charging by a reversal of the chemical action, which finally results in the plates assuming their original condition when the battery is discharged.

When electricity flows in a wire, the wire is surrounded by a sheath of magnetism. When the wire is in the form of a coil wound, for preference, on a soft iron core, the iron becomes a magnet while the electricity flows.

Alternatively, an ordinary coil of wire with its ends joined together will have a current of electricity induced in it if its iron core is magnetized. But the electricity will only manifest itself while the magnetization is taking place ; in short, it will merely be an electric impulse.

Soft iron is readily magnetized by placing it near a permanent steel magnet. If the permanent magnet is of horseshoe form, and the iron is turned round between its poles or extremities so that one end of the iron is first adjacent to the north pole and then to the south pole, the iron will be magnetized, demagnetized, and remagnetized in the opposite sense. If a coil of wire is wound on the piece of iron, an electric impulse will be generated at each change in the magnetization.

This is the basis of the action of a magneto. When the armature revolves, its iron core alternately becomes a magnet in one direction and then in the other.

Electricity so produced is of the pulsating kind; at one moment it is at a maximum, at another it is zero. It is when the electricity is at a maximum that we must produce the spark.

There are two sorts of spark, the low-tension and the high-tension.

If electricity is flowing in a closed conduit, and you switch off the current, the momentum of the electricity will make it jump across the gap. This is a low-tension spark.

If in an open circuit a very sudden impulse of electricity is generated, it may be sufficient to jump a small gap of its own accord without any preliminary closing of the switch. This is the high-tension spark.

Whereas quite a feeble electric pressure suffices to produce a low-tension spark, it needs about 10,000 volts to make a high-tension spark jump even half a millimetre gap under compression.

The advantage of a jump spark is that it avoids moving switches inside the cylinders. In the old days of low-tension magneto systems, the igniter tappet adjustments needed constant attention.

High-tension electricity can be produced from low-tension electricity in a very simple way. If two coils of wire are wound on an iron core, and one of the coils is caused to pulsate with electricity, then the other coil will reproduce the pulsations in sympathy, although it is not electrically connected to the first coil.

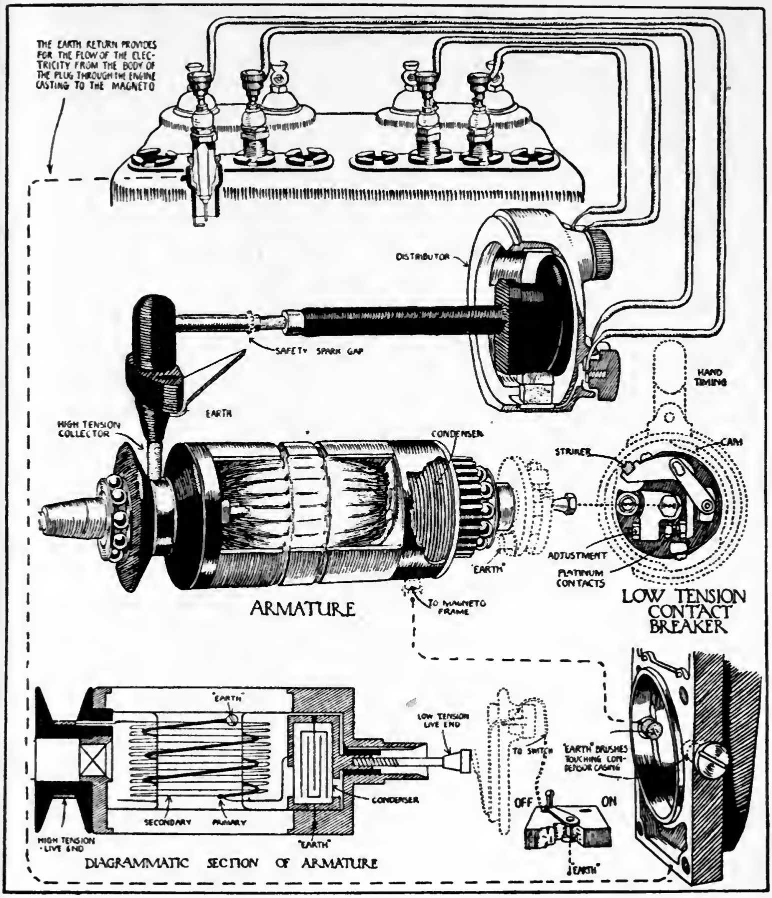
The voltage of the electric pressure in the second coil will be 1000 times greater than in the first coil if it has 1000 times as many turns in its winding.

In this way we can make the electricity of our secondary winding jump a small fixed gap. *But* it is very important in a motor-car to be able to time the occurrence of this spark so that it synchronizes with the action of the engine.

In fine, we need to be able at will so to disturb the electrical conditions as shall make the momentary pulsations of extreme violence. This can be done by suddenly switching off the primary current, if a condenser is already connected across the switch contacts. By the switch, is in this case meant the contact breaker of the magneto.

The condenser is a bundle of tin foil sheets in two groups interleaved alternately and insulated with mica from each other. It is capable of being charged with electricity like the surface of sealing-wax. It prevents the low-tension spark that otherwise would occur at the contact breaker, and it also acts like a spring buffer in jerking the electricity to and fro in the coil. Instantly, the secondary coil responds to the violent pulsations, and causes a spark to jump the ignition plug gap.

The spark itself is merely an example of high incandescence due to the heating effect of the electricity. The light of an electric lamp is similarly due to the filament being white hot. It is made white hot by the electricity, but the electricity itself is not the light.



"Auto" Copyright Drawing

Diagram of connections for a typical four-cylinder magneto, based on the design of the ZU 4 Bosch of 1912. The connections are applicable in principle to any high-tension magneto system, but the internal connections of the Bosch armature differ from common practice in respect to the earthing of the secondary winding through the primary. The "earth" circuit, which is formed by the metallic parts of the engine, etc., is indicated by a dotted line. When the magneto bracket is not part of the engine it is necessary to complete the earth return from the engine to the magneto frame by a wire.

When the armature of a magneto revolves, the magnetism clings to its core. In consequence, the maximum impulse occurs later as the speed increases. On the other hand, the timing is required to take place earlier as the engine runs faster, and so there is a tendency for the magneto either to be weak when starting or else when running fast on full advance. In order to overcome this difficulty specially shaped pole pieces have been devised.

A diagram on page 299 shows the electrical connections for a typical high-tension magneto circuit. The armature of the magneto contains two coils of wire, one being of finer gauge and having very many more turns than the other. In most magnetos one end of each coil is connected to the iron core of the armature. In the Bosch magneto illustrated the secondary winding is attached to the primary winding, and the other end of the primary winding is alone directly attached to the iron core. The end so attached is said to be earthed, in contradistinction to the other end, which is said to be live. The live end of the primary winding is connected to the adjustment screw of the contact breaker. Against this screw presses the platinum tip of the pivoted lever that is operated by the cam. The pivoted lever is earthed. When the contact is closed electricity flows in the primary circuit ; the flow is interrupted by the sudden separation of the contacts, which causes an electro-magnetic disturbance in the circuit, and so generates a high electric tension in the secondary winding of the armature.

The live end of the secondary winding is connected to the distributor brush, which acts as a revolving switch, and so places each of the ignition plugs separately in circuit with the magneto in their proper firing sequence. The electricity from the ignition plug returns to the magneto through the metal parts of the engine, with which the base of the magneto must be in electrical connection. This part of the circuit is known as the "earth" return. When a magneto is switched off, the switch contact must maintain a closed primary circuit, that is to say, they must form an electrical bridge across the contact breaker, and so neutralize the effect of its mechanical operation.

THE ATLANTIC PASSAGE

THE offer of a prize of £10,000 by the *Daily Mail* for a flight across the Atlantic, to be completed within 72 consecutive hours, brings definitely to the fore a problem that has often been informally discussed. In considering a non-stop flight of this magnitude it is very important to recognize the possible limitations that may be imposed by the fundamental mechanics of aviation. A rough-and-ready estimate of the possibilities of a non-stop flight serves indeed as an excellent object-lesson in this phase of the subject, but this particular prize permits, of course, of descents *en route*.

In order to obtain a starting-point for one's calculations, it is necessary to review the available data in respect to modern machines. From the evidence provided by the analysis of the Military Trials, it seems reasonable to assume three provisional figures for this purpose. The first is that any aeroplane is likely to weigh 15 lb. per h.p. in its construction alone; secondly, it is improbable that any machine at the present time has a resistance of much less than 1 in 6 at 70 m.p.h.; thirdly, the fuel consumption of an aeroplane engine is seldom more economical than half a pint of petrol per h.p. hour.

So long as these figures hold good, the size of the machine is immaterial, that is to say, we can work in units of 1 h.p.

Looking at a map of the world, the shortest distance from land to land in the vicinity of a steamship route is somewhat less than 2000 miles. Let us, however, take 2000 miles to be the distance to be flown in one stretch. At 70 m.p.h. this will be accomplished in about 29 hours, let us say 30 hours for convenience.

An engine working continuously for 30 hours, and consuming half a pint of petrol per h.p. per hour will thus consume 15 pints of fuel per h.p. on the whole journey. The weight of petrol is about 0·9 lb. per pint, but in order to be on the safe side we might allow for 15 lb. of petrol per h.p. for the complete journey.

Thus the machine itself weighs 15 lb. per h.p., and the petrol that it initially carries likewise weighs 15 lb. per h.p., the total being 30 lb. per h.p. One-sixth of this weight represents the resistance to flight at 70 m.p.h., according to the hypothesis.

That is to say, the resistance to flight is 5 lb. at the speed in question.

Five lb. resistance at 70 m.p.h. represents 350 mile lb. per hour, or 94 per cent of 1 h.p., which is in excess of any propeller efficiency thus far attained. Allowing for the reduction in weight during the flight, owing to the consumption of the fuel, the mean resistance of the fuel might be reckoned as that equivalent to half the initial weight of the petrol. The mean resistance of the machine and fuel on this basis would, therefore, be 3·75 lb., which at 70 m.p.h. represents 260 mile lb. per hour or 70% of 1h.p.

It is apparent from these figures alone that the problem of flying non-stop across the Atlantic is beyond the limit of present-day possibility, for each of the three figures chosen to represent the hypothetical conditions represents a comparatively low actual value, and even with them it is difficult to show any appreciable margin of reserve.

Moreover, it must be borne in mind that the above calculation supposes the machine to be flying without a pilot. A journey of this duration would require the presence of two pilots on board such a machine. Their weight would be at least 300 lb., and this would in some measure determine the actual engine power required. If the attempt were made with a 100-h.p. engine, the weight of the pilots would represent 3 lb. per h.p., and thus add half a pound per h.p. to the resistance. If the engine were more powerful than this, the weight of the pilot would represent a smaller proportionate increment to the resistance.

The prospect of building the machine lighter than the specified weight is less promising than the prospect of reducing the resistance by the application of the principles of stream-line design. It is possible that a practical aeroplane might have a resistance appreciably less than 1 in 6 at 70 m.p.h., and it is towards the improvement in body design and the elimination of unnecessary superstructure that the offer of this particular prize may be expected to direct most attention.

The arbitrary choice of 70 m.p.h. as the flying speed is based on the practical consideration that it is essential for any machine attempting such a journey to be capable of meeting and forcing its way through strong winds. Misfortune in respect to weather would probably doom such an attempt to failure in any case, and the best that can be done under the circumstances is to reduce the risks as far as possible by reducing the time during which the pilot is exposed to them. On the other hand, to assume a speed greater than 70 m.p.h. would be to specify something in excess of the values that can readily be attained by existing machines, and the hypothesis itself would, therefore, call for something in the nature of a special design.

NEWTON'S LAWS OF MOTION

1. IF a body be at rest it will remain at rest; or if in motion, it will move uniformly in a straight line until acted upon by some force.

2. The rate of change of the quantity of motion (momentum) is proportional to the force which causes it, and takes place in the direction of the straight line in which the force acts.

If a body be acted upon by several forces, it will obey each as though the others did not exist, and this whether the body be at rest or in motion.

3. To every action there is opposed an equal and opposite reaction.

Inasmuch as air has mass, weighing, as it does, nearly 0·08 lb. per cu. ft. (about 13 cu. ft. of air weigh 1 lb.) it obeys Newton's laws of motion, and gives rise to a reaction when a force is applied to accelerate it from rest. Thus, the wing in flight continually accelerates a stratum of air downwards, and *must* derive a lift therefrom. Similarly, the propeller continually accelerates a stream of air horizontally, and must derive a thrust by so doing.

The total force in each case is proportional to the mass per second and to the acceleration, thus:

$$\text{Pressure (lift or thrust)} = \text{mass per second} \times \text{acceleration}$$

$$P = mf$$

There is some difficulty in estimating the theoretical force that should be exerted by a wing or a propeller, because neither the mass per second nor the acceleration can accurately be defined.

If we take a given area of wing A, a given velocity of flight v and a given mass-density for the air $\frac{\rho}{g}$, then the lift P at some particular angle of incidence θ is an expression in the form:

$$P\ (\text{lb.}) = C\,\frac{\rho}{g}Av^2$$

where C is a constant known as the lift coefficient, which must be determined by experiment on a model for any particular wing shape and angle of incidence.

PRESSURE AND RESISTANCE CONSTANTS

AERODYNAMICS is a science that is advanced mainly by experimental data compiled in laboratories in different parts of the world. It is, therefore, of great importance that the results of various investigators should readily be comparable at a glance. This is facilitated by expressing the results, when possible, in such a form that the coefficient is an absolute constant, that is to say, its numerical value is unaffected by the system of units employed.

The pressure on a flat plate facing the wind may be expressed in the form:

$$\begin{array}{ccccccccc} \text{Force} = & \text{Constant} & \times & \text{density} & \times & \text{Area} & \times & \text{velocity}^2 \\ F = & C & & \rho & & A & & v^2 \end{array}$$

In order to express the force in pounds, when v is in feet per second and A is in sq. ft. the expression is divided by gravity thus:

$$F\ (\text{lb.}) = C\frac{\rho}{g}Av^2$$

$$\text{For } \rho = 0{\cdot}08;\ \frac{\rho}{g} = \frac{1}{400}$$

whence:

$$F\ (\text{lb.}) = \frac{CAv^2}{400}$$

When the velocity V is expressed in miles per hour, the equation becomes:

$$F\ (\text{lb.}) = \frac{CAV^2}{190}$$

Thus, when $C = 1$, the force per sq. ft. is numerically equal to $v^2 \div 190$. This is an easy figure to remember, and can readily be altered to correspond with other values of C.

THE RESISTANCE OF FLAT PLATES

If a flat plate facing the stream were to bring every filament of the current to rest, C would have a value equal 1·0.

If the resistance of the above plate were numerically equal to the head corresponding to the velocity of the stream $H=\left(\frac{V^2}{2g}\right)$ then C would equal 0·5.

The above are purely theoretical values. Experiments give the following results:

Small plates	C=0·507
Large plates	C=0·62

From the latter, the approximate formula for the pressure per sq. ft. on the face of a large surface is given by the expression $F\,(\text{lb.})=\frac{V^2}{306}$, where V is the air speed in miles per hour.

THE RESISTANCE OF PERFORATED PLATES

According to experiments made by Dr. Stanton at the National Physical Laboratory, almost 10 per cent of the area may be removed by the holes without affecting the total air pressure. Even when as much as 40 per cent of the surface is missing, nearly 90 per cent of the initial pressure remains. The theory is that the dead water on the lee side virtually forms a backing to the plate, and so receives on its behalf a limited amount of momentum. As the holes become more numerous, the dead water is rapidly washed away, thus when 90 per cent of the plate is removed, the total pressure is 12 per cent of the initial value, an amount that is only slightly greater than the extent of the remaining surface.

THE RESISTANCE OF PLATES IN TANDEM

To the same order of things belong the phenomena related to the shielding of one plate by another in front of it. Thus, Dr. Stanton found that a pair of plates placed in tandem 1·5 diameters apart experienced less than 75 per cent of the pressure that either one of them would experience when standing alone. The distance apart had to be increased to 2·15 diameters before the total pressure was made equal to that on one plate singly. Even when 5 diameters apart, the total pressure was only 1·78 times the pressure on one plate separately.

THE RESISTANCE OF HONEYCOMB RADIATORS

The resistance of a honeycomb radiator having 75% of its area as wind passage is approximately one half that of a flat plate of the same dimensions, i.e.

$$C=0{\cdot}26$$

The resistance of a radiator may thus approximately be expressed as $V^2 \div 730$ lb. per sq. ft. super.

The speed of the air through the tubes of the honeycomb (tubes 19/64″ inside diameter, length $3\frac{7}{8}$″) was found to be 75% of the approaching air. Halving the length increased the velocity through the tube to 82%.

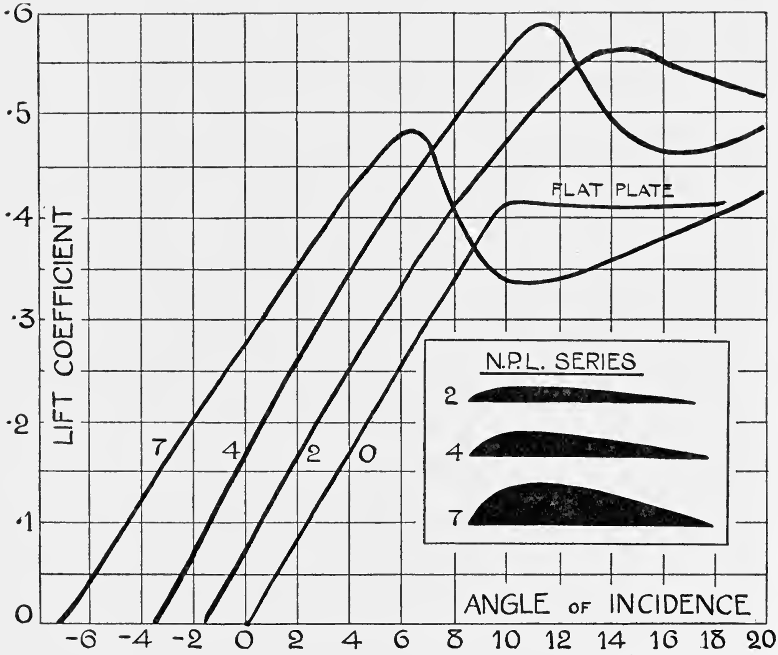


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Chart comparing the lifting efforts of three flat-bottomed wing sections and a flat plate. It will be observed that all the cambered sections continue to lift while inclined at a negative angle of incidence. The results are from the N.P.L. experiments published in the Technical Report for 1912.

THE LIFT AND RESISTANCE OF WINGS

In respect to the lift of aeroplane wings, the constant C is called the lift coefficient. Although the critical angle of maximum lift is ordinarily less than 12½°, the value of C may be even slightly higher than 0·62 for some sections in this attitude. That is to say, a cambered wing thus inclined may experience an upward lift that is greater than the pressure on the flat face of a plate standing upright against the wind.

The numerical value of the lift coefficient C depends on the angle of incidence and also on the shape of the section. A chart opposite shows the nature of the variation for three different sections tested at the N.P.L.

It will be noticed that in all cases a cambered wing has a positive lift coefficient when the angle of incidence is zero. For a flat plate, the lift coefficient itself is, of course, zero when the angle of incidence is zero. Cambered wings reach their

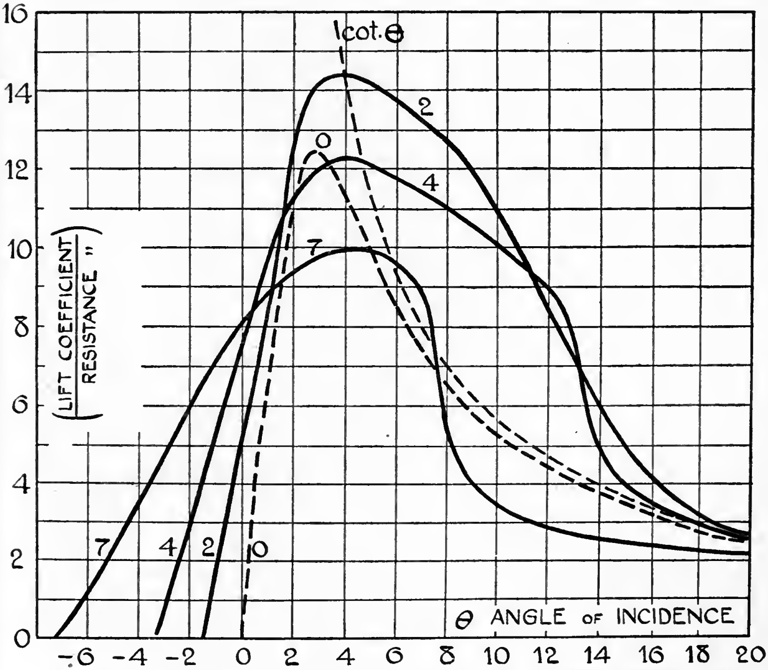

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Chart comparing the lift with the resistance of the wing sections and flat plate referred to in the preceding diagram. The theoretical limit to the lift resistance ratio of a flat plate is defined by the cotangent of the angle of inclination, which is shown as a curve on the chart. It will be observed that all the cambered sections develop a superior lift resistance ratio throughout some portion of the range of useful attitudes.

attitudes of no lift when set at a negative angle of incidence. The amount of the negative angle corresponding to no lift depends on the shape of the section. Thicker sections, that is to say those having a greater height of camber, have higher lift coefficients at fine angles of incidence than thin sections.

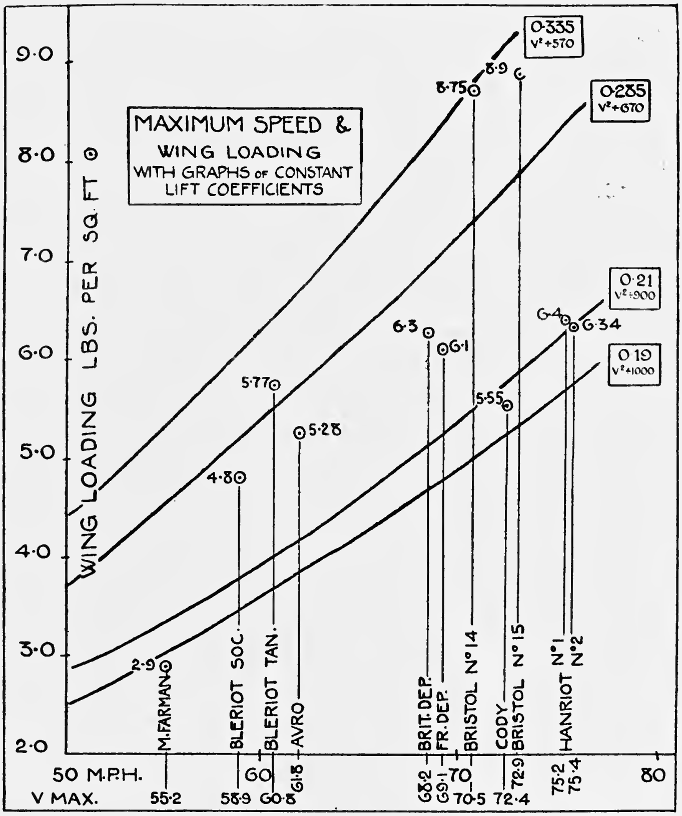

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Chart showing the wing loading of various machines in the British Military Trials, 1912, and the maximum speeds attained. Graphs are drawn on the chart showing four different lift coefficients, which serve as datum lines for the comparison of different wing loadings at different speeds.

In the Military Trials, when flying their fastest, very few wings reduced their lift coefficient below 0·21, which corresponds to $V^2 \div 900$.

The resistance coefficient of a wing also depends on the angle of incidence and the section, but the greatest ratio of lift coefficient to resistance coefficient occurs for all sections at a fine angle, generally in the neighbourhood of from 3 to 6 degrees angle of incidence. Thin sections attain the highest ratio, but at the angles of highest lift:resistance ratio the lift coefficient is small. Nevertheless, for a given ratio, the thin section appears to have a higher lift coefficient than the very thick wing. Curves showing the lift:resistance ratios of three flat-bottomed wing sections tested at the N.P.L. are given on page 307.

There is also shown on this chart the lift:resistance ratio of a flat plate, calculated on a theoretical basis as to skin friction. The lift:resistance ratio of a flat plate cannot exceed the cotangent of the angle of inclination. The curve of cotangents is shown on the chart, and it will be observed that the cambered wings demonstrate lift:resistance ratios of a superior value to this over a range of several degrees. A table of tangents appears at end of book. The cotangent $\theta = \frac{1}{\tan \theta}$

THE RESISTANCE OF WIRES

The resistance of a given wire is approximately proportional to the square of the velocity. Actually, the rate of the increase in the resistance of large wires is rather more rapid than is in accordance with the V^2 law; with small wires the rate of increase is rather less rapid.

The resistance increases in proportion to the diameter, and also, of course, in proportion to the length. The product diameter × length represents the projected area of the wire, which value must be used for A in the expression $F = C\rho Av^2$.

The approximate values of C are as follows:

Smooth wires	$C = 0{\cdot}435$
Stranded cable	$C = 0{\cdot}52$

It will be observed that the resistance of a smooth wire is slightly less, and that of a stranded cable slightly greater than the resistance of a *small* flat plate of corresponding area.

THE RESISTANCE OF STRUTS

Tests made at the N.P.L. on a circular section strut of 1 in. diameter showed a value of $C = 0{\cdot}57$. That is to say, the resistance of such a strut is in the same order as that of a flat plate equivalent to its projected area.

A convenient figure to remember is that a 1-in. circular section strut has a resistance of about 40 lb. per 100 ft. run at 40 miles an hour. The resistance varies as the length, the diameter, and the square of the speed.

THE RESISTANCE OF FAIR SHAPES

Tests on strut sections of fair shape, such as are often used in aeroplane construction, showed that the value of C might be reduced to 0·1 or even less. This indicates that a fair-shape strut section may have a resistance only one-sixth that of a circular section strut. The choice of the best strut section for constructional purposes must, of course, necessarily take into account the question of relative strength and weight. But it is important to remember that on a machine having a gliding angle of, say, one in six, every pound saved in head resistance enables the machine to carry 6 lb. extra weight in flight. Thus a relatively heavy fair-shaped strut *may* be an economy in load. Alternatively, a strut that is economical of weight from the standpoint of strength might be encased in a low-resistance form of some light material.

Fair shapes employed in strut sections do not ordinarily exceed three diameters in length. The ratio of the fore-and-aft length to the diameter is called the fineness ratio.

Other fair-shaped bodies may, of course, have a much greater fineness ratio, but the computation of their resistance is only possible when their form is analogous to that of a model already tested.

FRICTIONAL RESISTANCE

When a flat plate is placed edgewise in the wind, there is a resistance due to the friction of the air passing over its surfaces. The expression of this force involves a term representing the kinematic viscosity of the fluid.

Zahm's formula (corrected[1]) for friction is:

$$F = kA^{0.93} v^{1.86}$$

The coefficient k having a value 0·0000082 when F is the total resistance of *both* surfaces of a board that measures A sq. ft. in *single* surface area.

Theoretically, a perfect stream-line body should experience only frictional resistance; from experiments at the N.P.L. it would appear, nevertheless, that the coefficients for fair-shaped model dirigible envelopes is sometimes twice as much as that for a flat surface. Even in the best cases the flat-surface co-efficient only represented 75% of the measured resistance.

At first sight, the inadequacy of the flat-surface coefficient to account for the total resistance suggests that the nature of the resistance is not wholly frictional, but that the difference might be expressed as resistance due to the projected cross-sectional area.

Were such the case, this part of the resistance would be expressed in the form $C\rho Av^2$.

Analyses of tests have been made on these lines, and opinions seem to differ as to their values. Personally, I regard the evidence at present available as being in favour of supposing the resistance of fair shapes to be wholly of the order

$$F = kA^{0.93} v^{1.86}$$

and not divisible into two parts.

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[1] In its original form Zahm's formula did not possess the dimensions of a force: the above expression is the form in which it is used for reference by the N.P.L.

DISTRIBUTION OF PRESSURE ON WING SECTIONS

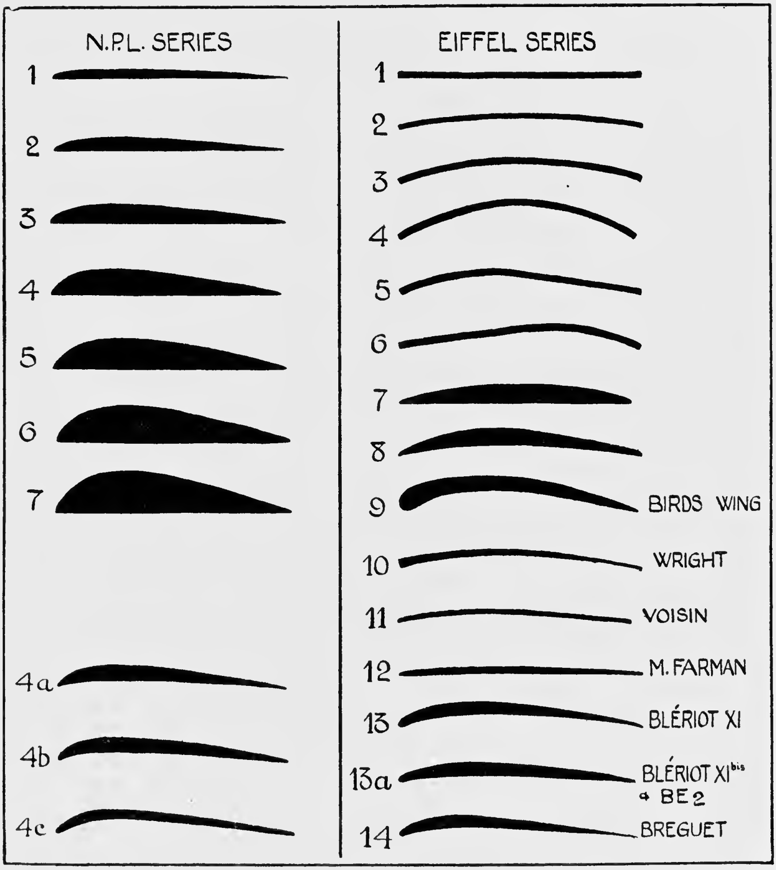
THE diagrams on page 102 are prepared from the researches of Eiffel, but differ somewhat from his method of presenting the results. They are intended to show more graphically the nature of the distribution of pressure over various wing sections, all of which are inclined at 6° angle of incidence to the line of flight. The wing sections are shown in black; above each is a shaded region indicating suction; below is another shaded region indicating pressure. The radial distance of the outer edge of the shaded region from the surface of the wing indicates the relative intensity of the force at that point.

The suction and the pressure together provide the lifting force that supports the wing in flight. It is evident at a glance that the suction is in all cases much superior to the pressure; in other words, that the upper surface is by far the more important of the two.

Comparing the diagrams of the cambered sections with that of the flat plate No. 1 it will be observed that the former show a general tendency to tilt forwards in front. The portion that seems to lean up-wind is situated over the dipping front edge of the wing section. The fact that it exceeds in magnitude the drag on the surface aft accounts for a Net up-wind force parallel to the chord, which Lilienthal called the "tangential." The diagrams thus serve as a graphic illustration of the fundamental advantage of the cambered wing over the flat plate.

The flat plate cannot possibly have any part of its diagram tilted forwards, consequently it never has any up-wind component. Its lift:resistance ratio, even neglecting skin friction, could thus never exceed the numerical value of the cotangent of the angle of its inclination. It is shown elsewhere that the lift:resistance ratio of the cambered wing commonly does exceed this value at angles greater than 4 or 5 degrees. The reason for this superior merit is rendered evident in the forward tilt above mentioned.

It is important to realize that the diagrams materially change their shape with alterations in the angle of incidence. From information of this character, properly plotted to scale, the



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At Eiffel's Laboratory in Paris and at the National Physical Laboratory at Teddington, the qualities of certain wing sections have already been very thoroughly investigated. In the above diagram the sections so tested are illustrated, and in the table opposite certain of the principal qualities relating to each are specified. The full particulars relating to these series appear in Eiffel's *Résistance de l'Air* and the Technical Report for 1912 respectively.

position of the centre of pressure can be located for any given angle. The position of the C.P. and its travel are discussed on page 15.

There is no known theoretical limit to the local intensity of the suction on the upper surface, but tests show that it may be expected to reach a value ($-1\cdot5\ \rho.v^2$) in the vicinity of the leading edge.

The maximum local pressure on the bottom of the wing cannot exceed ($+\frac{1}{2}\rho v^2$).

TABLE OF COEFFICIENTS FOR THE SECTIONS

C_1 = lift coefficient at critical angle
L : R = maximum lift : resistance ratio
C_2 = lift coefficient corresponding to L : R

N.P.L. Series				Eiffel Series			
No.	C_1	L : R	C_2	No.	C_1	L : R	C_2
1	0·48	13·8	0·16	1	0·50	6·4	0·21
2	0·57	15·0	0·225	2	0·52	12·5	0·18
3	0·61	14·3	0·275	3	0·62	11·0	0·34
4	0·59	12·7	0·325	4	0·75	7·1	0·56
5	0·56	11·7	0·35	5	0·62	11·0	0·36
6	0·53	11·1	0·38	6	0·64	10·6	0·32
7	0·48	10·2	0·42	7	0·46	13·9	0·15
4*a*	0·62	12·7	0·36	8	0·60	11·4	0·28
4*b*	0·64	12·7	0·38	9	0·67	7·8	0·46
4*c*	0·66	12·7	0·40	10	0·56	10·4	0·26
				11	0·51	14·0	0·17
				12	0·48	15·4	0·13
				13	0·62	9·1	0·28
				13*a*	0·54	13·2	0·26

ANALYSIS OF FORCES ON WING SECTIONS

IN the Technical Report of the Advisory Committee, the forces acting on various wing sections are analysed in detail throughout a full range of angles. The accompanying charts illustrate the composition of these forces in a way that indicates some of the more important characteristics of a cambered wing.

The first diagram shows the forces normal to the chord. As the angle of inclination is always small, these forces may be regarded as perpendicular. They, therefore, represent the lift. Curves are plotted to show the contribution of the upper and lower surfaces separately.

The lift due to the upper surface is about three times that due to the lower surface, as may also be seen very clearly from the diagram of distribution of pressure on page 102.

The lower surface of this wing exerts a downward pressure below (+4°) angle of incidence, while the wing as a whole ceases to lift at about (−2°).

If one of the diagrams showing the distribution of pressure on a cambered wing (page 102) is integrated, the resultant force would be tilted slightly forward of the normal to the chord. In fine, it would have an up-wind component parallel to the chord. The contributions of the upper and lower surfaces to these forces parallel to the chord are shown in the second of the diagrams herewith.

It will be noticed that the lower surface is of small consequence. If it were flat it would have no force parallel to the chord except that due to frictional resistance. Similarly, if the section under investigation were a flat plate instead of a cambered wing, there would be no force parallel to the upper surface except friction. The net total force parallel to the chord is that which Lilienthal called the tangential. For all angles greater than about (+3°), the tangential is an up-wind force tending to reduce resistance.

It is important to differentiate between the tangential which may be an up-wind force and the net resistance which is invariably a down-wind force.

If the section were a flat plate there would be no " tangential "

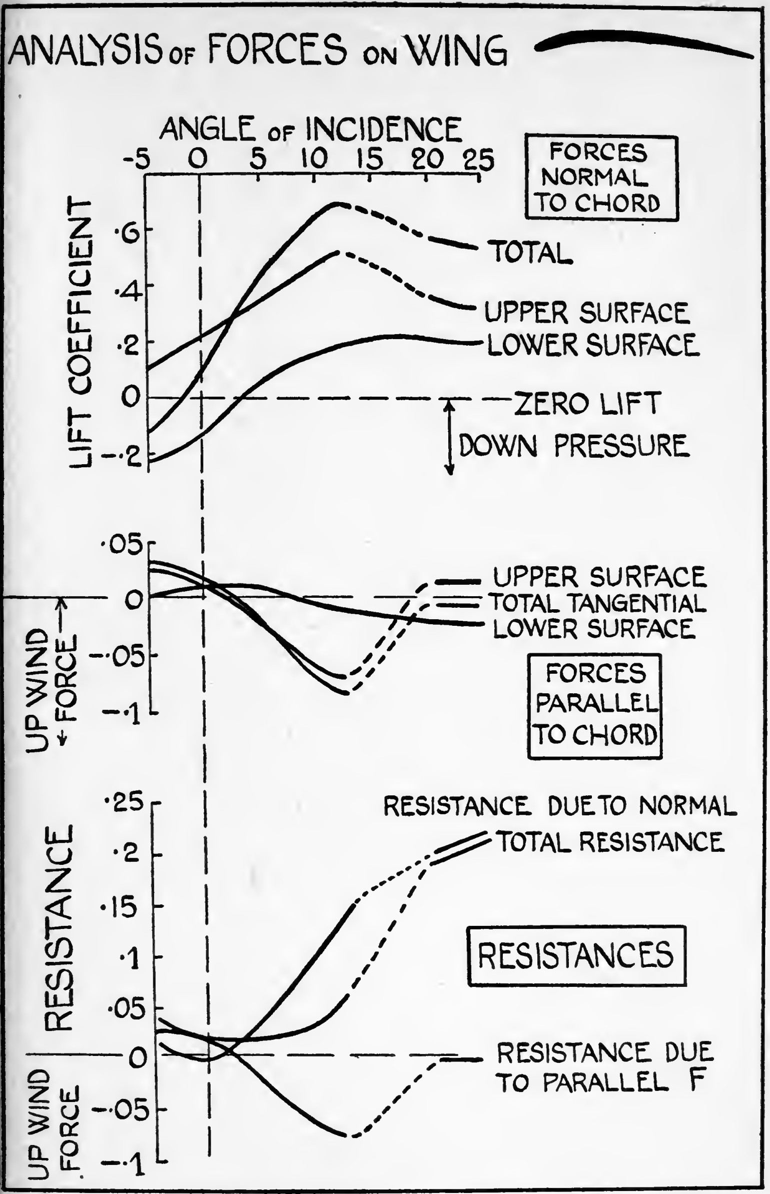

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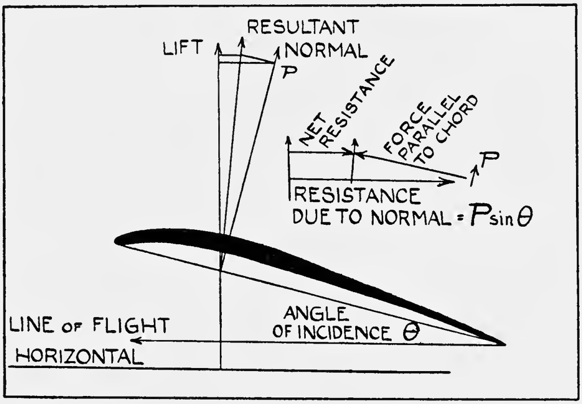
Diagram illustrating an analysis of the forces on a cambered wing as obtained by experiment at the National Physical Laboratory. The particulars are published in the Technical Report of the Advisory Committee for 1912. An explanation appears in the text of this book.

consequences, the resistance would be at least equal to the normal force multiplied by the sine of the angle of inclination (P sin θ). The value of the net resistance of a cambered wing is made up, for any angle, by the difference between P sin θ and the tangential. The degree to which the " tangential " assists in reducing P sin θ is shown in the third diagram.

The low value of the net resistance over all the finer angles in the flight region indicates in a very striking manner one of the chief reasons for the merit of the cambered wing. The other reason is its superior lift coefficient at any given angle. This is illustrated by the chart on page 306.



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Vector diagram illustrating the forces on a wing as built up from the details of the analysis of forces illustrated in the preceding diagram. The force P normal to the chord would give rise to a resistance P sin θ but for the existence of the up-wind tangential which causes the resultant to be inclined forward of the normal and so reduces the net resistance to the value shown.

For an explanation of the coefficients the reader is referred to page 307.

It will be noticed that the curves are dotted above the angle of $12\frac{1}{2}°$, this is the critical angle for the wing in question, and from that point up to 20° the upper-surface pressures are unsteady. At about 20° the suction again becomes steady; its distribution is, however, then uniform all over the upper surface, which thus no longer contributes an up-wind force. On the contrary, the force parallel to the chord now acts downwind, and tends to augment the resistance, but as the lower surface still contributes an up-wind force, the net tangential is practically zero.

A vector diagram is given herewith to show the forces acting at $12\frac{1}{2}°$ angle of incidence. It is of assistance in visualizing the series of conditions that are graphically shown in the charts.

It is most important to recognise that the existence of any force parallel to the chord, other than that due to friction, is entirely due to the *uneven* distribution of pressure along the chord at all ordinary flight angles. If the pressure distribution on the surface were uniform, the up-wind pull on the dipping front edge would be neutralized by the down-wind drag on the trailing portion of the wing. Similarly if the wing has no camber (i.e. flat plate) there is no chance of any " tug-of-war " through a tilting of the forces, and the potential advantage of an uneven pressure distribution is lost.

THE TRAVEL OF THE C.P. ON WING SECTIONS

A SERIES of diagrams on page 15 show a wing section in a range of attitudes from 4° to —1° angle of inclination. On each diagram a vertical arrow is drawn to indicate the centre of pressure. It can be seen at a glance how the C.P. travels towards the trailing edge as the angle becomes finer. Above 5°, only a slight forward movement of the C.P. accompanies an increase in the angle of incidence; above 19° the movement reverses its direction.

The travel of the C.P. is shown in another manner on page 319.

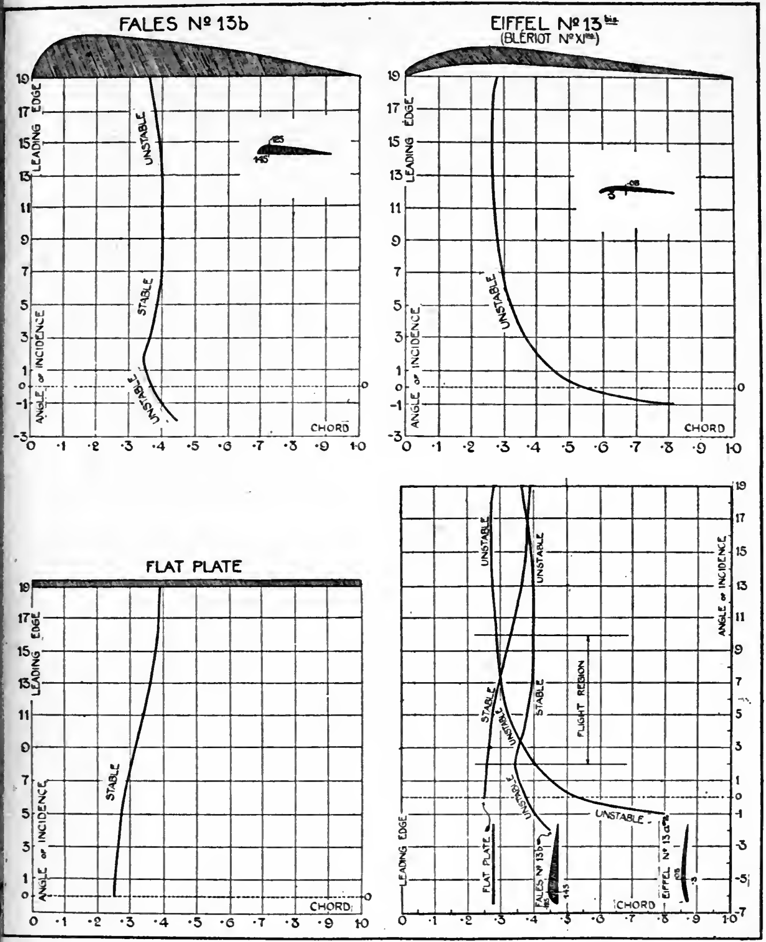
Different wing sections exhibit these phenomena at different angles, but within the range of attitudes employed in flight, wing sections commonly now used are unstable in the sense that the C.P. retreats as the angle diminishes. A disturbance tending to reduce the angle would thus be augmented by the direction in which the C.P. would travel, and the initial disturbance would in consequence culminate in a nose dive. It is the tail of the modern aeroplane that neutralizes this unstable movement of the C.P. on its wings.

A flat plate has an inherently stable movement of the C.P., as may be seen from the slope of the graph in an accompanying chart.

A stable movement of the C.P. throughout a range of about 8° in the flight region is also a characteristic of a wing section, No. 13b, tested by E. N. Fales at the Massachusetts Institute of Technology. Its graph is also shown in the chart opposite. It is interesting to compare these various characteristics, and this has been done by superimposing the graphs on a common chart.

Reflexed wing sections (i.e. having an up-turned trailing edge) are also being investigated for stability of C.P. travel.

If a satisfactory stable wing section could be found, an aeroplane might be constructed without such a long tail.



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Charts illustrating the travel of the centre of pressure on two wing sections and a flat plate. They are shown on separate diagrams and also superimposed on a common diagram. The Fales wing section is particularly interesting inasmuch as it demonstrates a stable travel of the C.P. within a portion of the flight region. The chart for the Bleriot wing is based on the Technical Report,

THE SYNTHESIS OF AEROPLANE RESISTANCE

IT is obviously important to have a convenient method of combining the data relating to the resistance of various details in such a form as shall enable the designer to estimate the resistance of the complete aeroplane.

The method employed at the Royal Aircraft Factory and elsewhere is illustrated by the charts opposite. Actually, the R.A.F. method is to superimpose the curves on one chart, but it is more convenient to explain them separately.

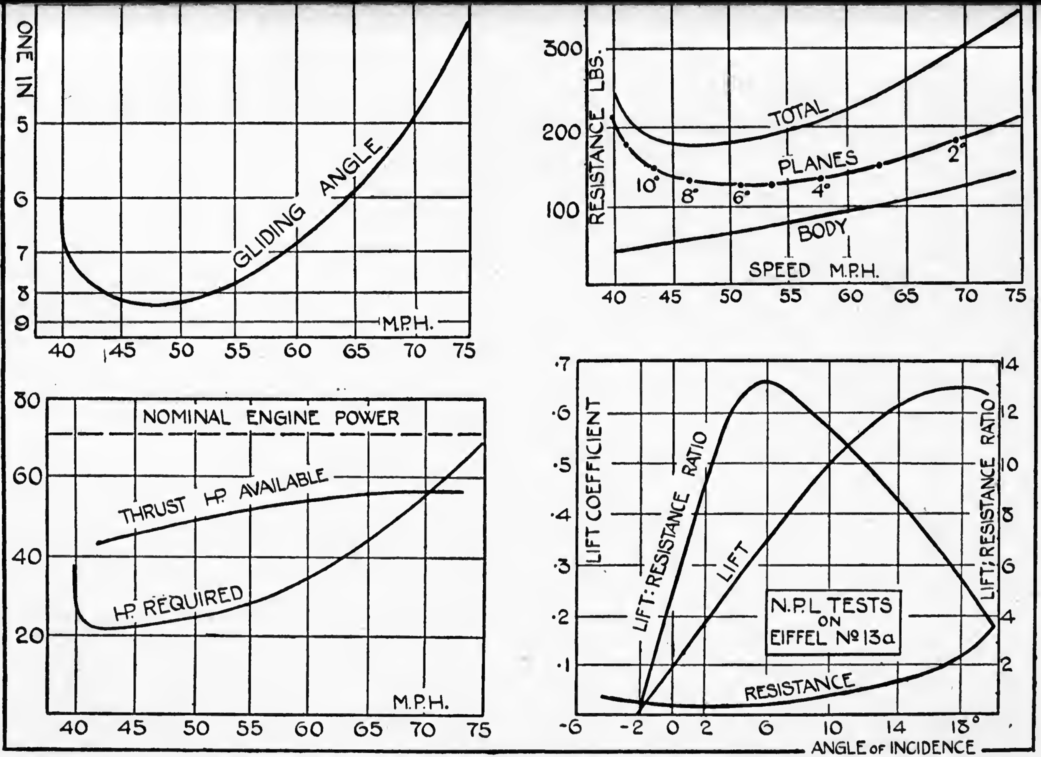
All the graphs are drawn to a common scale of flight speed, which forms the basis of the investigation. The vertical scale of each diagram varies according to the nature of the graph.

The first step is to plot the curve of wing resistances by calculating the lift coefficient required to support the weight in flight at any given velocity, and finding the corresponding resistance coefficient from the characteristic curves of the wing section employed. It is, of course, essential to have these characteristic curves, which are only to be obtained by tests on scale models. The characteristic curves for Bleriot 11 *bis* as tested at the N.P.L., are given on the same page. Characteristic curves for other wing sections tested at the N.P.L. appear in the Technical Report, and those tested by Eiffel are given in his *Résistance de l'air et de l'aviation.* A numerical example showing the calculation of the lift coefficient required at a given speed is given on page 329.

Having plotted the resistance of the planes (with an allowance for biplane interference when calculating the lift) the next step is to calculate the resistance of the struts, wires, and body. Notes on the resistances of various objects are given on p. 305.

These resistances are plotted on the same chart, and are added together to give the total resistance.

It is useful to replot this total resistance, so as to express the "gliding angle," i.e. resistance:weight ratio, at any speed. The gliding angle is generally expressed as 1 in —, but this system does not give a uniform scale on the chart. The scale is found by first using the uniformly divided scale of resistance, and then ascertaining the actual resistance corresponding to



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Diagrams showing the R.A.F. method of preparing estimates of resistance and power required for experimental aeroplanes. The lower right-hand diagram gives the results of the N.P.L. tests of the Bleriot 11 *bis* (Eiffel 13 *bis*) wing section. It is from a diagram of this kind that the graph of the resistance of the planes, shown in the upper diagram, must be plotted.

any given gliding angle for the weight in question. For example, if the weight is 1700 lb., the gliding angle required is 1 in 5, then the corresponding place on the scale for the 1 in 5 mark is 1700/5=340 lb. Similarly for 1 in 6, 1 in 7, etc.

The next step is to convert the resistance into power required by multiplying the resistance by the corresponding speed in m.p.h. and dividing by 375, in order to express the result in h.p.

On the chart of power required, may be plotted a graph showing the power available with a given propeller and given engine. The vertical height between these two curves gives the reserve power available for climbing, etc., at any speed, and where the curves intersect is the limiting speed in horizontal flight.

Supposing the power available is such that the curves intersect in the flight region at a slow speed as well as at a high speed, a condition of especial significance is indicated by the former point. The machine can just fly straight. It has no reserve power for acceleration, consequently it is unable to enter the proper flight region without the assistance of gravity, which involves a partial descent. The attitude of the machine, however, is not appropriate to descent, because the tail being down, any manœuvre such as turning involves either descent or acceleration, consequently the condition is a critical one that should be strictly avoided. It is liable to occur to a pilot who persists in flying a machine with an engine that is not giving its proper power output.

NOTE ON THE CENTRIFUGAL COUPLE

IN connection with the general problem of steering an aeroplane it has been pointed out that the centripetal force is derived as a component of the wing pressure, when the wings are canted.

When flying on a circular course the outer wing tip necessarily proceeds faster than the inner wing tip. In the differential negative warp control, positive portions of the wings are assumed to be symmetrical. It would seem, therefore, that the centre of pressure must be displaced to the far side of the centre of gravity, and, therefore, tend to increase the bank.

In this connection it is, therefore, interesting to consider the influence of the centrifugal couple as giving rise to a force tending to prevent such increase.

If a stick has a string attached to the centre of its length, and is whirled at the end of the string, it has two positions of equilibrium, only one of which is stable. When the stick is upright and at right angles to the string, the centrifugal forces of its halves are balanced. If one end of the stick is now displaced so that the stick lies obliquely to the string, then the mean velocity of one half of the stick exceeds that of the other, and the centrifugal force is greater in the faster portion. This augments the tilt until the stick lies in line with the string, where it assumes a position of stable equilibrium.

The wings of an aeroplane when banked would seem to be in a position similar to the tilted stick of the above experiment. The centrifugal couple tends always to destroy the bank, and so tends to counteract the couple due to the superior mean velocity of the outer wing. If they tend to a position of stable equilibrium, then the balance of the system as a whole may be stable during circular flight, in spite of the symmetry of the positive angles of opposite wings.

That this balance between the surplus lift and the centrifugal couple is plausible may be deduced from the general consideration that both are dependent on the superior mean speed of the outer wing. As the bank increases, the difference in the mean speeds diminishes, and therewith the surplus lift decreases. For an imaginary bank of 90°, in which the wing spars would be vertical to the ground, the condition of balance for circular flight would be identical with those of straight-line flight, the relative speeds of the two wings having become equal once more.

Although the surplus lift depends only on the difference in the mean speeds of the positive parts of the wings, and is thus a maximum when the circular course is flown with level wings, the centrifugal couple depends also on the bank itself, and tends to a maximum when the bank is 45°.

Assuming that the symmetrical positive parts of the wings are automatically balanced by the centrifugal couple in the way suggested, then the warping of one negative wing tip suffices for the needs of steering a circular course with fixed controls.

NUMERICAL EXAMPLES

MOST of these calculations are only accurate to the degree of approximation obtainable with a six-inch slide rule, but the method of working by logs is freely indicated as a guide to greater precision when necessary.

LOGARITHMS.—In the tables the mantissa only is given: it is always a positive quantity.

The characteristic is $\pm$ as the number is $> <$ unity.

e.g. $\log 120 = 2{\cdot}079$; $\log 12 = 1{\cdot}079$; $\log 1{\cdot}2 = 0{\cdot}079$
$\log 0.12 = \bar{1}{\cdot}079$; $\log 0{\cdot}012 = \bar{2}{\cdot}079$.

Fractional indices by logs:
e.g. $117^{1.86}$; $\log 117^{1.86} = 1{\cdot}86 \log 117 = 1{\cdot}86 \times 2{\cdot}068$
$= 3{\cdot}85 = \log 7080$
$\therefore 117^{1.86} = 7080$.
e.g. 117^2, $\log 117^2 = 2 \log 117 = 2 \times 2{\cdot}068 = 4{\cdot}136 = \log 13700$.
$\therefore 117^2 = 12.700$.

FRICTIONAL RESISTANCE.—*Assuming Zahm's formula for air friction, calculate the friction on* 1170 *ft.*^{2} *of exposed surface at* 80 *m.p.h.*

Zahm's formula; $F(\text{lbs.}) = 0{\cdot}0000082 A^{0.93} v^{1.86}$
v is in ft./sec.
$\therefore$ 80 m.p.h. $= 1{\cdot}46 \times 80 = 117$ ft./sec.
Thus, the friction F(lbs.)
$= 0{\cdot}0000082\ (1170)^{0.93} (117)^{1.86}$.
$(1170)^{0.93}$; $0{\cdot}93 \log 1170 = 0{\cdot}93 \times 3{\cdot}068 = 2{\cdot}85 = \log 708$.
$\therefore (1170)^{0.93} = 708$.
$(117)^{1.86}$; $1{\cdot}86 \log 117 = 1{\cdot}86 \times 2{\cdot}068 = 3{\cdot}85 = \log 7080$.
$\therefore (117)^{1.86} = 7080$.
$\therefore F(\text{lbs.}) = 0{\cdot}0000082 \times 708 \times 7080$
$= 0{\cdot}0000082 \times 5{,}000{,}000$
$= 41$.

Imagine air friction to be $\propto Av^2$ *instead of* $A^{0.93}v^{1.86}$, *and that the coefficient remains unaltered, what would be the difference for the case in question?*

$$Av^2 = 1170 \times 117^2 = 1170 \times 13{,}700 = 16{,}000{,}000,$$
$$\text{and } A^{0.93}v^{1.86} = 5{,}000{,}000.$$
$$\therefore Av^2/A^{0.93}v^{1.86} = 16 \div 5 = 3{\cdot}2.$$

Thus, the resistance to motion would be more than trebled.

What is the pressure on a flat plate measuring 35 *ft. by* 33 *ft.* 6 *in. facing a wind of* 80 *m.p.h.?*

The formula for air-pressure on flat plates is $P = c\rho Av^2$.

$$A = 35 \times 33{\cdot}5 \text{ ft.}^2 = 1170 \text{ ft.}^2$$
$$v \text{ ft./sec.} = 80 \times 1{\cdot}46 = 117.$$

ρ for air at atmospheric temp. and pressure $= 0{\cdot}08$ lbs./ft.^{3}

$$\therefore \frac{\rho}{g} = \frac{1}{400} \text{ approx.}$$

C for large plates $= 0{\cdot}62$ (experimental value).

$$\therefore P(\text{lbs.}) = C\frac{\rho}{g}Av^2$$
$$= 0{\cdot}62 \times \frac{1}{400} \times 1170 \times 117^2$$
$$= \frac{0{\cdot}62 \times 1170 \times 13{,}700}{400}$$
$$= 24{,}800.$$

In the above case, compare the pressure per square foot and per square metre.

$$P(\text{lbs./ft.}^2) = C\frac{\rho}{g}v^2 = \frac{0{\cdot}62 \times 13{,}700}{400} = 21{\cdot}2.$$

$$P(\text{kgs./m}^2) = C\frac{\rho}{g}v^2 \text{ (metric).}$$

$$\rho = 1{\cdot}29 \text{ kg./m}^3; \quad g = 9{\cdot}81 \text{ m./sec./sec.}$$

$$\therefore \frac{\rho}{g} = \frac{1}{7{\cdot}65}$$
$$v = 117 \times 0{\cdot}305 = 35{\cdot}6 \text{ m./sec.}$$
$$\therefore v^2 = 1280.$$

C being an absolute constant is still $0{\cdot}62$.

$$\therefore P(\text{kgs./m}^2) = \frac{0{\cdot}62 \times 1280}{7{\cdot}65} = 104.$$

Ratio :—lbs./ft.^{2} : kgs./m^2 $= 21.2/104 = 1/4.9$.

Compare with the figure given in the Pressure Conversion Table, page 345.

In the preceding examples, compare the pressure on the plate when facing the wind with the surface friction when it is set edgewise.

The area of the plate facing the wind is 1170 ft.^{2}.

The surface that it exposes to friction when edgewise is, therefore, 2×1170 ft.^{2}.

For convenience call the pressure P and the friction F.

Then $P = 24{,}800$ lbs., and $F = 2 \times 41 = 82$ lbs.

$\therefore$ Ratio $P/F = 24800/82 = 300$ nearly.

That is to say, at 80 m.p.h. the pressure on a flat plate of 1170 ft.^{2} area is about 300 times the total friction on its surface when placed edgewise. This ratio only holds for this particular area at this particular speed.

In the above, what would be the effect of 25% increase in speed?

New speed $= 80 + (\cdot 25 \times 80) = 80 + 20 = 100$ m.p.h.

For the face pressure $P \propto v^2$.

$$\therefore \text{ Increase in } P = \frac{100^2}{80^2} = 1\cdot 25^2 = 1\cdot 57 = 57\%.$$

For the surface friction $F \propto v^{1.86}$.

$$\therefore \text{ Increase in } F = \frac{(100)}{80}^{1.86} = 1\cdot 25^{1.86}.$$

$1\cdot 25^{1.86}$; $1\cdot 86 \log 1\cdot 25 = 1\cdot 86 \times 0\cdot 097 = 0\cdot 18 = \log 1\cdot 51$.

$\therefore 1\cdot 25^{1.86} = 1\cdot 51$.

$\therefore$ Increase in $F = 51\%$.

In the above, what would be the effect of halving the area of the plate?

The face pressure P is proportional to the area

$\therefore$ P is reduced by 50%.

The friction F is proportional to $A^{0.93}$

$$\therefore F \propto (\tfrac{1}{2})^{\cdot 93}; \quad 0\cdot 93 (\log 1 - \log 2)$$

$$\log 1 = 0\cdot 0; \quad \log 2 = 0\cdot 301; \quad 0 - 0\cdot 301 = \bar{1}\cdot 699$$

$$0\cdot 93 \times \bar{1}\cdot 699 = 0\cdot 93 \times (-0\cdot 301) = -0\cdot 28 = \bar{1}\cdot 72 = \log \cdot 525.$$

$$\therefore (\tfrac{1}{2})^{\cdot 93} = 0\cdot 525.$$

That is to say, the friction F will now be 0·525 of what it was formerly. This represents a reduction of $(1 - 525) = 0.475$, i.e. $47\frac{1}{2}\%$.

What would be a plausible value for the estimated resistance of a fair-shaped body having 1170 ft.^{2} of exposed surface?

From the tests recorded in the Technical Report on dirigible shapes, the resistance calculated by Zahm's formula was found to vary indiscriminately from 50% to 75% of the total resistance.

Thus, if the fair-shaped body in question is in any way less symmetrical in form than these examples, it seems improbable that its resistance would be less than twice that calculated by Zahm's formula.

Thus, the resistance calculated above is 41 lbs.

$\therefore$ a plausible figure for the resistance of the fair-shaped body is $2 \times 41 = 82$ lbs. at 80 m.p.h.

The resistance of the body will be $\propto A^{\cdot 93}v^{1\cdot 86}$ according to the Technical Report.

Having regard to the fact that any fair-shaped body must have a considerable fineness ratio, and also to the fact that the exposed surface necessarily increases with the length, it is interesting to discuss roughly the limiting ratio of length to diameter that would make the resistance of a fair shape under given conditions equal to that of its cross-sectional area as a flat plate.

In a previous example, the face-pressure on a flat plate was shown to be 600 times greater than the friction on the *same area* of exposed surface for a *particular case.*

Allowing the friction so calculated to be 50% of the total resistance of the fair shape, the ratio of face-pressure to surface resistance becomes 300 : 1.

Suppose for convenience that the surface is expressed, as that of a cylinder, by π DL, where D = diameter and L = length.

Then the cross-sectional area $= \frac{\pi}{4} D^2$.

$$\therefore \text{ the ratio } \frac{\text{surface}}{\text{section}} = \frac{\pi DL}{\frac{\pi}{4} D^2} = 4\frac{L}{D}.$$

And L/D = fineness ratio.

$\therefore$ when $4\ L/D = 300$ the resistances will be equal.

i.e. when $L = \frac{300}{4} D = 75\ D$.

In the above, roughly speaking, how would the resistance of the fair shape compare with the pressure on the section as a flat plate if the fineness ratio were 7·5?

$$\text{The ratio of areas } \frac{\text{surface}}{\text{section}} = 4\frac{7\cdot 5}{1} = 30.$$

$$\text{The ratio of resistances } \frac{\text{unit surface}}{\text{unit section}} = 300.$$

$\therefore$ since the actual surface is 30 times the cross-sectional area, the resistance of the body might be expected to be about $\frac{1}{10}$th that of its cross-sectional area as a flat plate for this *particular case.*

Since $F \propto A^{0\cdot 93}v^{1\cdot 86}$, whereas $P \propto Av^2$, it is apparent that the above ratio will not hold for any other speed or area of exposed surface than the particular value for which it was calculated.

A certain aeroplane loaded weighs 2000 lbs. The wing selected for its use has the characteristics graphically illustrated in the chart on p. 321. Choose a suitable area.

The lift of a wing is given by the formula $P(\text{lbs.}) = C\frac{\rho}{g}Av^2$, of which the constant C varies with the angle as shown on the chart; the mass density of air $\frac{\rho}{g}$ is conveniently taken as $\frac{1}{400}$; A is the area required in ft.² and v is the flight speed in ft./sec.

The weight in flight is constant and = 2000 lbs.

$$\therefore\ P = C\frac{\rho}{g}Av^2 = 2000 \text{ lbs.}$$

It is obviously desirable to maintain a fairly high lift:resistance ratio throughout the flight region. By inspection of the graph, the lift:resistance ratio of 10 suggests itself as a plausible lower limit for the purposes of calculation. This value occurs when the angle of incidence is 2° and again when it is 12°. The corresponding lift coefficients are 0·2 and 0·56 respectively.

Of these, the latter represents the limit of normal low-speed flight. It determines the area, if ability to fly slowly is a consideration of first importance. Suppose a safe speed of 40 m.p.h. is required.

Then 40 m.p.h. $= 1{\cdot}46 \times 40 = 48{\cdot}4$ ft./sec.

$$P = C\frac{\rho}{g}Av^2 = 0{\cdot}56 \times \frac{1}{400} \times A \times (48{\cdot}4)^2 = 2000 \text{ lbs.}$$

$$\therefore\ A = \frac{2000 \times 400}{0{\cdot}56 \times (48{\cdot}4)^2} = \frac{800{,}000}{0{\cdot}56 \times 2350} = \frac{800{,}000}{1320}$$
$$= 610 \text{ ft.}^2.$$

The wing loading is thus $\frac{2000}{610} = 3{\cdot}3$ lbs. nearly.

It now remains to consider the speed required to support flight at 2° angle of incidence, when the lift coefficient is 0·2. Thus, from the above:

$$v^2 = \frac{800{,}000}{0{\cdot}2 \times 610} = 6600$$
$$\therefore\ v = \sqrt{6600} = (6600)^{0{\cdot}5}$$
$$\tfrac{1}{2}\log 6600 = \tfrac{1}{2}(3{\cdot}8195) = 1{\cdot}9047$$
$$= \log 80{\cdot}3.$$
$$\therefore\ v = 80{\cdot}3 \text{ ft./sec.} = 55{\cdot}5 \text{ m.p.h.}$$

The speed range of 40 to 55·5 m.p.h. represents 15·5 m.p.h. increase on 40 m.p.h., or 39%.

In the above, suppose the inclusive resistance to horizontal flight is graphically illustrated by the gliding angle curve on p. 321. *Discuss the possibilities of the machine if* 80 *h.p. is available at the propeller under all conditions of flight.*

At 40 m.p.h. the gliding angle by the graph is 1 in 6. The resistance to flight is therefore $2000 \div 6 = 333$ lbs.

333 lbs. × 40 m.p.h. = 13,320 mile lbs./hr.

$(13{,}320 \div 375) = 35{\cdot}5$ h.p.

There is, thus $(80 - 35{\cdot}5) = 44{\cdot}5$ h.p. or 55% of the engine power in reserve at the low speed.

At 55·5 m.p.h. the resistance is 1 in 7·7 = 260 lbs.

260 lbs. × 55·5 m.p.h. = 38·5 h.p.

Suppose the resistance from this point upwards increases in proportion to V^2, *what is the limit in speed for* 80 *h.p.* ?

Since power is the product resistance × velocity, and resistance is, by the above assumption, made proportional to V^2, then the power required becomes proportional to $V^2 \times V = V^3$. Alternatively, the speed is proportional $\sqrt[3]{\ }$ power.

Thus, $\sqrt[3]{38{\cdot}5}$ h.p. corresponds to 55·5 m.p.h.

Then $\sqrt[3]{80}$ h.p. . . . . $55{\cdot}5\left[\sqrt[3]{\left(\frac{80}{38{\cdot}5}\right)}\right]$

$= 55{\cdot}5[\sqrt[3]{2{\cdot}08}]$

$$\tfrac{1}{3}\log 2{\cdot}08 = \tfrac{1}{3} \times 0{\cdot}3181 = 0{\cdot}106.$$
$$= \log 1{\cdot}28$$
$$\therefore \sqrt[3]{2{\cdot}08} = 1{\cdot}28$$

and $V = 55{\cdot}5 \times 1{\cdot}28 = 71$ m.p.h.

At 71 m.p.h. with 80 h.p., the resistance is $\frac{80 \times 375}{71} = 424$ lbs. And for a weight of 2000 lbs. this represents a "gliding angle" of 1 in 4·75.

It will be observed that this figure is fairly in accord with the value given on the graph for this speed.

In the above, it is apparent that there is a reserve of about 80 *h.p. at the lower speeds. If this is all available for ascent what is the initial rate of climbing, neglecting all losses* ?

40 h.p. = (40 × 33,000) ft. lbs./min.

The weight raised is 2000 lbs.

$\therefore$ Initial rate of ascent is $\frac{40 \times 33{,}000}{2000} = 660$ ft./min.

Suppose it to be possible to ascend until the scale of lift coefficients is reduced by 33% owing to the change in atmospheric density, what is the limiting altitude?

Neglecting temperature change, the ratio of densities gives the ratio of the barometer readings, viz. $3:2=1\cdot5$.

An approximate formula connecting this ratio with altitude is $H(\text{ft.})=60{,}720 \log q$,

where $q=\left(\frac{p^1}{p^2}\right)$ the ratio of the pressures, viz. in this case $1\cdot5$.

Thus
$$H(\text{ft.})=60{,}720 \log 1\cdot5=60{,}720\times\cdot1761$$
$$=10{,}700 \text{ ft. (approx.)}.$$

If the barometer reads 760 mm. initially it will finally read $\frac{2\times760}{3}=505$ mm.

A table is given on p. 352 showing the heights in metres corresponding to barometer and temperature.

For 505 mm. a plausible reading is about 3250 metres or $3\cdot28\times3300=10{,}700$ ft.

An aeroplane flying at 600 ft. altitude and 70 m.p.h. is observed to descend steeply with the engine shut off. When it has travelled 600 ft. measured horizontally, it is only 100 ft. above the ground. What is its probable speed at this point if its resistance is 1 in 6 at 70 m.p.h. and increases as V^2?

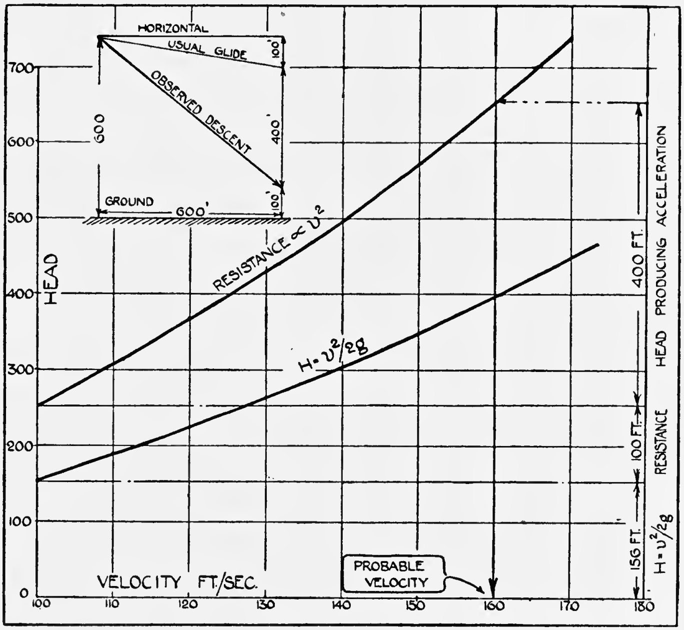
Problems of this character should always be visualized by diagrams and may most readily be solved graphically.

Thus, from the diagram, it is apparent that if the glide had been accomplished at 70 m.p.h. against 1 in 6 resistance, the descent would have been 100 ft. in a distance of 600 ft. There is thus 400 ft. loss of altitude unaccounted for by resistance and this head must, therefore, be producing acceleration.

The head through which a body would have to fall in vacuo to acquire 70 m.p.h. or $(1\cdot46\times70)$=say, 100 ft. sec. (approx.) is: $H=v^2\div2g=(100)^2\div64=156$ ft.

A graph of $H=v^2/2g$ is drawn over a suitable range of speeds, and above this is plotted a curve representing the additional head required to overcome resistance $\propto v^2$. This curve starts 100 ft. above the first curve at 100 ft./sec., and the subsequent heights above the first curve are made proportional to the squares of the speeds. Thus $(100)^2$ corresponds to 100 ft. $\therefore (110)^2=120$ ft.; $(120)^2=145$ ft.; $(130)^2=170$ ft., etc.

The total head under consideration is 156 ft., representing the initial velocity, +100 ft. representing the initial resistance +400 ft. representing the acceleration, =656 ft. A horizontal line drawn at this altitude on the chart intersects the resistance curve above the speed of 160 ft./sec. = 110 m.p.h., which is thus an estimate of the probable speed at the moment under consideration.



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Graphic solution to the above problem.

Whereabouts, approximately, would the c.p. on the wings be situated at 110 *m.p.h., assuming the wing section to be that represented by the graphs on p.* 321 *and p.* 319. *The machine weighs* 2000 *lbs. and has* 610 *ft.*^{2} *wing area.*

In horizontal flight the wing loading would be (2000÷610) = 3·3 ft. lbs.^{2}, but owing to the sloping descent less than the full weight of the machine is air-borne.

The tangent of the angle of descent is given by the fall of 500 ft. in 600 ft. $=\frac{5}{6}=0{\cdot}835=\tan 40^\circ$. That is to say, the slope is 40° to the horizontal. The air-borne weight on the wings is proportional to the cosine of the slope; cos 40 = 0·76.

∴ the wing loading $=0{\cdot}76\times3{\cdot}3=2{\cdot}5$ lbs./ft.^{2}

$$\text{Thus } P=C\frac{\rho}{g}v^2=C\times\frac{1}{400}\times(110)^2=2{\cdot}5$$

$$\therefore\ C=\frac{2{\cdot}5\times400}{(110)^2}=0{\cdot}083.$$

From the graph on p. 321 a coefficient 0·083 corresponds to nearly $-\frac{1}{2}°$ angle of incidence, and from the graph on p. 319 the c.p. at $-\frac{1}{2}°$ is about 0·65 of the chord from the leading edge; that is to say, it is appreciably aft of the middle of the wing.

In the above, suppose the wing chord measures 6 ft.: the front and rear spars being 1 ft. and 4 ft. 6 ins. from the leading edge respectively. Compare the loads on the two spars at 9° and $-\frac{1}{2}°$ angles of incidence.

At 9°, the c.p. is about ·27 of the chord for the front.

$0{\cdot}27 \times 6$ ft. $= 1{\cdot}62$ ft.

The c.p. is thus 0·62 ft. behind the front spar and 2·88 ft. from the rear spar.

The loads on the spars, which are 3·5 ft. apart, are inversely as the distance of the c.p. from each.

Thus the front spar carries $\frac{2{\cdot}88}{3{\cdot}5} = 82\%$

and the rear spar carries $\frac{0{\cdot}62}{3{\cdot}5} = 18\%$.

At $-\frac{1}{2}°$, the c.p. is about 0·65 of the chord from the front: thus, $0{\cdot}65 \times 6$ ft. $= 3{\cdot}9$ ft.

The c.p. is thus 2·9 ft. behind the front spar and 0·6 ft. in front of the rear spar.

It is obvious, without further calculation, that the distribution of the load is reversed, the rear spar now carrying over 82% of the total load.

It is apparent, therefore, that the rear spar must be at least as strong as the front spar for the above arrangement. If the rear spar were further forward it would be liable to carry more load than the front spar.

If this fine angle is only acquired on steep slopes, there will be a reduction of the total air-borne load, as explained in a former example. On a slope of 40° the load supported by the wings is 76% of the total weight of the machine, in which case the load on the rear spar becomes $\cdot 76 \times \cdot 82 = 62\%$ of the total. This apparent advantage, however, might readily disappear under the sudden stress of flattening out.

Discuss the question of a limiting speed for an aeroplane descending headlong.

Suppose the normal speed of the machine is V m.p.h., and that its resistance at this speed is $\frac{1}{6}$ W. From the curve on p. 321 it appears reasonable to assume that the inclusive resistance of a machine in flight increases as the square of the speed at high speeds

When falling headlong vertically, the propelling force of the earth's attraction is equal to the weight of the machine.

Steady motion will thus be attained when the normal resistance $\frac{1}{6}$ W is increased to W, i.e. to 6 times its original value.

As the resistance is assumed to increase as V^2, the velocity required will be $\sqrt{6}V = 2{\cdot}45V$. That is to say, the limiting speed for the case in question would be about $2\frac{1}{2}$ times the normal flying speed.

It is required to absorb by springs giving 9 *ins. compression the shock of landing a machine which alights at* 40 *m.p.h. while gliding on a slope of* 1 *in* 6 *without flattening out. Calculate the force on the springs.*

The rate of vertical descent is $\frac{1}{6} \times (1{\cdot}46 \times 40) = 9{\cdot}8$ ft./sec.

The distance in which this velocity of impact is reduced to zero is 0·75 ft.

From the fundamental formula $v = \sqrt{2fH}$

the retardation $f = \frac{v^2}{2H}$, where H is the compression range of the spring and v is the initial velocity.

Thus $f = \frac{(9{\cdot}8)^2}{2 \times 0{\cdot}75} = \frac{96}{1{\cdot}5} = 64$ ft./sec./sec.

The force of a blow $= mf$, where $m = \text{mass} = \frac{W}{g}$ (lbs.).

Thus $\frac{W}{g} f = \frac{W \times 64}{32} = 2W$.

That is to say, the force of the blow is equal to twice the weight of the machine.

A flat rudder plate of 12 *ft.*² *area is pivoted* 30 *ft. from the c.g. of the aeroplane. What is the couple produced by moving the rudder* 10° *when the machine is flying at* 100 *ft./sec.?*

According to the graph on p. 306 a flat plate at 10° gives a pressure coefficient of about 0·43.

$$\text{The total pressure } P = C\frac{\rho}{g}Av^2$$

$$= \frac{0{\cdot}43 \times 12 \times (100)^2}{400}$$

$$= 129 \text{ lbs.}$$

The couple $= 129 \times 30$ ft. $= 3770$ lb. ft.

A propeller exerting a thrust of 300 *lbs. is situated* 18 *ins. above the centre of resistance. What downward force on a tail plane* 30 *ft. to the rear will balance the couple?*

The couple due to the propeller is $(300\times1\cdot5)$ lb. ft. That due to the tail is $(P\times30)$ lb. ft.

$$\therefore\ =\frac{300\times1\cdot5}{30}=15 \text{ lbs.}$$

In the above, the machine weighs 2000 lbs. *How far behind the c.p. should the c.g. be situated to balance the propeller thrust?*

As before, couple due to thrust $=(300\times1\cdot5)$ lb. ft.
and couple due to c.g. $=(x\times2000)$ lb. ft.

$$\therefore\ x=\frac{300\times1\cdot5}{2000}=0\cdot225 \text{ ft.}=2\cdot7 \text{ ins.}$$

An aeroplane capable of 70 *m.p.h. steers due north in a wind of* 30 *m.p.h. blowing across its path at* 60°. *What is its course, and in what direction should it steer to proceed due north?*

The problem is best solved graphically as below by drawing vectors representing the relative motion of the machine and wind to scale. The resultant course and speed are measured off the diagram to scale.

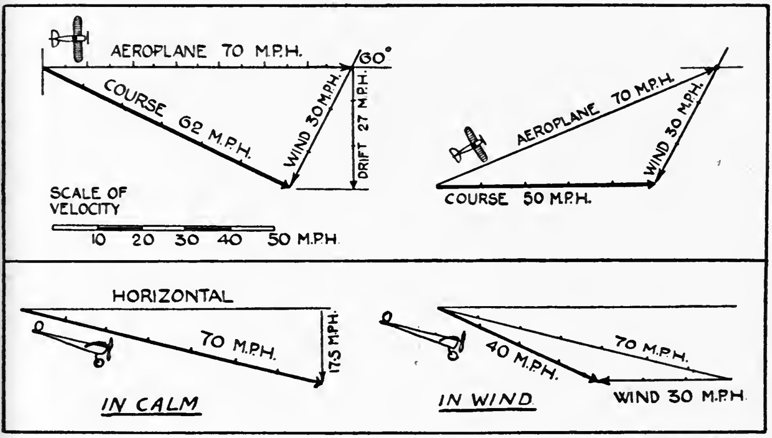

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Diagram illustrating the graphic solutions to these problems.

A machine flying at 70 *m.p.h. against a* 30 *m.p.h. wind descends at that speed on a slope of* 1 *in* 4 *to the relative wind. What is its apparent path to an observer on the ground?*

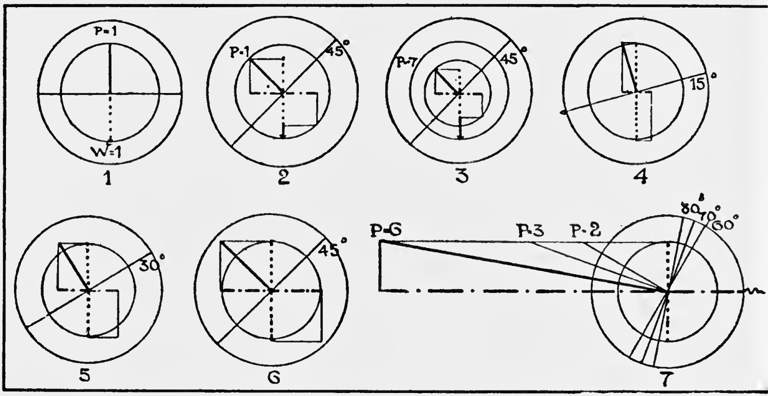
As before, the problem is solved graphically. It is important to recognize how a head wind increases the steepness of the apparent descent. The attitude of the machine itself, however, is unchanged.

By what force does an aeroplane steer a circular course?

Solely by the centripetal force obtained from a banked attitude; the centripetal force being the horizontal component of the wing pressure in this position.

Compare and discuss the centripetal forces under various conditions.

Consider for a moment the accompanying diagrams, which are supposed to represent the forces as seen in an end-on view of an approaching aeroplane. Fig. 1 shows the lift, P, equal to the weight, W, the wings being level. In Fig. 2 the wings are canted to 45°. As the pressure remains at right angles to the wing spar, its direction is tilted in sympathy with the bank. Assuming the relative air speed to be unchanged, the magnitude of the pressure will be the same as before. In its new direction it is unable to support the entire load of the weight, a fraction of which thus initiates downward acceleration.



Flight" Copyright Drawing

Diagrams illustrating the centripetal forces that steer an aeroplane when it is banked.

But there is now a horizontal component of the pressure causing acceleration to the left (supposing the machine to be advancing out of the plane of the paper towards the spectator) and this centripetal force is opposed by the equal centrifugal force as the machine proceeds along its appropriate circular path.

For the particular speed, there is a particular radius that will provide the proper centrifugal force to balance the centripetal force due to the bank, and the circular path corresponding to this radius the machine automatically pursues *without any aid from the rudder.*

While the bank, represented in Fig. 2, is being established, the radius of the turning circle is diminishing; when the bank is fixed, the centre of the turning circle is also fixed. The conditions of Fig. 2 may thus represent the beginning of the turn, or any instantaneous position during the turn.

It will be understood, therefore, that Fig. 2 represents a state of turning on a circular path, accompanied by an accelerated descent due to the weight being insufficiently supported. This latter is, of course, a possible source of danger at low altitudes when the ground may intervene to prevent the proper completion of the turn. If the lift should be reduced for any reason, the unsupported fraction of the weight is increased at the same time that the radius of turning increases, as shown in Fig. 3.

In order to turn on the same level, it is necessary to increase the speed or the angle of incidence, which may mean increasing the power output. Reserve power is in any case a primary factor of safety for turning.

In Fig. 4 is shown the case of a 15° bank, with increased pressure sufficient to support the load and maintain a rather wide turning circle. In Fig. 5 the increase in the wing pressure needed to support a 30° bank is indicated, and in Fig. 6 the bank is again 45°, as in Figs. 2 and 3. The pressure, it will be observed, is nearly one-third greater than normal. If $P \propto V^2$, then the velocity required represents an increase of about 15 per cent.

Beyond the angle of 45° the wing pressure needed to support the load plus the centrifugal force increases very rapidly, as is shown in Fig. 7. For a bank of 60° the wing pressure is about twice the normal, for 70° it is about three times the normal, and for 80° it is about six times the normal value.

For a bank of 45° the centrifugal force is equal to the weight supported against gravity. The radius of a given bank increases as the square of the speed needed for the support of the load due to the centrifugal force and the weight.

Thus, if a bank of 45° is completely supported at 80 ft. per second, the radius of the turning circle is 200 ft.; if a lower loading permitted the same bank to be maintained at 60 ft. per second the radius would be reduced to about 112 ft.

The question of a small turning circle depends on the reserve power that can be converted into extra wing pressure. Other things being equal, the lower speed machine will manœuvre in the least radius and will be able to put about in the least time.

The calculations for radius of turning circle are as follows:

Centripetal Force: $F = P \sin \phi$,

where P = wing pressure; ϕ = angle of bank.

If machine is to maintain the same level while turning, either the speed or the angle of incidence must be increased to make :

$$P=\frac{W}{\cos\phi}.$$

∴ turning without descent :

$$F=\frac{W\sin\phi}{\cos\phi}=W\tan\phi.$$

For the special case of 45°, $\tan 45°=1$. ∴ $F=W$.

The centrifugal force of any object W turning at v ft./sec. in a circle of radius r is :

$$F=Wv^2/gr.$$

Fundamentally :—Centrifugal force=Centripetal force.

∴ $W\tan\phi=Wv^2/gr$.

∴ $r=v^2/g\tan\phi$, for any angle of bank ϕ and for the special case of 45°, where $\tan\phi=1$

$r=v^2/g$.

For example, when $v=80$ ft./sec.

$r=6400/32=200$ ft.

and when $v=60$ ft./sec.

$r=3600/32=112$ ft.

What reserve power is required to turn on a bank of 45° *without descending?*

The wing pressure required to maintain the same level is

$$P=\frac{W}{\cos 45°}=\frac{W}{0{\cdot}707}=1{\cdot}42W.$$

The reserve power necessary to obtain this increase in wing pressure depends entirely on the prevailing attitude of the machine and whether it is necessary to increase the speed or merely to increase the angle.

If the machine is already flying very fine with the wings at an inefficient angle, increasing the angle will improve the efficiency of the wings, which will compensate more or less for the increased pressure.

Thus, suppose the wing shown in the graph on p. 321 is flying at 2° incidence, where the left coefficient is about 0·2. Then increasing the coefficient to $(1{\cdot}42\times0{\cdot}2)=0{\cdot}285$ will call for an angle of about 5°. The lift:resistance ratio in this latter attitude is about 12, whereas formerly it was only 9.

The effect, so far as the wings are concerned, is thus from a resistance of $(\frac{1}{9}\times1)=0{\cdot}11W$ to a resistance of $(\frac{1}{12}\times1{\cdot}42)=0{\cdot}118W$. That is to say, there is an increase of only 7%.

On the other hand, had the wings been flying in their attitude of maximum lift:resistance ratio, any alteration would involve a loss in lift:resistance ratio and consequently a very serious increase in power required. If the lift;resistance ratio remained unchanged the increase in the wing pressure by 42% would involve a corresponding increase in the power output at the same speed.

A consideration of this problem shows how fundamentally important it is to provide aeroplanes with sufficiently powerful engines, because even the initial assumption in the above estimate presupposed the machine to be flying faster than its speed of least resistance and, therefore, of having sufficient reserve power for this purpose.

What is the magnitude of the gyroscopic couple produced by the rotary engine and the propeller on an aeroplane that changes its course by 90° in 4 seconds? The data relating to the engine and propeller are as follows:

Engine. Weight $W = 280$ lbs.
Radius of gyration $\lambda = 0{\cdot}7$ ft.
Revs. per min. $= 1200$.
Propeller. Weight $W = 32$ lbs.
Radius of gyration $\lambda = 2{\cdot}5$ ft.
Revs. per min. $= 1200$.

Gyroscopic couple $M = m\lambda^2 W\Omega$.

Where M = mass, λ = radius of gyration, W = angular velocity of rotation in radians per sec., Ω = precession or angular velocity of displaced axis.

Engine:

$$m = \frac{W}{g} = \frac{280}{32} = 8{\cdot}75$$

$$\lambda^2 = 0{\cdot}7^2 = 0{\cdot}49$$

$$W = \left(\frac{1200}{60}\right) 2\pi = 125$$

$$\Omega = 90^\circ \text{ in } 4 \text{ secs.} = 1 \text{ rev. in } 4 \times 4 = 16 \text{ secs.}$$

$$\therefore \text{revs./sec.} = \frac{1}{16}$$

$$\therefore \Omega = \frac{2\pi}{16} = 0{\cdot}395.$$

$$\therefore M = m\lambda^2 w\Omega$$

$$= 8{\cdot}75 \times 0{\cdot}49 \times 125 \times 0{\cdot}395$$

$$= 212 \text{ lb. ft.}$$

Propeller:—

$$M = \frac{32}{32} = 1{\cdot}0$$

$$\lambda^2 = 2{\cdot}5^2 = 6{\cdot}2$$

W Ω as for the engine.

$$\therefore M = \lambda^2 w\Omega$$

$$= 1{\cdot}0 \times 6{\cdot}2 \times 125 \times 0{\cdot}395$$

$$= 305 \text{ lb. ft.}$$

Total $M = 212 + 305 = 517$ lb. ft.

At a radius of 20 ft. the force is $\frac{517}{20} = 26$ lbs.

On an elevator of 13 sq. ft. area at this distance from the c.g. the pressure required to counteract couple is 2 lb./ft.^{2} nearly.

It is apparent that, for the case in question, the control needed to counteract the gyroscopic couple is not more than might ordinarily be required to meet disturbances due to gusts. Further, the gyroscopic couple does not come unexpectedly.

It is interesting to note that the couple due to the propeller alone may be more than that due to the rotary engine alone.

Assuming a flight speed of 69 m.p.h., what radius and bank would satisfy the hypothesis of the previous problem?

In the previous problem, the machine turns 90° in 4 secs. ∴ it completes the circle in $(4\times4)=16$ secs.

$$\text{But } \frac{\text{circumference}}{\text{velocity}}=\text{time}=16 \text{ secs.}$$

$$\therefore \frac{2\pi r}{v}=16.$$

$$\therefore r=\frac{16v}{2\pi}=\frac{16\times(69\times1{\cdot}46)}{2\times3{\cdot}14}$$

$$=260 \text{ ft.}$$

Turning at $(69\times1{\cdot}46)=100$ ft. sec. on a radius of 260 ft. creates a centrifugal force:

$$F=\frac{Wv^2}{gr}=\frac{W(100)^2}{32\times260}=1{\cdot}21W,$$

which requires a corresponding centripetal force:

$$F=W\tan\phi=1{\cdot}62W$$

$$\therefore \tan\phi=1{\cdot}21.$$

$$\therefore \phi={\cdot}50°.$$

Where ϕ=angle of bank. It is evident that the conditions are exceptionally severe.

What is the direction of the gyroscopic couple?

Draw in plan view the shaft and the rotating mass. Mark an arrow on the latter showing its rotation, then indicate the angular precession of the axis by another arrow. The gyroscopic couple will tend to place the rotating mass so that its arrows correspond to those drawn to indicate the precession.

The above may perhaps be memorized by the phrase "Rotation replaces precession."

What is the theoretical limit to the increase in the static thrust of a propeller when the power applied to the shaft is doubled?

The theoretical limit to the thrust/power ratio of a propeller is based on the assumption of a uniform slip stream v ft./sec. through the entire disc area $A=(D^2\ /4)$ ft.^{2}.

The thrust $F=mv$

$m=\text{mass/sec.}=\rho A v^2$

$$\therefore\ F(\text{lbs.})=\frac{\rho}{g}Av^2=\frac{Av^2}{400}.$$

The minimum energy per second in the slip stream

$$=\tfrac{1}{2}mv^2=\tfrac{1}{2}\frac{\rho}{g}Av^3 \text{ ft. lbs./sec.}$$

$$=\frac{Av^3}{800\times 550}\text{ H.P.}$$

Since the power h.p. $\propto v^3$, $\therefore\ v\propto \sqrt[3]{\text{h.p.}}$

And since the thrust $\propto v^2$, $\therefore\ F\propto(\sqrt[3]{\text{h.p.}})^2\propto \text{h.p.}^{2/3}\propto \text{h.p.}^{0\cdot 66}$.

Thus if the energy is doubled the thrust is increased $2^{0\cdot 66}$ times

$2^{0\cdot 66}$; $0\cdot 66 \log 2=0\cdot 66\times\cdot 301=0\cdot 2=\log 1\cdot 59$

i.e. the thrust is increased 59%.

As this calculation takes no account of blade friction, turbulence, and other losses that are likely also to increase simultaneously, the actual gain in thrust would be considerably less than this estimate.

A graph drawn to represent h.p.$^{2/3}$ serves, however, as a very useful datum line for the comparison of static thrust tests, but such tests are in themselves of no particular value.

The above example is given primarily as an illustration of the fundamental relationship between force and energy in fluids. It is applicable only where the boundary of the stream can be defined. In respect to propellers, it is useful as emphasizing the importance of having a sufficiently large diameter for slow speed flight.

What is the theoretical limit to the efficiency of a propeller in flight?

Neglecting turbulence and blade friction as in the previous example,

The work lost in the slip stream $=\tfrac{1}{2}mv_1^2$

The useful work done $=Fv=mv_1v$

$v_1=$ slip stream velocity, $v=$ flight speed; $F=$ thrust.

The mass in both cases $=\left[\frac{\rho}{g}A(v_1+v)\right]$

The total work done $=[\tfrac{1}{2}mv_1^2+mv_1v]$

$$\therefore\ \text{efficiency}=\frac{\text{useful work}}{\text{total work}}=\frac{mv_1v}{[\tfrac{1}{2}mv_1^2+mv_1v]}$$

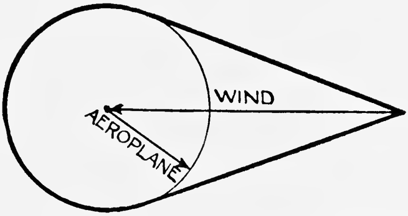
$$=\frac{v}{[\tfrac{1}{2}v_1+v]}=\frac{\text{flight speed}}{[\tfrac{1}{2}\text{ slip}+\text{flight-speed}]}$$

For a given propeller it is apparent that the theoretical limit to the efficiency increases with the flight speed.

Suppose the slip stream velocity=20% of the flight speed: then $v_1=0{\cdot}2v$

$$\therefore \text{Efficiency}=\frac{v}{[0{\cdot}2v+v]}=\frac{v}{1{\cdot}2v}=83{\cdot}5\%.$$

Draw a plan indicating the places within reach of a one hour's flight on an aeroplane when there is a real wind of greater velocity than the speed of the machine.



"Flight" Copyright Drawing

Diagram illustrating graphic solution to above problem.

At one extremity of a line representing the wind to scale and direction draw a circle of radius representing the real air speed of the machine to scale. Draw tangents from the circle to the other end of the wind line. Any point within the boundaries is within reach of an hour's flight starting from this end of the wind line.

A certain wing has been chosen for an aeroplane and its characteristic shows that 600 ft.² of area will be required to support the load in flight. What allowance must be made for biplane construction if the gap is equal to the chord?

The loss in lift coefficient with biplane construction, gap =chord is about 17%.

$\therefore$ area required$=(600+17\times 6)=702$ ft.²

What is the approximate range of vision at 1000 ft. altitude?

$$\begin{aligned}\text{Range (miles)} &= \sqrt{H+{\cdot}75H} \text{ where } H=\text{altitude}\\ &=\sqrt{1000+750}=\sqrt{1750}\\ &=42 \text{ miles.}\end{aligned}$$

Compare the maxima local forces on the top and bottom of a wing at 100 *ft./sec.*

Tests show that one may expect a local intensity of suction $=(-1\cdot5\rho v^2)$

The maximum pressure on the bottom surface $=0\cdot5\rho v^2$

$$\therefore\ 0\cdot5\frac{\rho}{g}v^2=\frac{0\cdot5\times(100)^2}{400}=12\cdot5\ \text{lbs./ft.}^2$$

$\therefore$ the probable suction at some point on the upper surface $=3\times12\cdot5=37\cdot5$ lbs./ft.^{2}

As 100 ft./sec.=69 m.p.h. the above would be quite a usual local stress on the wing fabric.

At 110 m.p.h., which, might be acquired during a dive, the local stress might be

$$\frac{1\cdot5\times(110\times1\cdot46)^2}{400}=\frac{1\cdot5\times(160)^2}{400}=97\ \text{lbs./ft.}^2$$

As this local intensity at some point is liable to occur on any wing at that speed, the necessity for a secure fabric fastening and strong ribs is clearly indicated. The fabric itself, unless deteriorated, is usually amply strong for its purpose.

A machine travelling at 50 *m.p.h., rolls in flight so as to depress one of its wings* 18 *ins. in a second. What is the alteration in the effective angle of wing tip incidence during this action?*

Speed of machine=73 ft./sec.

Descent of wing tip=1·5 ft./sec. for 1 ft.

$\therefore$ in 73 ft. wing tip descends 1·5 ft.

$$\therefore\ \text{tangent of angle of virtual inclination}=\frac{1\cdot5}{73}=0\cdot025\ \text{nearly}$$

$=\tan 1\tfrac{1}{2}^\circ$ approx.

That is to say, the angle of incidence at the tip is virtually increased $1\tfrac{1}{2}^\circ$ while descending. Similarly, the other wing tip is virtually reduced by this amount.

SYMBOLS EMPLOYED WITH A UNIFORM SIGNIFICANCE THROUGHOUT THIS BOOK

A = area ft.^{2}
C = the constant for air pressure in absolute units = 0·62 for a large flat plate.
D = diameter.
F = force.
H = head.
L = length
P = pressure.
V = speed m.p.h.
W = weight.

f = acceleration ft./sec./sec.
g = gravity = 32·2 ft./sec./sec.
k = a coefficient.
m = mass = $\frac{W}{g}$
v = velocity ft./secs.

θ = angle of incidence.
υ = kinematic viscosity.
$\pi = \frac{\text{circumference}}{\text{diameter}} = 3{\cdot}14159.$
ρ = density = 0·08 lbs./ft.^{3} for air.
ω = angular velocity radians/sec.

LETTERS OF THE GREEK ALPHABET COMMONLY EMPLOYED AS MATHEMATICAL SYMBOLS

α = alpha.
β = bēta.
γ = gamma.
δ = delta.
ϵ = epsīlon
ζ = zeta.
η = eta.
θ = theta.
λ = lambda
μ = mu.
ν = nu.
ξ = xi.
π = pi.
ρ = rho.
σ = sigma
τ = tau.
ϕ = phi.
ψ = psi.
ω = omega.

LIFT COEFFICIENT CONVERSION FACTORS

Wherever an *absolute* lift coefficient is given, either in this book or elsewhere, it may, for approximate purposes, be converted into "pounds lift per square foot of wing area" by multiplying by 0·0051 V^2; where V is the flight speed in m.p.h.

The following table gives useful values of the conversion factor for several speeds:

V m.p.h.	0·0051 V^2
40	8·15
50	12·7
60	18·3
70	25·0
80	32·6
90	41·5
100	51·0

e.g. A lift coefficient of 0·25 corresponds to (0·25 × 25) = 6·25 lbs. per sq. ft. at 70 m.p.h. under normal atmospheric conditions.

LENGTH

1 in.=25·4 cms.
1 ft.= 0·305 m.
1 yd.= 0·914 m.
1 mile=5280 ft.
=1760 yds.
= 1·61 km.
1 sea mile=6080 ft.
1° Equator=60 sea mi.
1 m.= 3·28 ft.

WEIGHT

1 oz.=28·35 grammes
1 lb.=16 oz.
=0·4536 kg.
=445,000 dynes
1 ton=2240 lbs.
=1016·05 kg.
1 U.S.A. ton=2000 lbs.
1 kg.=2·2 lbs.
=981,000 dynes

COUPLES

1 kg. m.=7·25 lbs. ft.
1 lb. ft.=0·138 kg. m.

AREA

1 ft.^{2}=144 in.^{2}
=0·093 m.^{2}
1 m.^{2}=10·76 ft.^{2}
1 yd.^{2}=0·836 m.^{2}
1 acre=4840 yds.^{2}
=4046·7 m.^{2}
1 sq. mile=640 acres.

PRESSURE

1 kg./m.^{2}=0·205 lbs./ft.^{2}
1 lb./ft.^{2}=4·9 kg./m.^{2}
1 lb./in.^{2}=0·07 kg./cm.^{2}
=68,976 dynes/cm.^{2}
=2·04″Hg. @ 62° F.
=2·3 ft. H_2O ,,
1″H_2O@62° F.=5·196 lbs./ft.^{2}
=0·073″ Hg.
=65 ft. air
1 atm.@62° F.=29·95″ Hg.
=760 mm. Hg.
=33·94 ft. H_2O
=14·76 lbs./in.^{2}
=1×10^6 dynes/cm.^{2}
=·95 ton/ft.^{2}
1 kg./cm.^{2}=14·223 lbs./in.^{2}
=·975 atm.
1 oz./yd.^{2}=33·9 grammes/m.^{2}

KINEMATIC VISCOSITY

Air=0·147
Water=0·105.

VELOCITY

1 m.p.h. = 1·46 ft./sec.
= 88 ft./min.
= 1·609 k.p.h.
1 knot = 1·152 m.p.h.
1 k.p.h. = 0·6214 m.p.h.
= 0·9113 ft./sec.
1 cm./sec. = 2 ft./min. (appx.)
1 ft./sec. = 0·685 m.p.h.
1 m./sec. = 2·25 m.p.h.

SOUND IN AIR 1142 FT./SEC.

WIND

Altitude. ft.	Velocity. m.p.h.
1,000	10
2,000	20
3,000	25
4,000	28
6,000	30
8,000	32
12,000	35

DENSITY (ρ)

If sp. gr. water = 1·00
then lb./in.^{3} = sp.gr. × ·036
1 gramme/cm^3 = 62·43lbs./ft.^{3}
1 kg./m^3 = 0·0623 lbs./ft.^{3}
1 lb./ft.^{3} = 15·8 kgs./m.^{3}
Air = 0·08 lbs./ft.^{3}
= 1·29 kg./m.^{3}
Hydrogen = 0·005 lbs./ft.^{3}
= 0·0895 lbs./m.^{3}
Coal gas = 0·0403 lbs./ft.^{3}
= 0·646 lbs./m.^{3}
Water = 62·5 lbs./ft.^{3}
= 10 lbs./gal.
Petrol (·72 sp. gr.) = 45 lbs./ft.^{3}
= 7·2 lbs./gal.
Ash = 49 lbs./ft.^{3}
Bamboo = 25 ,,
Cork = 15 ,,
Mahogany = 40 ,,
Oak = 50 ,,
Pine = 36 ,,
Spruce = 31 ,,
Walnut = 42 ,,

THE ATMOSPHERE

Altitude. ft.	Density ρ lbs./ft.^{3}
0	0·78
4,000	0·68
8,000	0·59
12,000	0·51
16,000	0·47
20,000	0·41

POWER

1 h.p. = 375 mile lbs./hour
= 33000 ft. lbs./min.
= 550 ft. lbs./sec.
= 77·5 kg. metres/sec.
= 0·746 kilowatts
= 42·416 B.Th.U./min. (lb.° F.)
= 10·711 calories/min. (kg°. C.)
= 0·175 lbs. carbon oxidized/hour
= 2·64 lbs. water evaporated@212° F./hour

Joules equivalent : 1 B.Th.U. = 772 ft. lbs.

VOLUME

1 gal. = 8 pts.
= 160 fl. ozs.
= 227·27 in.^{3}
= 0·16 ft.^{3}
= 4·546 litres
1 U.S.A. gal. = 231 in.^{3}
1 litre = ·1 m.^{3}
= 1·76 pts.
= 61·02 in.^{3}
= 0·22 gallon
1 ft.^{3} = 1728 in.^{3}
= 50 pints
= ·0283 m.^{3}
1 m.^{3} = 35·315 ft.^{3}
= 1·307 yds.^{3}
1 fluid oz. = 480 drops H_2O
1 teapsoonful = 60 drops (abt.)

TEMPERATURE

°C. = 0·555 (°F. − 32)
°F. = 32 + (1·8° C.)

Absolute zero = − 459° F.
= − 273° C.

The earth, increase in temp. with depth + 1° C. per 100 ft. (approx.).

The atmosphere, decrease in temp. with altitude :—

4000 ft. . . . − 2½° F. per 1000 ft.
16000 ft. . . . − 3° F. ,, ,,
17000 ft. . . . − 3½° F. ,, ,,
28000 ft. . . . − 4° F. ,, ,,

ANGULAR

1 circle = 360°
1 radian = $360° \div 2\pi$
= 57·296°
ω = angular velocity
= radians/sec.
= 2π revs./sec.
Revs./sec. = $\omega/2\pi$

DIMENSIONS

Velocity LT^{-1}
Acceleration LT^{-2}
Kinematic viscosity L^2T^{-1}
Density ML^{-3}
Force MLT^{-2}

Temperature. °Fahr.		°Cent.
0	=	−18
10	=	−12
20	=	− 7
32	=	0
40	=	4
50	=	10
60	=	16
70	=	21
80	=	27
90	=	32
100	=	38
110	=	43
120	=	49
130	=	54
140	=	60
150	=	65
160	=	71
170	=	77
180	=	82
190	=	88
200	=	93
212	=	100
220	=	104
230	=	110
240	=	115
250	=	121
260	=	126
270	=	132

Weight. Cwts.		Kgs.
5	=	254
10	=	508
12	=	610
14	=	712
16	=	813
18	=	915
20	=	1,016
22	=	1,118
24	=	1,220
26	=	1,321
28	=	1,423
30	=	1,524
32	=	1,626
34	=	1,728
36	=	1,829
38	=	1,931
40	=	2,032
42	=	2,134
44	=	2,235
46	=	2,337
48	=	2,438
50	=	2,540
52	=	2,640
54	=	2,740
56	=	2,840
58	=	2,940
60	=	3,050

Miles per gal.		Litres per 100 kiloms.
5	=	55
6	=	48
7	=	40
8	=	36
9	=	31
10	=	28
11	=	26
12	=	23
13	=	22
14	=	20
15	=	19
16	=	18
17	=	17
18	=	16
19	=	15
20	=	14
21	=	13·5
22	=	13·0
23	=	12·0
24	=	11·5
25	=	11·2
26	=	10·8
27	=	10·4
28	=	10·0
29	=	9·6
30	=	9·4
31	=	9·1
32	=	8·8
33	=	8·5
34	=	8·3
35	=	8·0

Exchange. £	*s.*	*d.*		fr.	c.
0	0	1	=	0	10
0	0	2	=	0	20
0	0	3	=	0	30
0	0	4	=	0	40
0	0	5	=	0	50
0	0	6	=	0	60
0	0	7	=	0	70
0	0	8	=	0	80
0	0	9	=	0	90
0	0	10	=	1	0
0	0	11	=	1	10
0	1	0	=	1	20
0	2	0	=	2	50
0	3	0	=	3	70
0	4	0	=	5	0
0	5	0	=	6	30
0	6	0	=	7	50
0	7	0	=	8	80
0	8	0	=	10	0
0	9	0	=	11	30
0	10	0	=	12	50
1	0	0	=	25	0
2	0	0	=	50	0
3	0	0	=	75	0
4	0	0	=	100	0
5	0	0	=	126	0
10	0	0	=	252	0

The above tables are only approximate.

MENSURATION

Surfaces—
Triangle =Base $\times \frac{1}{2}$ perpendicular.
Circle $=D^2 \times \cdot 7854$.
Sector =Arc $\times \frac{1}{2}$ radius.
Parabola =Base $\times \frac{2}{3}$ height.
Ellipse =Major axis $\times \cdot 7854$ minor axis.
Cone =Base area + (Base circ. $\times \frac{1}{2}$ slant height).
Sphere $=D^2 \times 3\cdot 14159$.

Volumes—
Cylinder =Base area × length.
Sphere $=D^3 \times \cdot 5236$.
Segment =·5236 Height (Height^2 + 3 Base Radius).
Cone =Base area $\times \frac{1}{3}$ perpendicular.
Wedge =Base area $\times \frac{1}{2}$ perpendicular.

The Circle—
Circumference $=D \times 3\cdot 14159$.
Equal Square $=D \times 0\cdot 886226$.
Inscribed ,, $=D \times 0\cdot 7071$.

Feet.		Metres.	Miles.		Kiloms.	Gallons.		Litres.	Lbs.		Kgs.
1	=	·3	1	=	1·6	1	=	4·5	1	=	·45
2	=	·6	2	=	3·2	2	=	9·0	2	=	·9
3	=	·9	3	=	4·8	3	=	13·6	3	=	1·4
4	=	1·2	4	=	6·4	4	=	18·2	4	=	1·8
5	=	1·5	5	=	8·0	5	=	22·7	5	=	2·3
6	=	1·8	6	=	9·6	6	=	27·3	6	=	2·7
7	=	2·1	7	=	11·2	7	=	31·8	7	=	3·2
8	=	2·4	8	=	12·8	8	=	36·3	8	=	3·6
9	=	2·7	9	=	14·5	9	=	40·9	9	=	4·1
10	=	3·0	10	=	16·1	10	=	45·4	10	=	4·5

Cu. ins.		Cu. cms.	Sq. ft.		Sq. metres.	Per lb.			Per kilog.		Per yard.			Per metre.	
						s.	d.		fr.	c.	s.	d.		fr.	c.
1	=	16·3	1	=	·09	1	0	=	2	80	1	0	=	1	40
2	=	32·7	2	=	·18	2	0	=	5	60	2	0	=	2	80
3	=	49·1	3	=	·28	3	0	=	8	40	3	0	=	4	15
4	=	65·5	4	=	·37	4	0	=	11	10	4	0	=	5	50
5	=	81·9	5	=	·46	5	0	=	13	90	5	0	=	6	90
6	=	98·3	6	=	·56	6	0	=	16	70	6	0	=	8	30
7	=	114·7	7	=	·65	7	0	=	19	50	7	0	=	9	65
8	=	131·1	8	=	·74	8	0	=	22	30	8	0	=	11	10
9	=	147·5	9	=	·84	9	0	=	25	0	9	0	=	12	40
10	=	163·0	10	=	·92	10	0	=	27	80	10	0	=	13	80

Pressure.

Lbs. per sq. in.		Atmospheres (or kilogs. per sq. centimetre).		Metres d'eau.
1	=	·07	=	0·7
2	=	·14	=	1·4
3	=	·2	=	2·1
4	=	·27	=	2·8
5	=	·34	=	3·5
6	=	·41	=	4·2
7	=	·48	=	4·9
8	=	·54	=	5·6
9	=	·61	=	6·3
10	=	·68	=	7·0
20	=	1·4	=	14·0
30	=	2·0	=	21·0
40	=	2·7	=	28·0
50	=	3·4	=	35·0
60	=	4·1	=	42·0
70	=	4·7	=	49·0
80	=	5·4	=	56·0
90	=	6·1	=	63·0
100	=	6·8	=	70·0

Price of Petrol.

Per gal.			Per litre.		Per bidon.	
s.	d.		c.		fr.	c.
1	0	=	28	=	1	40
1	1	=	30	=	1	50
1	2	=	33	=	1	65
1	3	=	35	=	1	75
1	4	=	37	=	1	85
1	5	=	39	=	1	95
1	6	=	42	=	2	10
1	7	=	44	=	2	20
1	8	=	46	=	2	30
1	9	=	49	=	2	45
1	10	=	51	=	2	55
1	11	=	53	=	2	65
2	0	=	55	=	2	75
2	1	=	58	=	2	90
2	2	=	60	=	3	0
2	3	=	63	=	3	15
2	4	=	65	=	3	25
2	5	=	67	=	3	35
2	6	=	69	=	3	45

The above tables are only approximate.

COMPASS

Points.		Angle. °	′	″
¼	=	2	48	45
½	=	5	37	30
¾	=	8	26	15
1	=	11	15	0
1¼	=	14	3	45
1½	=	16	52	30
1¾	=	19	41	15
2	=	22	30	0
2¼	=	25	18	45
2½	=	28	7	30
2¾	=	30	56	15
3	=	33	45	0
3¼	=	36	33	45
3½	=	39	22	30
3¾	=	42	11	15
4	=	45	0	0

Miles per hour.		Kiloms. per hour.
Only approximate.		
5	=	8
10	=	16
15	=	24
20	=	32
22	=	35
24	=	38
26	=	41
28	=	45
30	=	48
32	=	51
34	=	54
36	=	57
38	=	61
40	=	64
42	=	67
44	=	71
46	=	74
48	=	77
50	=	80
52	=	83
54	=	86
56	=	90
58	=	93
60	=	100
64	=	103
66	=	106
68	=	110
70	=	113
72	=	116
74	=	119
76	=	122
78	=	125
80	=	128
90	=	144
100	=	160
105	=	168
110	=	176
120	=	193

MORSE CODE

A	● ▬
B	▬ ● ● ●
C	▬ ● ▬ ●
D	▬ ● ●
E	●
F	● ● ▬ ●
G	▬ ▬ ●
H	● ● ● ●
I	● ●
J	● ▬ ▬ ▬
K	▬ ● ▬
L	● ▬ ● ●
M	▬ ▬
N	▬ ●
O	▬ ▬ ▬
P	● ▬ ▬ ●
Q	▬ ▬ ● ▬
R	● ▬ ●
S	● ● ●
T	▬
U	● ● ▬
V	● ● ● ▬
W	● ▬ ▬
X	▬ ● ● ▬
Y	▬ ● ▬ ▬
Z	▬ ▬ ● ●

NUMERALS

1	● ▬ ▬ ▬ ▬
2	● ● ▬ ▬ ▬
3	● ● ● ▬ ▬
4	● ● ● ● ▬
5	● ● ● ● ●
6	▬ ● ● ● ●
7	▬ ▬ ● ● ●
8	▬ ▬ ▬ ● ●
9	▬ ▬ ▬ ▬ ●
0	▬ ▬ ▬ ▬ ▬

FORMULÆ OF THE HYDROCARBONS, ETC., OF IMPORTANCE IN CONNECTION WITH LIQUID FUEL

1. The paraffin series—C_nH_{2n+2}

		bolts at ° C.		
Methane	CH_4	.	gas.	
Ethane	C_2H_6	.		
Propane	C_3H_8	.		
Butane	C_4H_{10}	.		
Pentane	C_5H_{12}	37		Spirit, the benzines or naphthas.
Hexane	C_6H_{14}	69	petrol	
Neptane	C_7H_{16}	98		
Octane	C_8H_{18}	120		
Nonane	C_9H_{20}	130		
Decane	$C_{10}H_{22}$	158	Kerosene or lamp oil, "Solar" or Intermediate oil,	
Undecane	$C_{11}H_{24}$	180		
Duodecane	$C_{12}H_{26}$	200		
etc. etc.			Lubricating oil, Vaseline, Wax.	
	$C_{17}H_{36}$	.		
etc. etc.				

2. The Olefine series C_nH_{2n}
Ethylene C_2H_4
etc. etc.

3. The Acetylene series C_nH_{2n-2}
Acetylene C_2H_2
etc. etc.

4. The Benzene series C_nH_{2n-6}
Benzene C_6H_6 boils at 81° C. } Benzol.
Tolvene C_7H_8 ,, 111
Xylene C_8H_{10}
etc.

5. Naphthalene C_nH_{2n-12}
Naphthalene $C_{10}H_8$ boils at 218° C.

6. Alcohol C_2H_5OH
Methylic Alcohol CH_4O boils at 63° C.
Ethylic ,, C_2H_6O ,, 78° C.

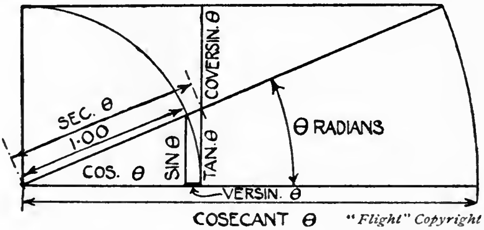


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Diagram illustrating the trigonometrical ratios.

ALTITUDE (METRES) Corresponding to Barometer mm.

Bar. mm.	Mean Temperature, ° C.				
	20°.	10°.	0°.	-10°.	-20°.
770	–90	–87	–84	–81	–78
760	33	22	21	20	19
750	137	132	127	123	118
740	252	243	235	227	219
730	369	356	344	332	320
720	488	471	455	439	423
710	608	587	567	547	527
700	730	705	680	656	632
690	854	825	796	767	738
680	980	946	913	880	847
670	1,107	1,070	1,032	994	956
660	1,237	1,195	1,152	1,109	1,067
650	1,368	1,322	1,275	1,228	1,181
640	1,502	1,450	1,399	1,348	1,297
630	1,637	1,581	1,525	1,469	1,413
620	1,775	1,714	1,654	1,593	1,532
610	1,915	1,850	1,784	1,718	1,653
600	2,057	1,987	1,917	1,847	1,777
590	2,202	2,127	2,052	1,977	1,902
580	2,349	2,269	2,189	2,109	2,029
570	2,499	2,414	2,328	2,243	2,158
560	2,651	2,561	2,470	2,380	2,290
550	2,807	2,711	2,615	2,519	2,423
540	2,965	2,863	2,762	2,661	2,560
530	3,126	3,019	2,912	2,805	2,698
520	3,290	3,177	3,065	2,953	2,841
510	3,457	3,339	3,221	3,103	2,985
500	3,628	3,504	3,380	3,256	3,132
490	—	3,672	3,542	3,412	3,282
480	—	3,843	3,708	3,572	3,436
470	—	4,019	3,876	3,734	3,592
460	—	4,198	4,049	3,901	3,753
450	—	4,380	4,226	4,071	3,916
440	—	4,567	4,406	4,245	4,083
430	—	4,759	4,591	4,422	4,253
420	—	4,955	4,780	4,604	4,428
410	—	5,155	4,973	4,791	4,608
400	—	5,361	5,171	4,982	4,792
390	—	5,572	5,375	5,178	4,981
380	—	5,788	5,583	5,379	5,174
370	—	6,010	5,797	5,585	5,372
360	—	6,238	6,017	5,797	5,576
350	—	6,473	6,244	6,015	5,786
340	—	6,714	6,477	6,239	6,002
330	—	6,963	6,716	6,470	6,224
320	—	7,219	6,964	6,709	6,453
310	—	7,483	7,219	6,954	6,690
300	—	7,757	7,482	7,208	6,934
290	—	8,039	7,755	7,471	7,186
280	—	8,331	8,037	7,742	7,448
270	—	8,634	8,329	8,024	7,718
260	—	8,949	8,633	8,317	8,000
250	—	9,276	8,948	8,620	8,292
200	—	11,153	10,742	10,348	9,954
150	—	13,536	13,058	12,579	12,101
100	—	16,925	16,327	15,729	15,130
50	—	22,717	21,914	21,110	20,308

SINES AND TANGENTS

Degs.	Sine.	Tangent		Degs.	Sine.	Tangent.	
0	·00000	·00000	90	46	·71934	1·03553	44
1	·01745	·01746	89	47	·73135	1·07237	43
2	·03490	·03492	88	48	·74314	1·11061	42
3	·05234	·05241	87	49	·75471	1·15037	41
4	·06976	·06993	86	50	·76604	1·19175	40
5	·08716	·08749	85	51	·77715	1·23490	39
6	·10453	·10510	84	52	·78801	1·27994	38
7	·12187	·12278	83	53	·79864	1·32704	37
8	·13917	·14054	82	54	·80902	1·37638	36
9	·15643	·15838	81	55	·81915	1·42815	35
10	·17365	·17633	80	56	·82904	1·48256	34
11	·19081	·19438	79	57	·83867	1·53987	33
12	·20791	·21256	78	58	·84805	1·60033	32
13	·22495	·23087	77	59	·85717	1·66428	31
14	·24192	·24933	76	60	·86603	1·73205	30
15	·25882	·26795	75	61	·87462	1·80405	29
16	·27564	·28675	74	62	·88295	1·88073	28
17	·29237	·30573	73	63	·89101	1·96261	27
18	·30902	·32492	72	64	·89879	2·05030	26
19	·32557	·34433	71	65	·90631	2·14451	25
20	·34202	·36397	70	66	·91355	2·24604	24
21	·35837	·38386	69	67	·92050	2·35585	23
22	·37461	·43403	68	68	·92718	2·47509	22
23	·36073	·42447	67	69	·93358	2·60509	21
24	·40674	·44523	66	70	·93969	2·74748	20
25	·42262	·44631	65	71	·94552	2·90421	19
26	·43837	·48773	64	72	·95106	3·07768	18
27	·45399	·50593	63	73	·95630	3·27085	17
28	·46947	·53171	62	74	·96126	3·48741	16
29	·48481	·55431	61	75	·96593	3·73205	15
30	·50000	·57735	60	76	·97030	4·01078	14
31	·51504	·60086	59	77	·97437	4·33148	13
32	·52992	·62487	58	78	·97815	4·70463	12
33	·54464	·64941	57	79	·98163	5·14455	11
34	·55919	·67451	56	80	·98481	5·67128	10
35	·57358	·70021	55	81	·98769	6·31375	9
36	·58779	·72654	54	82	·99027	7·11537	8
37	·60182	·75355	53	83	·99255	8·14435	7
38	·61566	·78129	52	84	·99452	9·51436	6
39	·62329	·80978	51	85	·99619	11·43005	5
40	·64279	·83910	50	86	·99756	14·30067	4
41	·65606	·86929	49	87	·99863	19·08114	3
42	·66913	·90040	48	88	·99939	28·63625	2
43	·68200	·93252	47	89	·99985	57·28996	1
44	·69466	·96569	46	90	1·00000	Infinite	0
45	·70711	1·00000	45				
	Cosine.	Contangent.	Degs.		Cosine.	Contangent.	Degs.

COSINES AND CONTANGENTS

LOGARITHMS

No.	0	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374
11	0414	0453	0492	0531	0569	0707	0645	0682	0719	0755
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279
17	2304	2330	1355	2380	2405	2430	2455	2480	2504	2529
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989
20	3010	3032	2054	3075	3096	3118	3139	3160	3181	3201
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551
36	5513	5575	5557	5599	5611	5623	5635	5647	5658	5670
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425
44	6435	6444	6454	6464	6474	6484	6494	6503	6513	6522
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803
48	6812	6821	6830	6839	6846	6857	6866	6875	6884	6893
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	8681
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396

LOGARITHMS—*continued*

No.	0	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9217	9212	9222	9227	9232	9238
84	9243	9248	9253	9258	9262	9263	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9175	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996

INDEX

INDEX TO FIRST REFERENCES

The following index is for the convenience of those who may want to refer in Part I to the first use of an expression for the purpose of ascertaining its meaning.

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