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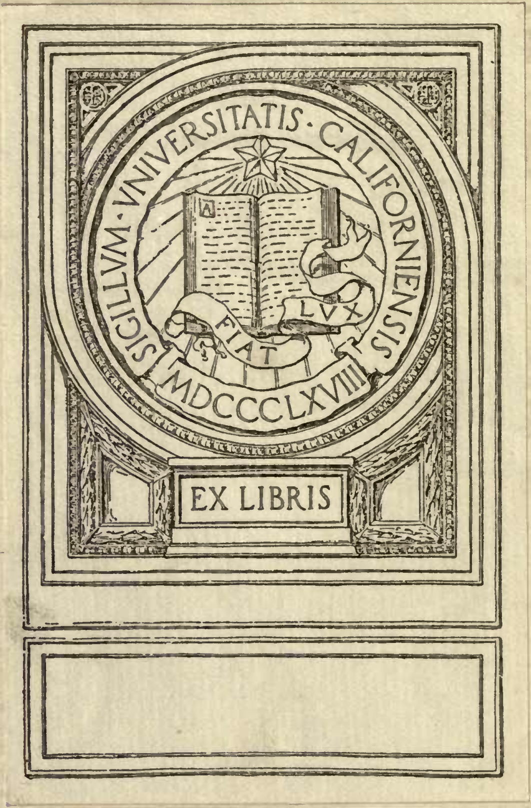

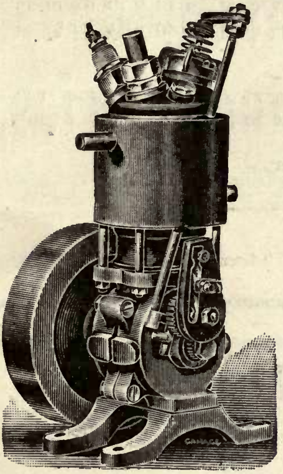

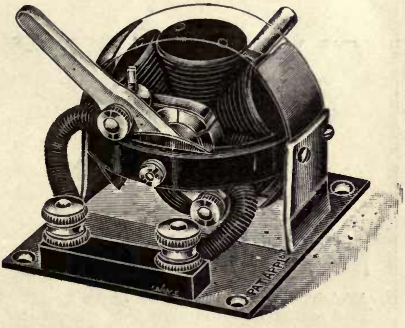
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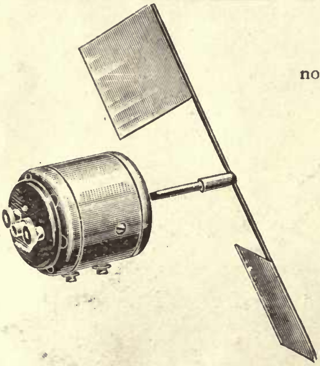

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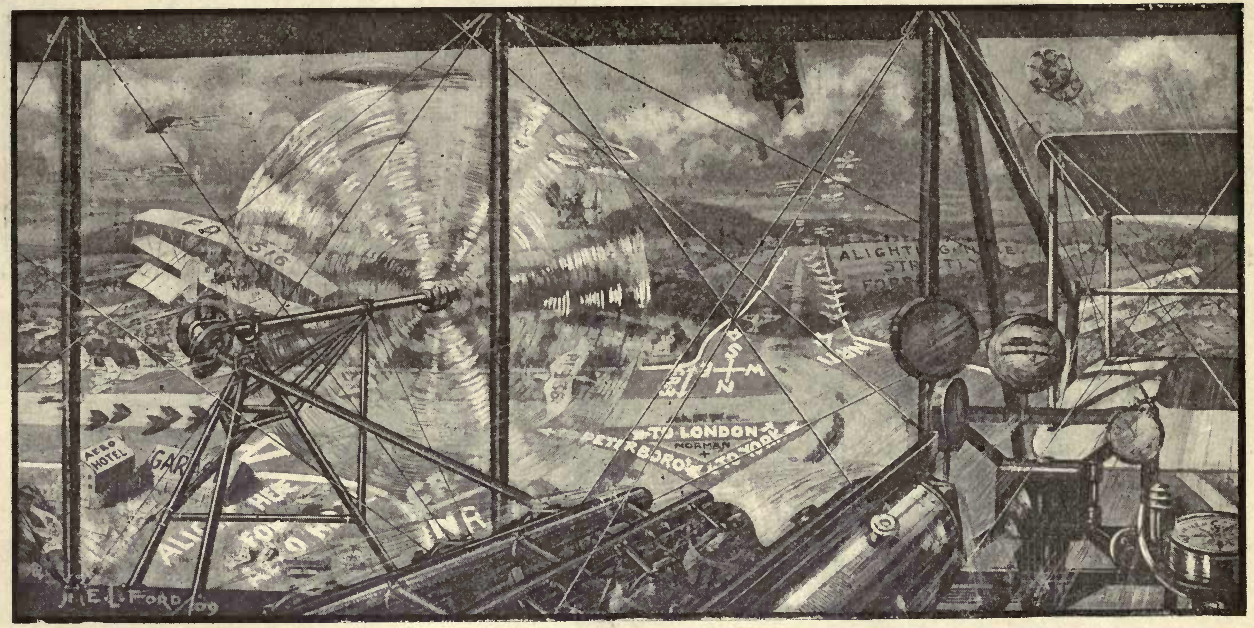

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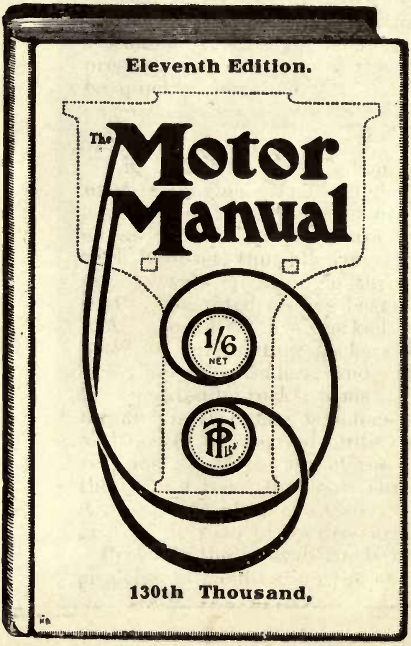

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INTRODUCTION.

At first thought, the man in the street would probably be inclined to assert that, in connection with the art of human flight, very little indeed had been written. And, although he would be in error, he would, paradoxically, be justified in his assertion. As a matter of fact, an immense amount has been written concerning aviation: from the earliest times the subject has appealed to the imagination and has inflamed the desires of man. Condemned to inhabit the lowest depths of an ocean of air, man has never ceased to envy the ability of the birds to rise off the solid bottom and float in the elastic medium that encloses them, and he has never ceased to study the means employed by them, or to investigate the possibilities of imitating them. And, although the advanced thinker along this line of thought has ever had to bear the sneers of his contemporaries, not a little of his work has been placed on record to serve some purpose—more or less useful—in the elucidation of the problem.

Thus a complete library of all that has been written on the subject of aviation would equal in bulk the contents of many an average bookcase. But—and it is a very big but—the literature of aviation is in many languages and considerably scattered, and much of it, in the light of latter-day knowledge, is mere chaff, the only difficulty about the sifting of the wheat from it being that we are only just learning to distinguish between the grain and the husk. The work of experimenters in the very first decade of the twentieth century has already provided us with some power of differentiation, and it is in the exercise of this power—admittedly imperfect—that "The Aero Manual" has been prepared.

The scheme underlying its compilation has been first a very severe winnowing of the wheat from the chaff and the presentment of the work of those investigators of the past whose work would now appear to count. And it has been found that much of the work that, had this Manual been prepared ten years ago, would have been dealt with therein, can now be disregarded. No previous decade has ever permitted of such extensive and useful weeding out. The importance of this lies in the fact that by our mistakes we learn and by our ability to recognise and disregard that which is useless so do we progress. This vein of thought has dominated the preparation of the historical section of "The Aero Manual" in order that it may usefully contribute to further investigation of the subject.

The work of the brothers Wilbur and Orville Wright is dealt with fully and in their own words, because of its immense value. Their achievements have set the seal on the work of the school which, starting with Lilienthal, has attained the success that man has sought through many centuries. The Wrights have told us personally that gliding is the basis of aviation and that to first gain perfection in gliding will materially quicken the attainment of the art of flying. For this reason, we have devoted space to the subject of gliding and have prepared designs for a suitable machine, based upon practical experience of men who have actually glided with them.

The information given in the Manual concerning airships is not carried so far as is that dealing with aeroplanes and gliders for the obvious reason that the airship is less likely to interest either the student or the sportsman, its function being almost entirely different to that of the heavier-than-air machine. The information about existing aeroplanes, engines suitable for aviation, component parts, constructional details, etc., has been very carefully written and revised up to the last moment, for improvement is always going on, naturally.

OUR FRONTISPIECE.

The scene, as observed from the pilot's seat of an aeroplane, 50 years hence, will show great departures from present-day methods of locomotion. The difficulty of the aeronaut in ascertaining his whereabouts has been overcome by the artist. To meet the many difficulties the highways have been considerably widened, the broad road for motor traffic being bordered on either side by great green swards, which serve as landing places for flying machines. Over these great trackways flying machines may travel, and, to facilitate night travelling, each trackway is bordered with a broad band of white chalk so that the searchlights of the flying machines may pick out the road boundaries. Each road is given a distinguishing symbol, the great national roads being lettered N R and numbered. Thus the aeroplane in the picture is travelling over N R—71, the great north road between London and York, whilst branching to the left is C R—3, the county road to Peterborough. The names and the signs are all laid in white chalk set into the green grass, and the name of each place is similarly shown as clearly as possible. The artist has assumed that navigation in the air will be governed by the same rules that control the navigation of ships at sea. A new regulation is needed only for the variation of altitude. It can be defined by a parody on the verse that refers to ships crossing:

If, beneath you, planes appear,
It is your duty to keep clear;
To act as judgment says is proper,
To port or starboard—rise, or drop her!

Flying clubs can be seen in the picture at a couple of points, and the Aero Hotel at Norman Cross has made ample provision in the way of landing space and machine storage.

PREFACE.

Aeroplane Design and Construction.

By Professor Herbert Chatley, B.Sc., A.M.I.C.E., Imperial Engineering College, North China.

There are quite a number of books on the subject of aviation which profess to tell the reader how to construct a machine, and, doubtless, by the exercise of considerable mental effort, useful information can be obtained from them, but the average man who has a bent for mechanical invention and is drawn into the glamour of this subject, wants to know a few particular things and not much more. He is, probably, aware that very few people know much about the subject, and thinks that, by breaking out in a new direction, he may do something fresh. Within limits, this is probably true. What, then, are the points he wants to get hold of?

He hears a lot about gliding angles, skin friction, etc., but the features that interest him most are sizes, shapes and weights. To start with, what size must a man-carrying machine be? Well, for every pound weight (including that of itself and the load) there must be nearly a square foot of supporting surface, so that, when the machine is being designed, the inventor must figure out whether there is enough surface to support the weight. This means that there is a considerable width and length. As may be recognised from the numerous photographs of machines now accessible, the surfaces may be superposed, i.e., subdivided and placed in sheets one over another. The only precaution necessary is that the vertical distance between the planes must be equal to the smaller dimension thereof. Thus, two surfaces 4 ft. wide must be 4 ft., at least, apart. Furthermore, the surfaces must be narrow in the direction of motion, the breadth across the machine being 10 or 12 times the length. Next, how shall we arrange these surfaces? Well, as far as present information is concerned, they may be arranged just as one pleases, provided that two rules are observed. The first is that the centre of gravity (i.e., the place where the whole weight can be supported without turning) should lie between the surfaces so that the lift on those surfaces shall balance about the centre of gravity.

The second is similar to the first, and is that the surfaces must be symmetrically placed about the centre line.

What shape should the surfaces be? In section they should be curved if possible in this way:  The curvature should be quite small (about 1-12th or less of the width). In plan, they should taper away from the centre line.

The surfaces should be fixed in open frames, made of some tough timber with metal joints and good piano-wire stays. Coupling nuts should be used for tightening the latter. The frame should be arranged to rest on an under frame supported by springs on light wheels. The springs should have a total stiffness equal to at least twice the weight.

Steering is performed by surfaces which can be rotated about axes parallel to the length of the machine, perpendicular to the length of the machine and parallel to the breadth of the machine. These surfaces should also be balanced about the centre of gravity. As an alternative, the main surfaces may be warped, the joints of the frames being able to turn in suitable directions, and the planes pulled to the required shape with controlling wires.

Before the inventor thinks of a motor, he should try the machine down a slight slope against the wind and see if it will glide stably. A tail or balancer will probably be necessary at the rear of the machine. If he finds the machine will glide a certain number of feet from a given height, then the gliding angle for his machine is measured by the $\frac{\text{height of glide}}{\text{length of glide}}$. Multiply this fraction into the weight, and the result is the head resistance of the machine. This should be cut down as much as possible by carefully shaping all the exposed parts with easily curved sections so that the wind gets no grip on them.

Now as to the motor. If the propeller is properly designed, the motor should carry about 50 lb. per brake-horse-power, so that a machine weighing 1,000 lb. requires 20 b.h.p. This assumes, however, that the propeller is a good one, and that both it and the motor are running at the best speeds. It will be wisest for an amateur to purchase his propeller, since there is considerable knowledge required in the correct formation, and to ascertain what torque is required to drive it at the specified speed of advance and revolutions. He should then see that the motor is working with high efficiency, and, when direct coupled to the propeller, at the same number of revolutions and with the same torque. If the propeller is driven through gearing, then the torque and revolutions at the driving shaft should be the same as that of the propeller. This matter is most important. No good results can be expected unless the motor, propeller and aeroplane are in harmony. This involves a further equality between the propeller thrust and the aeroplane resistance at the specified speed of advance. The resistance will be rather higher than that mentioned above as the "head resistance" on account of the surface of the motor and accessories, and, perhaps, a rather higher speed, but in any case the thrust should be upwards of one-quarter the total weight.

The propellers should run at a level between the superposed surfaces, so that the head resistance on these is balanced. Well-designed, moderate-speed propellers are preferable to high-speed small ones. Unless one has thoroughly studied the subject, the making of a propeller should not even be attempted.

For those whose knowledge of mechanics is fairly advanced, there is plenty of scope for acquiring a fund of preliminary information. It must, however, be realised that no book-knowledge is comparable with experiment, but the books may help one to avoid unnecessary repetition of work and also to concentrate research on to the lines of known error and doubt.

HUMAN FLIGHT: THE SOLVED PROBLEM.

Man, the great adventurer, has sought to penetrate into every domain, to pry into the habits and methods of all other living creatures, and to imitate and adopt such of their methods as should prove interesting and useful to him. And, at last, after many centuries, he has evolved a machine which shall give him the mastery of the air as his machines have already given him the mastery of the land and the sea. He has always envied the bird and its freedom and sense of easy, perfect motion, and he has wondered and thought and experimented and tried, never daunted by failure a thousand times repeated, until the first decade of the twentieth century sees him rise a victor in the struggle. He has compared the human skeleton with that of the bird and marked the likeness, and he has seen in the bones of a bird's wing a resemblance to those of the human arm, all of which has made him think that he need only discover the secret of flight to be the equal of the bird at least in some measure. But, with all his study, the goal of winged flight is not yet within man's reach. He knows better than he did, thanks to modern high-speed recording photographic apparatus, what the bird does when it flaps its wings, but, to devise a mechanical appliance or to develop the power to lift himself by means of his own arms, seems far beyond his present skill.

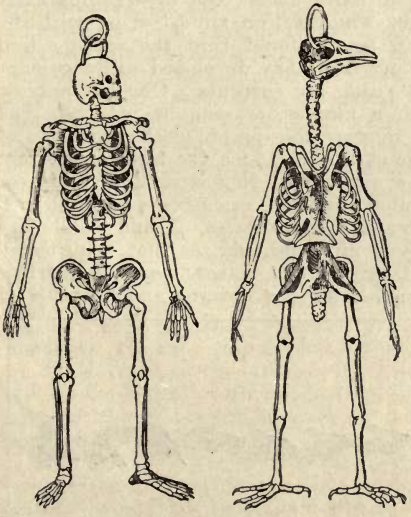

Fig. 1.—The human skeleton and the skeleton of a bird, the latter drawn to an enlarged scale,

The flapping mode of flight may, therefore, be said to have few, if any, advocates, for man has gained his successes — the small preliminary successes and the greater achievements of the past year or two—solely in his efforts to soar. He has watched the albatross, the buzzard, the gull and the kite, and, as a result, his toys, his models, and his man-lifting gliders have all been soaring machines and, when he finally found the forms that more nearly complied with the conditions laid down by nature, enterprise in another direction had prepared for him a source of power light enough for his purpose, and so, with the petrol engine, he used his adaptation of the reciprocating action of the tail and fins of the fish and the wings of the bird — the rotary propeller — and his flying apparatus was complete. And, almost as marvellous as this achievement is the fact that, whereas, five years ago, man had not a single flying machine, to-day he possesses a little handful of types—quite different—each of which is capable of successful free flight.

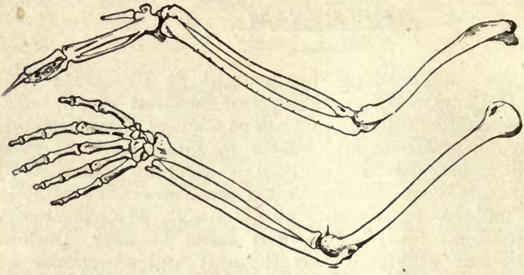

Fig. 2.—A comparison of the arm bones of a man and the wing bones of a bird, the latter drawn to an enlarged scale.

Success first began to come to man when he definitely ceased to attempt to hit off the flying machine by chance and, instead, devoted himself to the study of the principles underlying and governing the art. Then vanished his theories of some mysterious power that permitted a bird, like the albatross, for instance, to sweep for hundreds of miles across the ocean apparently effortless, gliding without wing motion and steering with delightful ease. There can be no doubt that the soaring bird (and also the wing-flapping bird) has developed extraordinary skill in the discovery of rising air currents. One has only to watch the movements of a number of seagulls in windy and gusty weather to secure innumerable proofs of the existence of this sense and also of the skill with which the birds counteract the influence of some new air current that is suddenly entered.

The air does not flow along sedately in currents parallel with the earth's surface, except in rare instances. Could we observe the movements of a body of air we should see that, whilst as a whole it moved forward, in itself it was a maze of whirling eddies, currents of warm air flowing upward and currents of

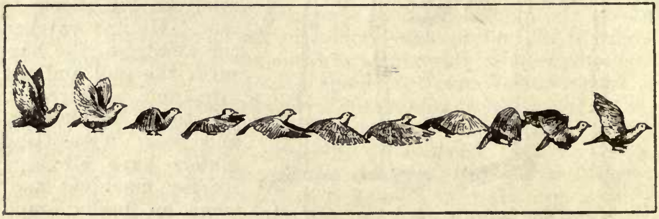

Fig. 3.—The successive positions of the wings of a pigeon in flight, photographed in 1890 by Professor Marey.

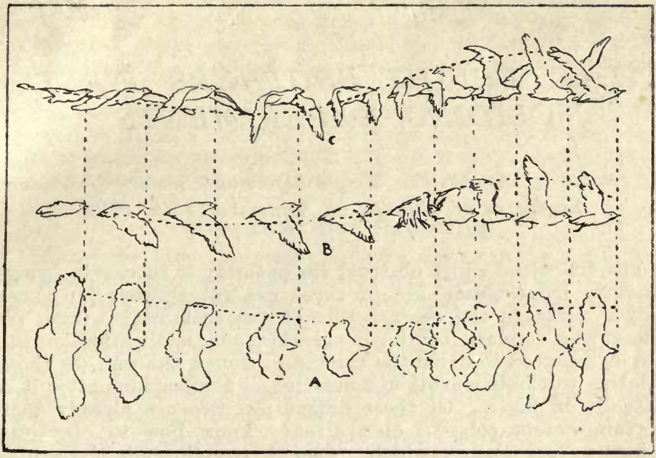

Fig. 4.—The successive positions of the wings of a seagull flying, with the trajectory of a fixed point on its wing, at A on a horizontal plane, at B on a vertical plane parallel to the line of flight, and at C on a vertical plane obliquely to the line of flight.

cooled air flowing downward to fill the space. Obstructions, such as a cliff face, will deflect the current upward, leaving a partial void at the summit, into which air will enter in a whirling mass of eddies. By taking advantage of all rising currents the soaring bird is able to lift itself at such intervals as will allow it to maintain the elevation desired by it. If we regard the bird as being in a constant state of falling by gravity towards the ground, of utilising this tendency to secure forward motion, and of opposing it by taking advantage of each rising current of air to maintain or increase its elevation, we get a much clearer idea of the work which the bird has to do, and we see that its soaring flights are not so effortless as they appear. In fact, there is the same deceptiveness about the walk of a man, for his efforts to maintain a balance are not noticeable, although they are constantly at work. That man will never approach the birds in skill is as obvious as is already the fact that he cannot emulate the feats of fish in their own element. He has equipped himself to move at moderate speeds on the surface of the waters and is content therewith, and he will equip himself with mechanism that in the air will enable him to attain a certain level of proficiency and be equally content.

That the problem of human flight has been solved is now beyond need of argument. The feats and performances of the past 18 months in 1907, 1908 and 1909 amply support the contention that man has at last planted his foot firmly upon the ladder of human flight, and from this time forward advancement in design and methods of construction will be rapid.

THE WRIGHT BROTHERS' FIRST GLIDING EXPERIMENTS.

As related by Mr. Wilbur Wright before the Society of Western Engineers of Chicago, on September 18th, 1901.

The difficulties which obstruct the pathway to success in flying-machine construction are of three general classes: (1) Those which relate to the construction of the sustaining wings; (2) those which relate to the generation and application of the power required to drive the machine through the air; (3) those relating to the balancing and steering of the machine after it is actually in flight. Of these difficulties, two are already to a certain extent solved. Men already know how to construct wings or aeroplanes, which, when driven through the air at sufficient speed, will not only sustain the weight of the wings themselves, but also that of the engine and of the engineer as well. Men also know how to build engines and screws of sufficient lightness and power to drive these planes at sustaining speed. As long ago as 1893 a machine weighing 8,000lb.* demonstrated its power both to lift itself from the ground and to maintain a speed of from 30 to 40 miles per hour; but it came to grief in an accidental free flight, owing to the inability of the operators to balance and steer it properly. This inability to balance and steer still confronts students of the flying problem, although nearly ten years have passed. When this one feature has been worked out, the age of flying machines will have arrived, for all other difficulties are of minor importance.

The person who merely watches the flight of a bird gathers the impression that the bird has nothing to think of but the flapping of its wings. As a matter of fact, this is a very small part of its mental labour. To even mention all the things the bird must constantly keep in mind, in order to fly securely through the air, would take a considerable time. If I take a piece of paper, and after placing it parallel with the ground, quickly let it fall, it will not settle steadily down as a staid, sensible piece of paper ought to do, but it insists on contravening every recognised rule of decorum, turning over and darting hither and thither in the most erratic manner, much after the style of an untrained horse. Yet this is the style of steed that men must learn to manage before flying can become an every-day sport. The bird has learned this art of equilibrium, and learnt it so thoroughly that its skill is not apparent to our sight. We only learn to appreciate it when we try to imitate it.

Now, there are only two ways of learning how to ride a fractious horse: one is to get on him and learn by actual practice how each motion and trick may be best met; the other is

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* *Made by Maxim.*

to sit on a fence and watch the beast a while, and then retire to the house and at leisure figure out the best way of overcoming his jumps and kicks. The latter system is the safer; but the former, on the whole, turns out the larger proportion of good riders. It is very much the same in learning to ride a flying machine; if you are looking for perfect safety, you will do well to sit on a fence and watch the birds; but if you really wish to learn, you must mount a machine and become acquainted with its tricks by actual trial.

Lilienthal and Balancing.

Herr Otto Lilienthal seem to have been the first man who really comprehended that balancing was the *first*, instead of the *last*, of the great problems in connection with human flight. He began where others left off, and thus saved the many thousands of dollars that it had theretofore been customary to spend in building and fitting expensive engines to machines which were uncontrollable when tried. He built a pair of wings suitable to sustain his own weight, and made use of gravity as his motor. This motor not only cost him nothing to begin with, but it required no expensive fuel while in operation, and never had to be sent to the shop for repairs. It had one serious drawback, however, in that it always insisted on fixing the conditions under which it would work. These were, that the man should first betake himself and machine to the top of a hill and fly with a downward as well as a forward motion. Unless the conditions were complied with, gravity served no better than a balky horse—it would not work at all. Although Lilienthal must have thought the conditions were rather hard, he nevertheless accepted them till something better should turn up, and, in this manner, he made some two thousand flights, in a few cases landing at a point more than a thousand feet distant from his place of starting. Other men, no doubt, long before had thought of trying such a plan.

Lilienthal not only thought, but acted; and, in so doing, probably, made the greatest contribution to the solution of the flying problem that has ever been made by any one man. He demonstrated the feasibility of actual practice in the air, without which success is impossible. Herr Lilienthal was followed by Mr. Pilcher, a young English engineer, and by Mr. Chanute, a distinguished member of the Society of Western Engineers of Chicago. A few others have built machines, but nearly all that is of real value is due to the experiments conducted under the direction of the three men just mentioned.

The Difficulty of Balancing.

The balancing of a gliding, or flying, machine is very simple in theory. It merely consists in causing the centre of pressure to coincide with the centre of gravity. But, in actual practice, there seems to be an almost boundless incompatibility of temper, which prevents their remaining peaceably together for a single instant, so that the operator, who in this case acts as peacemaker, often suffers injury to himself while attempting to bring them together. If a wind strikes a vertical plane, the pressure on that part to one side of the centre will exactly balance that on the other side, and the part above the centre will balance that below. This point we call the centre of pressure. But if the plane be slightly inclined, the pressure on the part nearest the wind is increased, and the pressure on the other part decreased, so that the centre of pressure is now located, not in the centre of the surface, but a little towards the side which is in advance. If the plane be still further inclined, the centre of pressure will move still farther forward. And, if the wind blow a little to one side, it will also move over as if to meet it. Now, since neither the wind nor the machine, for even an instant, maintains exactly the same direction and velocity, it is evident that the man who would trace the course of the centre of pressure must be very quick of mind; and he who would attempt to move his body to that spot at every change must be very active indeed.

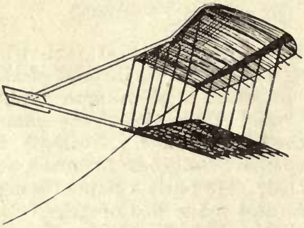


Fig. 5.—Wright Brothers' first glider of 1900.

Yet, that is what Herr Lilienthal attempted to do, and did with most remarkable skill, as his two thousand glides sufficiently attest. However, he did not escape being overturned by wind gusts several times, and, finally, lost his life through a breakage of his machine, due to defective construction. The Pilcher machine was similar to that of Lilienthal, and, like it, seems to have been structurally weak, for, on one occasion, while exhibiting the flight of his machine to several members of the Aeronautical Society of Great Britain, it suddenly collapsed and fell to the ground, causing injuries to the operator which proved sadly fatal. The method of management of this machine differed in no important respect from that of Lilienthal, the operator shifting his body to make the centres of pressure and gravity coincide. Although the fatalities which befell the designers of these machines were due to the lack of structural strength, rather than to lack of control, nevertheless, it had become clear to the students of the problem that a more perfect method of control must be evolved.

The Chanute machines marked a great advance in both respects. In the multiple-wing machine, the tips folded slightly backward under the pressure of wind gusts, so that the travel of the centre of pressure was thus largely counterbalanced. The guiding of the machine was done by a slight movement of the operator's body toward the direction in which it was desired that the machine should go. The double-deck machine, built and tried at the same time, marked a very great structural advance, as it was the first in which the principles of the modern truss bridges were fully applied to flying-machine construction. This machine, in addition to its greatly-improved construction and general design of parts, also differed from the machine of

Lilienthal in the operation of its tail. In the Lilienthal machine, the tail, instead of being fixed in one position, was prevented by a stop from folding downward beyond a certain point, but was free to fold upward without any hindrance. In the Chanute machine, the tail was at first rigid, but afterward, at the suggestion of Mr. Herring, it was held in place by a spring that allowed it to move slightly either upward or downward with reference to its normal position, thus modifying the action of the wind gusts upon it, very much to its advantage. The guiding of the machine was effected by slight movements of the operator's body, as in the multiple-wing machines. Both these machines were much more manageable than the Lilienthal type, and their structural strength, notwithstanding their extreme lightness, was such that no fatalities, or even accidents, marked the glides made with them, although winds were successfully encountered much greater in violence than any which previous experimenters had dared to attempt.

The Wrights' First Interest in Flight.

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 passed from the reading to the thinking, and, finally, 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 this brief practice, was remarkably successful in meeting the fluctuations and eddies of wind gusts. We thought that if some method could be found by which it would be possible to practise by the hour instead of by the second, there would be a hope of advancing the solution of a very difficult problem. It seemed feasible to do this by building a machine which would be sustained at a speed of 18 miles per hour, and then finding a locality where winds of this velocity were common. With these conditions, a rope attached to keep it from floating backward would answer very nearly the same purpose as a propeller driven by a motor, and it would be possible to practise by the hour, and without any serious danger, as it would not be necessary to rise far from the ground, and the machine would not have any forward motion at all. We found, according to the accepted tables of air pressures on curved surfaces, that a machine spreading 200 square feet of wing surface would be sufficient for our purpose, and that places could easily be found along the Atlantic coast where winds of 16 to 25 miles were not at all uncommon. When the winds were low, it was our plan to glide from the tops of sand hills, and when they were sufficiently strong, to use a rope for our motor and fly over one spot.

Our next work was to draw up the plans for a suitable machine. After much study, we finally concluded that tails were a source of trouble rather than of assistance; and, therefore, we decided to dispense with them altogether. It seemed reasonable that, if the body of the operator could be placed in a horizontal position instead of the upright, as in the machines of Lilienthal, Pilcher, and Chanute, the wind resistance could be very materially reduced, since only one square foot instead of five would be exposed. As a full half-horse-power could be saved by this change, we arranged to try at least the horizontal position. Then, the method of control used by Lilienthal, which consisted in shifting the body, did not seem quite as quick or effective as the case required; so, after long study, we contrived a system consisting of two large surfaces on the Chanute double-deck plan, and a smaller surface placed a short distance in front of the main surfaces in such a position that the action of the wind upon it would counterbalance the effect of the travel of the centre of pressure on the main surfaces. Thus, changes in the direction and velocity of the wind would have little disturbing effect, and the operator would be required to attend only to the steering of the machine, which was to be effected by curving the forward surface up or down. The lateral equilibrium and the steering to right or left were to be attained by a peculiar torsion of the main surfaces, which was equivalent to presenting one end of the wings at a greater angle than the other. In the main frame, a few changes were also made in the details of construction and trussing employed by Mr. Chanute. The most important of these were: (1) the moving of the forward main cross-piece of the frame to the extreme front edge; (2) the encasing in the cloth of all cross-pieces and ribs of the surfaces; (3) a rearrangement of the wires used in trussing the two surfaces together, which rendered it possible to tighten all the wires by simply shortening two of them.

With these plans we proceeded, in the summer of 1900, to Kitty Hawk, North Carolina, a little settlement located on the strip of land that separates Albemarle Sound from the Atlantic Ocean. Owing to the impossibility of obtaining suitable material for a 200-square-foot machine, we were compelled to make it only 165 sq. ft. in area, which, according to the Lilienthal tables, would be supported at an angle of three degrees in a wind of about 21 miles per hour. On the very day that the machine was completed, the wind blew from 25 to 30 miles per hour, and we took it out for trial as a kite. We found that, while it was supported with a man on it in a wind of about 25 miles, its angle was much nearer 20 degrees than 3 degrees. Even in gusts of 30 miles the angle of incidence did not get as low as 3 degrees, although the wind at this speed has more than twice the lifting power of a 21-mile wind. As winds of 30 miles per hour are not plentiful on clear days, it was at once evident that our plan of practising by the hour, day after day, would have to be postponed. Our system of twisting the surfaces to regulate the lateral balance was tried and found to be much more effective than shifting the operator's body. On subsequent days, when the wind was too light to support the machine with a man on it, we tested it as a kite, working the rudders by cords reaching to the ground. The results were very satisfactory, yet we were well aware that this method of testing is never wholly convincing until the results are confirmed by actual gliding experience.

Lift and Drift Experiments.

We then turned our attention to making a series of actual measurements of the lift and drift of the machine under various loads. So far as we were aware, this had never previously been done with any full-size machine. The results obtained were most astonishing, for it appeared that the total horizontal pull of the machine, while sustaining a weight of 52lb., was only 8.5lb., which was less than had previously been estimated for head resistance of the framing alone. Making allowance for the weight carried, it appeared that the head resistance of the framing was little more than 50 per cent. of the amount which Mr. Chanute had estimated as the head resistance of the framing of his machine. On the other hand, it appeared sadly deficient in lifting power as compared with the calculated lift of curved surfaces of its size. This deficiency we supposed might be due to one or more of the following causes: (1) That the depth of the curvature of our surfaces was insufficient, being only about 1 in 22, instead of 1 in 12; (2) that the cloth used in our wings was not sufficiently airtight; (3) that the Lilienthal tables might themselves be somewhat in error. We decided to arrange our machine for the following year so that the depth of curvature of its surfaces could be varied at will, and its covering air-proofed.

Our attention was next turned to gliding, but no hill suitable for the purpose could be found near our camp at Kitty Hawk. This compelled us to take the machine to a point four miles south, where the Kill Devil sandhill rises from the flat sand to a height of more than 100ft. Its main slope is toward the north-east and has an inclination of 10 degrees. On the day of our arrival the wind blew about 25 miles an hour, and, as we had had no experience at all in gliding, we deemed it unsafe to attempt to leave the ground. But, on the day following, the wind having subsided to 14 miles per hour, we made about a dozen glides. It had been the original intention that the operator should run with the machine to obtain initial velocity, and assume the horizontal position only after the machine was in free flight. When it came time to land he was to resume the upright position and alight on his feet, after the style of previous gliding experimenters. But, on actual trial, we found it much better to employ the help of two assistants in starting, which the peculiar form of our machine enabled us readily to do; and, in landing, we found that it was entirely practicable to land while still reclining in a horizontal position upon the machine. Although the landings were made while moving at speeds of more than 20 miles an hour, neither machine nor operator suffered any injury.

The slope of the hill was 9.5 degrees, or a drop of 1ft. in 6ft. We found that, after attaining a speed of about 25 or 30 miles with reference to the wind, or 10 to 15 miles over the ground, the machine not only glided parallel to the slope of the hill, but greatly increased its speed, thus indicating its ability to glide on a somewhat less angle than 9.5 degrees, when we should feel it safe to rise higher from the surface. The control of the machine proved even better than we had dared to expect, responding quickly to the slightest motion of the rudder.

The Conclusions of 1900.

With these glides our experiments for the year 1900 closed. Although the hours and hours of practice we had hoped to obtain finally dwindled down to about two minutes, we were very much pleased with the general results of the trip, for, setting out as we did, with almost revolutionary theories on many points and an entirely untried form of machine, we considered it quite a point to be able to return without having our pet theories completely knocked on the head by the hard logic of experience, and our own brains dashed out in the bargain. Everything seemed to us to confirm the correctness of our original opinions: (1) that practice is the key to the secret of flying; (2) that it is practicable to assume the horizontal position; (3) that a smaller surface set at a negative angle in front of the main bearing surfaces or wings will largely counteract the effect of the fore and aft travel of the centre of pressure; (4) that steering up and down can be attained with a rudder, without moving the position of the operator's body; (5) that twisting the wings so as to present their ends to the wind at different angles is a more prompt and efficient way of maintaining lateral equilibrium than shifting the body of the operator.

1901—A Memorable Year.

When the time came to design our new machine for 1901 we decided to make it exactly like the previous machine in theory and method of operation. But, as the former machine was not able to support the weight of the operator when flown as a kite, except in very high winds and at very large angles of incidence, we decided to increase its lifting power. Accordingly, the curvature of the surfaces was increased to 1 in 12 to conform to the shape on which Lilienthal's table was based, and, to be on the safe side, we decided also to increase the area of the machine from 165 sq. ft. to 308 sq. ft., although so large a machine had never before been deemed controllable. The Lilienthal machine had an area of 151 sq. ft.; that of Pilcher 165 sq. ft.; and the Chanute double-decker 134 sq. ft. As our system of control consisted in a manipulation of the surfaces themselves, instead of shifting the operator's body, we hoped that the new machine would be controllable, notwithstanding its great size. According to our calculations, it would obtain support in a wind of 17 miles per hour with an angle of incidence of only 3 degrees.

Our experience of the previous year having shown the necessity of a suitable building for housing the machine, we erected a cheap frame building 16ft. wide, 25ft. long, and 7ft. high at the eaves. As our machine was 22ft. wide, 14ft. long (including the rudder) and about 6ft. high, it was not necessary to take the machine apart in any way in order to house it. Both ends of the building, except the gable parts, were made into doors, which hinged above, so that when opened they formed an awning at each end, and left an entrance the full width of the building. We went into camp about the middle of July, and were soon joined by Mr. E. C. Huffaker, of Tennessee, an experienced aeronautical investigator in the employ of Mr. Chanute, by whom his services were kindly loaned, and by Dr. G. A. Spratt, of Pennsylvania, a young man who has made some valuable investigations of the properties of variously-curved surfaces and the travel of the centre of pressure thereon. Early in August Mr. Chanute came down from Chicago to witness our experiments, and spent a week in camp with us.

The machine was completed and tried for the first time on July 27th in a wind blowing about 13 miles an hour. The operator having taken a position where the centre of pressure was supposed to be, an attempt at gliding was made; but the machine turned downward and landed after going only a few yards. This indicated that the centre of gravity was too far in front of the centre of pressure. In the second attempt the operator took a position several inches further back, but the result was much the same. He kept moving further and further back with each trial, till finally he occupied a position nearly a foot back of that at which we had expected to find the centre of pressure. The machine then sailed off, and made an undulating flight of a little more than 300ft. To the onlookers this flight seemed very successful, but, to the operator, it was known that the full power of the rudder had been required to keep the machine from either running into the ground or rising so high as to lose all headway. In the 1900 machine one-fourth as much rudder action had been sufficient to give much better control. It was apparent that something was radically wrong, though we were for some time unable to locate the trouble. In one glide the machine rose higher and higher till it lost all headway. This was the position from which Lilienthal had always found difficulty in extricating himself, as his machine then, in spite of his greatest exertions, manifested a tendency to dive downward almost vertically and strike the ground head on with frightful velocity. In this case a warning cry from the ground caused the operator to turn the rudder to its full extent and also to move his body slightly forward. The machine then settled slowly to the ground, maintaining its horizontal position almost perfectly, and landed without any injury at all.

This was very encouraging, as it showed that one of the very greatest dangers in machines with horizontal tails had been overcome by the use of a front rudder. Several glides later, the same experience was repeated with the same result. In the

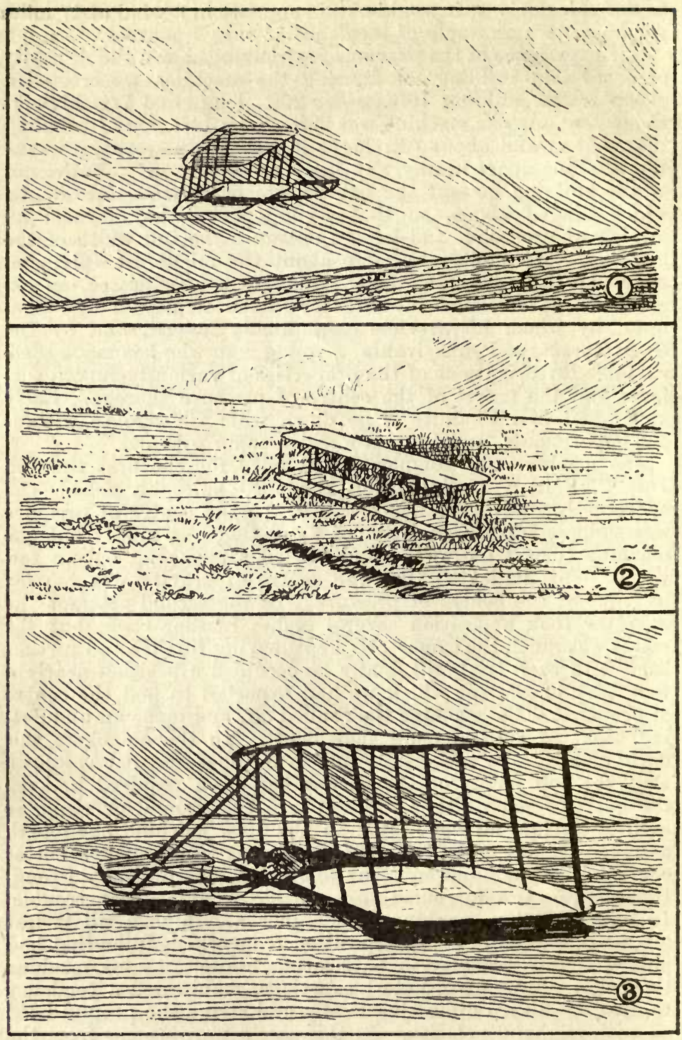


Fig. 6.—Wright Brothers' experiments of 1900.
1, a high glide; 2, a low glide; 3, landing.

latter case, the machine had even commenced to move backward, but was, nevertheless, brought safely to the ground in a horizontal position. On the whole, this day's experiments were encouraging, for, while the action of the rudder did not seem at all like that of our 1900 machine, yet we had escaped without difficulty from positions which had proved very dangerous to preceding experimenters, and, after less than one minute's actual practice, had made a glide of more than 300 feet, at an angle of descent of 10 degrees, and with a machine nearly twice as large as had previously been considered safe.

The trouble with its control, which has been mentioned, we believed could be corrected when we should have located its cause. Several possible explanations occurred to us, but we finally concluded that the trouble was due to a reversal of the direction of the travel of the centre of pressure at small angles. 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 surface 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 curvature as great as one in eight, on account of this action on the upper side; but he seems never to have investigated the curvature 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 curvature of 1 in 12 would be safe, as this was the curvature 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 curve 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 would find this reversal of the centre of pressure, but we believed it sufficiently guarded against. Accordingly, we were not at first disposed to believe that this reversal actually existed in our machine, although it offered a perfect explanation of the action we had noticed in gliding. Our peculiar plan of control by forward surfaces, instead of tails, was based on the assumption that the

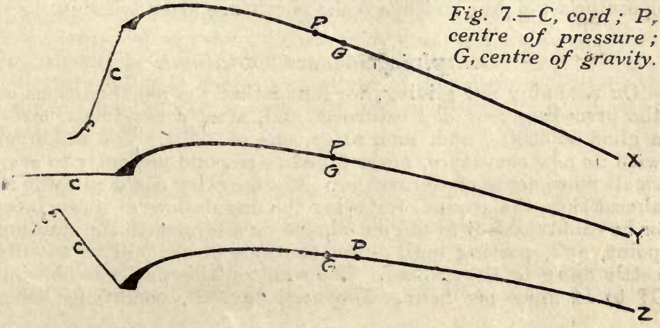


Fig. 7.—C, cord; P, centre of pressure; G, centre of gravity.

centre of pressure would continue to move farther and farther forward, as the angle of incidence became less, and it will be readily perceived that it would make quite a difference if the front surface, instead of counteracting this assumed forward travel, should in reality be expediting an actual backward movement. For several days we were in a state of indecision, but were finally convinced, by observing the following phenomena (Fig. 7). We had removed the upper surface from the machine and were flying it in a wind, to see at what angles it would be supported in winds of different strengths. We noticed that, in light winds, it flew in the upper position (X) shown in the figure, with a strong upward pull on the cord (C). As the wind became stronger, the angle of incidence became less, and the surface flew in the position shown in the middle of the figure, with a slight horizontal pull. But when the wind became still stronger, it took the lower position shown in the figure, with a strong downward pull. It at once occurred to me that here was the answer to our problem, for it is evident that, in the first case, the centre of pressure was in front of the centre of gravity and then pushed up the front edge; in the second case, they were in coincidence, and the surface in equilibrium, while, in the third case, the centre of pressure had reached a point even behind the centre of gravity, and there was therefore a downward pull on the cord. This point having been definitely settled, we proceeded to truss down the ribs of the whole machine, so as to reduce the depth of curvature. In Fig. 8, line 1 shows the original curvature; line 2 the curvature when supporting the operator's weight; and line 3 the curvature after trussing.

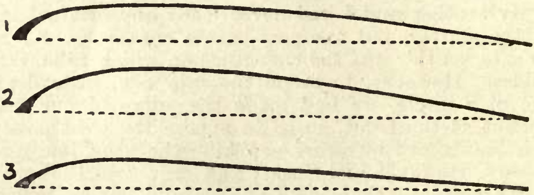


Fig. 8.—The changes effected in the curvature of the plane as the result of experience.

Complete Success Obtained.

On resuming our gliding, we found that the old conditions of the preceding year had returned, and, after a few trials, made a glide of 366ft., and, soon after, one of 389ft. The machine, with its new curvature, never failed to respond promptly to even small movements of the rudder. The operator could cause it to almost skim the ground, following the undulations of its surface, or he could cause it to sail out almost on a level with the starting point, and, passing high above the foot of the hill, gradually settle down to the ground. The wind on this day was blowing 11 to 14 miles per hour. The next day, the conditions being favourable, the machine was again taken out for trial. This time the velocity of the wind was 18 to 22 miles per hour. At first we felt some doubt as to the safety of attempting free flight in so strong a wind, with a machine of over 300 sq. ft., and a practice of less than five minutes spent in actual flight. But, after several preliminary experiments, we decided to try a glide. The control of the machine seemed so good that we then felt no apprehension in sailing boldly forth. And, thereafter, we made glide after glide, sometimes following the ground closely, and sometimes sailing high in the air. Mr. Chanute had his camera with him, and took pictures of some of these glides.

We made glides on subsequent days, whenever the conditions were favourable. The highest wind thus experimented in was a little over 12 metres per second—nearly 27 miles per hour.

It had been our intention, when building the machine, to do the larger part of the experimenting in the following manner: When the wind blew 17 miles an hour, or more, we would attach a rope to the machine and let it rise as a kite with the operator upon it. When it should reach a proper height, the operator would cast off the rope and glide down to the ground just as from the top of a hill. In this way, we would be saved the trouble of carrying the machine up hill after each glide, and could make at least 10 glides in the time required for one in the other way. But when we came to try it we found that a wind of 17 miles, as measured by Richard's anemometer, instead of sustaining the machine with its operator, a total weight of 240lb., at an angle of incidence of three degrees, in reality would not sustain the machine alone—100lb.—at this angle. Its lifting capacity seemed scarcely one-third of the calculated amount. In order to make sure that this was not due to the porosity of the cloth, we constructed two small experimental surfaces of equal size, one of which was air-proofed and the other left in its natural state; but we could detect no difference in their lifting powers. For a time, we were led to suspect that the lift of curved surfaces little exceeded that of planes of the same size, but further investigation and experiment led to the opinion that (1) the anemometer used by us over-recorded the true velocity of the wind by nearly 15 per cent.; (2) that the well-known Smeaton coefficient of .005 V^2 for the wind pressure at 90 degrees is probably too great by at least 20 per cent.; (3) that Lilienthal's estimate that the pressure on a curved surface having an angle of incidence of 3 degrees equals .545 of the pressure of 90 degrees is too large, being nearly 50 per cent. greater than very recent experiments of our own with a special pressure-testing machine indicator; (4) that the superposition of the surfaces somewhat reduced the lift per square foot, as compared with a single surface of equal area.

The Importance of the Ratio of Lift to Drift.

In gliding experiments, however, the amount of lift is of less relative importance than the ratio of lift to drift, as this alone decides the angle of gliding descent. In a plane, the pressure is always perpendicular to the surface, and the ratio of lift to drift is therefore the same as that of the cosine to the sine of the angle of incidence. But, in curved surfaces, a very remarkable situation is found. The pressure, instead of being uniformly normal to the chord of the arc, is usually inclined considerably in front of the perpendicular. The result is that the lift is greater and the drift less than if the pressure were normal. Lilienthal was the first to discover this exceedingly important fact, which is fully set forth in his book, "Bird Flight the Basis of the Flying Art," but, owing to some errors in the methods he used in making measurements, question was raised by other investigators not only as to the accuracy of his figures, but even as to the existence of any tangential force at all. Our experiments confirm the existence of this force, though our measurements differ considerably from those of Lilienthal. 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 23lb. 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 108lb. Now, if the pressure had been normal to the chord of the surface, the drift proper would have been to the lift (108lb.), as the sine of 13 degrees is to the cosine of 13 degrees or $\frac{.22 \times 108}{.97} = 24\frac{1}{2}$ lb.; but this slightly exceeds the total pull of 23lb. 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 toward 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 force 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 18lb. With the pressure normal to the chord, the drift proper would have been $\frac{.17 \times 98}{.98} = 17$lb., so that although the higher wind velocity must have caused an increase in the head resistance, the tangential force still came within 1lb. of overcoming it.

Pressures on Curved Surfaces.

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

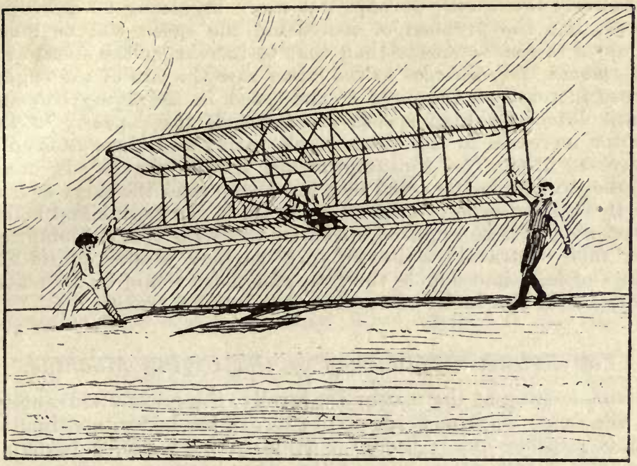


Fig. 9.—The machine of 1900, showing forward elevation plane.

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 40lb., which is equivalent to about 2⅓h.p. It must not be supposed, however, that a motor developing this power would be sufficient to drive a man-bearing machine. The extra weight of the motor would require either a larger machine, higher speed, or a greater angle of incidence, in order to support it, and, therefore, more power. It is probable, however, that an engine of 6h.p., weighing 100lb., would answer the purpose. Such an engine is entirely practicable. Indeed, working motors of one-half this weight per horse-power (9lb. per horse-power) have been constructed by several different builders. Increasing the speed of our machine from 24 to about 33 miles per hour reduced the total horizontal pressure from 40 to about 35lb. This was quite an advantage in gliding as it made it possible to sail about 15 per cent. further with a given drop. However, it would be of little or no advantage in reducing the size of the motor in a power-driven machine, because the lessened thrust would be counterbalanced by the increased speed per minute. Some years ago, Prof. Langley called attention to the great economy of thrust which might be obtained by using very high speeds, and from this many were led to suppose that high speed was essential to success in a motor-driven machine. But the economy to which Prof. Langley called attention was in foot-pounds per mile of travel, not in foot-pounds per minute. It is the foot-pounds per minute that fixes the size of the motor. The probability is that the first flying machines will have a relatively low speed, perhaps not much exceeding 20 miles per hour, but the problem of increasing the speed will be much simpler in some respects than that of increasing the speed of a steamboat, for, whereas in the latter case the size of the engine must increase as the cube of the speed in the flying machine until extremely high speeds are reached, the capacity of the motor increases in less than simple ratio; and there is even a decrease in the fuel consumption per mile of travel. In other words, to double the speed of a steamship (and the same is true of the balloon type of airship) eight times the engine and boiler capacity would be required, and four times the fuel consumption per mile of travel; while a flying machine would require engines of less than double the size, and there would be an actual decrease in the fuel consumption per mile of travel.

The Relative Efficiency of the Flying Machine.

But, looking at the matter conversely, the great disadvantage of the flying machine is apparent; for, in the latter, no flight at all is possible unless the proportion of horse-power to flying capacity is very high; but, on the other hand, a steamship is a mechanical success if its ratio of horse-power to tonnage is insignificant. A flying machine that would fly at a speed of 50 miles an hour with engines of 1,000h.p., would not be upheld by its wings at all at a speed of less than 25 miles an hour, and nothing less than 500h.p. could drive it at this speed. But a boat which could make 40 miles per hour with engines of 1,000h.p. would still move four miles per hour even if the

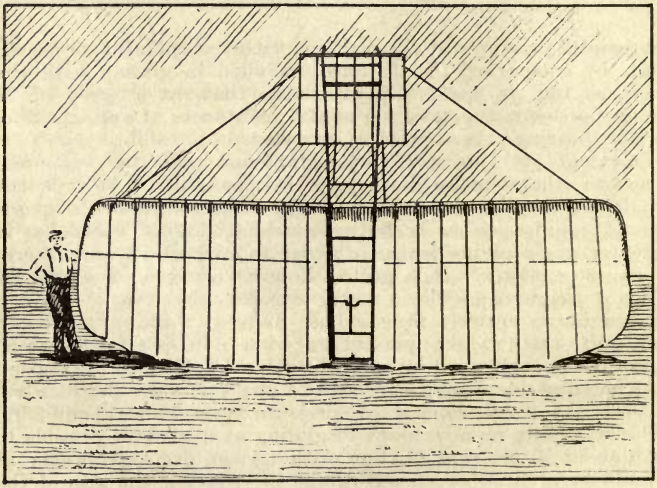


Fig. 10.—The 1900 machine: Under-view.

engines were reduced to 1h.p. The problems of land and water travel were solved in the 19th century, because it was possible to begin with small achievements and gradually work up to our present success. The flying problem was left over to the 20th century, because, in this case, the art must be highly developed before any flight of any considerable duration at all can be obtained.

However, there is another way of flying which requires no artificial motor, and many workers believe that success will first come by this road. I refer to the soaring flight, by which the machine is permanently sustained in the air by the same means that are employed by soaring birds. They spread their wings to the wind, and sail by the hour, with no perceptible exertion beyond that required to balance and steer themselves. What sustains them is not definitely known, though it is almost certain that it is a rising current of air. But, whether it be a rising current or something else, it is as well able to support a flying machine as a bird, if man once learns the art of utilising it. In gliding experiments it has long been known that the rate of vertical descent is very much retarded and the duration of the flight greatly prolonged if a strong wind blows *up* the face of the hill parallel to its surface. Our machine, when gliding in still air, has a rate of vertical descent of nearly 6ft. per second, while in a wind blowing 26 miles per hour up a steep hill we made glides in which the rate of descent was less than 2ft. per second; and, during the larger part of this time,

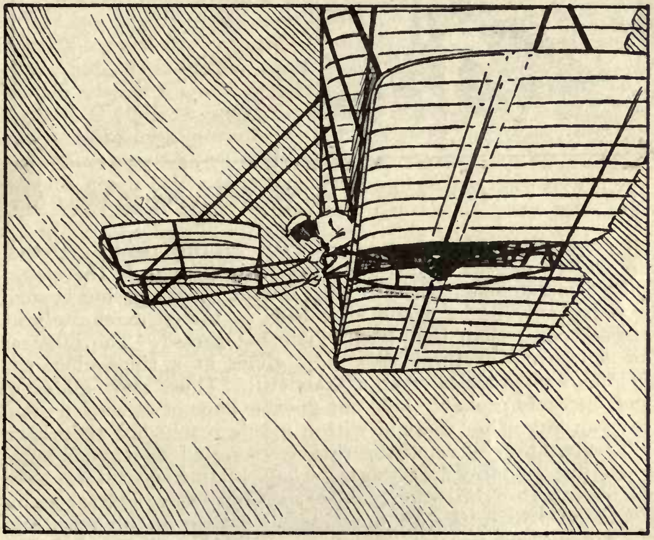


Fig. 11.—A soaring flight, the machine being practically at a standstill.

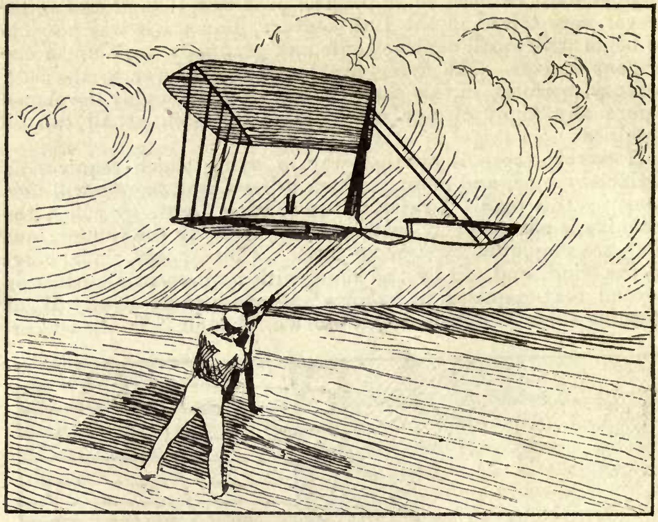


Fig. 12.—The 1900 machine soaring in a wind of 35m.p.h.

while the machine remained exactly in the rising current, *there was no descent at all, but even a slight rise.* If the operator had had sufficient skill to keep himself from passing beyond the rising current he would have been sustained indefinitely at a higher point than that from which he started. The illustration shows one of these very slow glides at a time when the machine was practically at a standstill. These slow glides in rising currents probably hold out greater hope of extensive practice than any other method within man's reach, but they have the disadvantage of requiring rather strong winds or very large supporting surfaces. However, when gliding operators have attained greater skill, they can, with comparative safety, maintain themselves in the air for hours at a time in this way, and thus by constant practice so increase their knowledge and skill that they can rise into the higher air and search out the currents which enable the soaring birds to transport themselves to any desired point by first rising in a circle and then sailing off at a descending angle. The illustration (Fig. 12) shows the machine, alone, flying in a wind of 35 miles per hour on the face of a steep hill 100ft. high. It will be seen that the machine not only pulls upward, but also pulls forward in the direction from which the wind blows, thus overcoming both gravity and the speed of the wind. We tried the same experiment with a man on it, but found danger that the forward pull would become so strong that the men holding the ropes would be dragged from their insecure foothold on the slope of the hill. So this form of experimenting was discontinued after four or five minutes' trial.

The Conclusions of 1901.

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 laboratory 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 degrees 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 toward 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 surface 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 drift than either surface separately, even after making allowance for weight and head resistance of the connections.

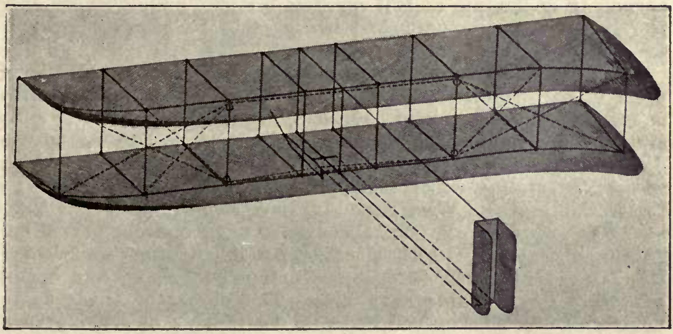


Fig. 13.—The manner in which the wings of a Wright aeroplane are warped. The left ends of the wings are raised and the right ends depressed for a turn to the left. Drawn from one of the latest machines.

THE LATER EXPERIMENTS OF THE WRIGHT BROTHERS IN SOARING FLIGHT.

Related by Wilbur Wright before the Society of Western Engineers of Chicago, June 1st, 1903.

In the address which I delivered before the Society of Western Engineers in September, 1901, some account was given of the gliding experiments made by my brother Orville Wright and myself in the years 1900 and 1901. Afterwards, laboratory experiments were undertaken for the purpose of determining for ourselves the amount and direction of the pressures produced by the wind upon plane and arched surfaces exposed at various angles of incidence. The results having indicated the possibility of a gliding machine capable of much better performance than any previously built by us, we set about designing a new one for the 1902 season, and, in August, repaired to our old camp at the Kill Devil hills.

The 1902 pattern was a double-deck machine having two surfaces, each 32ft. from tip to tip and 5ft. from front to rear. The total area of the main surfaces was about 305 sq. ft. The front rudder spread 15 sq. ft. additional, and the vertical tail about 12 sq. ft., which was subsequently reduced to 6 sq. ft. The weight was 116½lb. Including the operator, the total weight was from 250lb. to 260lb. It was built to withstand hard usage, and, in nearly a thousand glides, was injured but once. It repeatedly withstood without damage the immense strains arising from landing at full speed in a slight hollow where only the tip of the wings touched the earth, the entire weight of machine and operator being suspended between.

The practice ground at the Kill Devil hills consists of a level plain of bare sand, from which rises a group of detached hills or mounds formed of sand heaped up by the winds. These hills are constantly changing in height and slope, according to the direction and force of the prevailing winds. The three which we use for gliding experiments are known as the Big Hill, the Little Hill and the West Hill, and have heights of 100ft., 30ft. and 60ft. respectively. In accordance with our custom of beginning operations with the greatest possible caution, we selected the Little Hill as the field of our first experiments, and began by flying the machine as a kite. The object of this was to determine whether or not it would be capable of soaring in a wind having an upward trend of a trifle over 7 degrees, which was the slope of the hill up which the current was flowing.

When I speak of soaring I mean not only that the weight of the machine is fully sustained, but also that the direction of the pressure upon the wings is such that the propelling and the retarding forces are exactly in balance; in other words, the resultant of all the pressures is exactly vertical, and, therefore, without any unbalanced horizontal component. A kite is soaring when the string stands exactly vertical, this showing that there is no backward pull. The phenomenon is exhibited only when the kite is flown in a rising current of air. In principle, soaring is exactly equivalent to gliding, the practical difference being that in one case the wind moves with an upward trend against a motionless surface, while in the other the surface moves with a downward trend against motionless air. The reactions are identical. The soaring of birds consists in gliding downwards through a rising current of air, which has a rate of ascent equal to the bird's relative rate of descent.

Testing a gliding machine as a kite on a suitable slope, with just enough wind to sustain the machine at its most favourable angle of incidence, is one of the most satisfactory methods of determining its efficiency. In soaring, the kite must fly steadily with the string vertical or a little to the front. Merely darting up to this position for an instant is not soaring. On trial, we found that the machine would soar on the side of a hill having a slope of about 7 degrees, whenever the wind was of proper force to keep the angle of incidence between 4 and 8 degrees. If the wind became too strong or too weak the ropes would incline to leeward. The accompanying illustration (Fig. 14) was taken when the wind was too weak for real soaring. The surfaces are inclined 4 degrees above the horizon, which is marked by the ocean level in the distance. Since the wind had an upward trend of 7 degrees, the total angle of incidence was 11 degrees, which is outside the limits specified. On steeper slopes the ropes inclined to windward quite strongly. In experimenting on this plan it is essential that a uniform slope be found which will give the air current a rising trend just sufficient to cause the kite string to stand vertical.

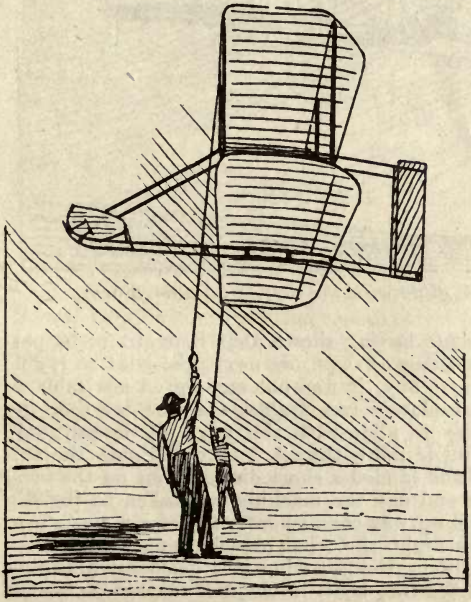


Fig. 14.—The 1902 machine flown as a kite in a light wind.

Then, both gravity and the pull on the string, which together provide the force counteracting the wind pressure on the surfaces, are applied in a single direction. It is, therefore, not material what proportion of the total counteracting force is due to each of the several components, nor even what is their total amount, because the experiment is exclusively for the purpose of determining the direction of the pressure on the surfaces by observing the direction of the reaction. When the kite string inclines to windward the slope is too steep; if to leeward, not steep enough. But it is not advisable to attempt to determine how much the slope varies from the proper amount by observing the angle of the string from the vertical, for, when the pull of the string differs in direction from that of gravity, it becomes necessary to know not only the angle, but also the exact amount of the pull and the proportion which it bears to the weight of the kite. It is, therefore, advisable to find a better slope rather than attempt to make so many observations.

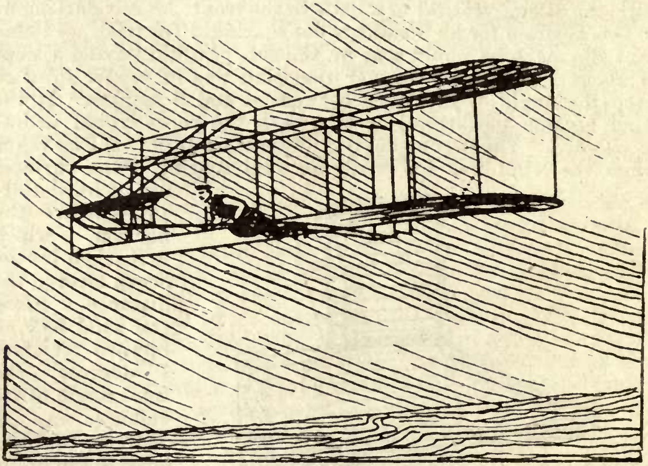


Fig. 15.—A glide with the double tail machine.

The kite experiments having shown that it ought to be possible to glide on the 7-degree slope, we next proceeded to try it. Although, on this first day, it was not considered advisable to venture upon any absolutely free flights, the machine soon demonstrated its ability to glide with this angle of descent. At a later period we made more than a hundred flights the full length of this slope and landed a short distance out on the level ground. On the second day the machine was taken to the Big Hill and regular gliding was commenced. The wind was somewhat brisk. In one flight the wind struck the machine from the left and began lifting the left wing in a decidedly alarming manner. Owing to the fact that, in the new machine, changes had been made in the mechanisms operating the rudders, so that the movements were exactly reversed, it was necessary to think a moment before proceeding to make the proper adjustment. But meanwhile the left wing was rising higher and higher. I therefore decided to bring the machine to the ground as quickly as possible, but, in my confusion, forgot the change that had been made in the front rudder, and instinctively turned it the wrong way. Almost instantly it reared up as though bent on a mad attempt to pierce the heavens. But, after a moment, it seemed to perceive the folly of such an undertaking and gradually slowed up till it came almost to a stop with the front of the machine still pointing heavenward. By this time I had recovered myself and reversed the rudder to its full extent, at the same time climbing upward toward the front so as to bring my weight to bear on the part that was too high. Under this heroic treatment the machine turned downward and soon began to gather headway again. By the time the ground was reached, it was under fair control, but, as one wing touched first, it swung around in landing and came to rest with the wind blowing in from the rear. There was no unusual shock in landing and no damage at all resulted.

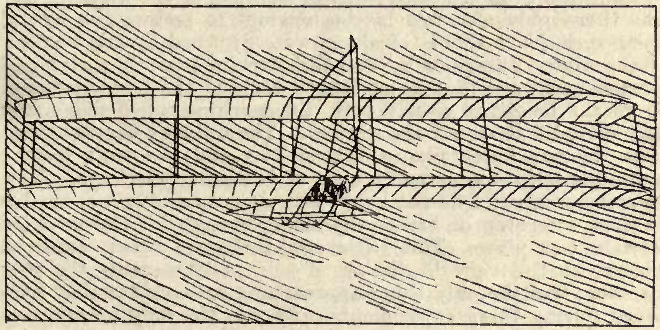


Fig. 16.—Rear view of machine with single tail.

In several other glides there were the disturbances of the lateral equilibrium more marked than we had been accustomed to experience with the former machines, and we were at a loss to know what the cause might be. The new machine had a much greater tip-to-tip dimension than our former machines; it also had a vertical tail, while the earlier ones were tailless, and the wing tips were on a line with the centre, while the old machines had the tips drawn down like a gull's wings. The trouble might be due to either of these differences. We decided to begin alterations at the wing tips, and the next day made the necessary changes in the trussing, thus bringing the tips 6in. lower than the centre. For several days thereafter the weather was not suitable for gliding on account of rain, but, finally, the sky cleared and the machine was taken out again. As the anemometer indicated a wind velocity of more than 11 metres a second, it was thought best to make use of the Little Hill in testing the effect of the changes that had been made. But later in the day, when the velocity fell to about nine metres a second, the Big Hill was tried again.

On this day my brother Orville did most of the gliding. After a few preliminary flights, to accustom himself to the new method of operating the front rudder, he felt himself ready to undertake the management of the lateral control also. Shortly afterwards he started on a flight with one wing slightly higher than the other. This caused the machine to veer to the left. He waited a moment to see whether it would right itself, but finding that it did not, then decided to apply the control. At the very instant he did this, however, the right wing most unexpectedly rose much higher than before and led him to think that possibly he had made a mistake. A moment of thought was required to assure himself that he had made the right motion, and another to increase the movement. Meanwhile he had neglected the front rudder, by which the fore-and-aft balance was maintained. The machine turned up in front more and more till it assumed a most dangerous attitude. We who were on the ground noticed this in advance of the aviator, who was thoroughly absorbed in the attempt to restore the lateral balance, but our shouts of alarm were drowned by the howling of the wind. It was only when the machine came to a stop and started backward that he at length realised the true situation. From the height of nearly 30ft. the machine sailed diagonally backward till it struck the ground. The unlucky aeronaut had time for one hasty glance behind him and the next instant found himself the centre of a mass of fluttering wreckage. How he escaped injury I do not know, but, afterwards, he was unable to show a scratch or bruise anywhere, though his clothes were torn in one place. This little misadventure, which occurred almost at the very beginning of our practice with the new machine, was the only thing approaching an accident that happened during these experiments, and was the only occasion on which the machine suffered any injury. The latter was made as good as new by a few days' labour, and was not again broken in any of the many hundred glides which we subsequently made with it.

By long practice the management of a flying machine should become as instinctive as the balancing movements a man unconsciously employs with every step in walking, but, in the early days, it is easy to make blunders. For the purpose of reducing the danger to the lowest possible point we usually kept close to the ground. Often, a glide of several hundred feet would be made at a height of a few feet or even a few inches sometimes. It was the aim to avoid unnecessary risk. While the high flights were more spectacular, the low ones were fully as valuable for training purposes. Skill comes by the constant repetition of familiar feats rather than by a few over-bold attempts at feats for which the performer is yet poorly prepared.

It had been noticed during the day that, when a side gust struck the machine, its effect was at first partly counteracted by the vertical tail, but, after a time, when the machine had acquired a lateral motion, the tail made matters worse instead of better. Although the change that had been made in the wing tips made some improvement, the lateral control still remained somewhat unsatisfactory. The tail was useful at times and at others was seriously in the way. It was finally concluded that the best way of overcoming the difficulty was by making the tail movable like a rudder. As originally built, the fixed vertical tail or vane was double, but, in changing to a movable rudder, it was made single, as the smaller area was believed to be sufficient. As reconstructed, it spread a little less than six square feet.

With this improvement our serious troubles ended, and, thereafter, we devoted ourselves to the work of gaining skill by continued practice. When properly applied, the means of control proved to possess a mastery over the forces tending to disturb the equilibrium. Since balancing was effected by adjustments of the surfaces, instead of by movements of weight, the controlling forces increased in power in the same ratio as the disturbing forces, when the machine was suddenly struck by a wind gust. For this reason, we did not seem to experience the same difficulty in managing the machine in high winds that Lilienthal, who used a different system, seems to have met.

Fully half of our glides were made in winds of 10 metres a second, over 20 miles an hour. One day we stopped gliding for a moment to take an anemometer reading and found that it indicated 16.7 metres a second, 37 miles an hour. Of course, such high winds require much greater readiness on the part of the operator than the low winds, since everything happens much more quickly, but, otherwise, the difference is not so very marked. In those machines which are controlled by the shifting of weight, the disturbing influences increase as the square of the velocity, while the controlling factor remains a constant quantity. For this reason, a limit to the wind velocity which it is possible to safely encounter with such machines is soon reached, regardless of the skill of the operator.

With the method we have been using, the capacity of control is evidently very great. The machine seems to have reached a higher state of development than the operators. As yet, we consider ourselves little more than novices in management. A thousand glides is equivalent to about four hours of steady practice, far too little to give anyone a complete mastery of the art of flying. Progress is very slow in the preliminary stages, but, when once it becomes possible to undertake continuous soaring, advancement should be rapid. Under special conditions, it is possible that this point is not so far away as might be supposed.

Since soaring is merely gliding in a rising current, it would be easy to soar in front of any hill of suitable slope, whenever the wind blew with sufficient force to furnish support, provided the wind were steady. But, by reason of changes in wind velocity, there is more support at times than is needed, while, at others, there is too little, so that a considerable degree of skill, experience, and sound judgment are required in order to keep the machine exactly in the rising current. So far, our only attempts at soaring have been made on the Little Hill, which has a slope of only 7 degrees. In a wind blowing from 11 to 16 metres a second, we frequently made glides of 8 to 15 seconds' duration with very little forward motion. As we kept within 5ft. or 6ft. of the ground, a momentary lessening of the wind speed, or a slight error in management, was sufficient to bring about a landing in a short time.

The wind had too little rising trend to make soaring easy. The buzzards themselves were baulked when they attempted to soar on this hill, as we observed more than once. It would be well within the power of the machine to soar on the Big Hill, which has steeper slopes, but we have not felt that our few hours of practice is sufficient to justify ambitious attempts too hastily. Before trying to rise to any dangerous height a man ought to know that, in an emergency, his mind and muscles will work by instinct rather than by conscious effort. There is no time to think.

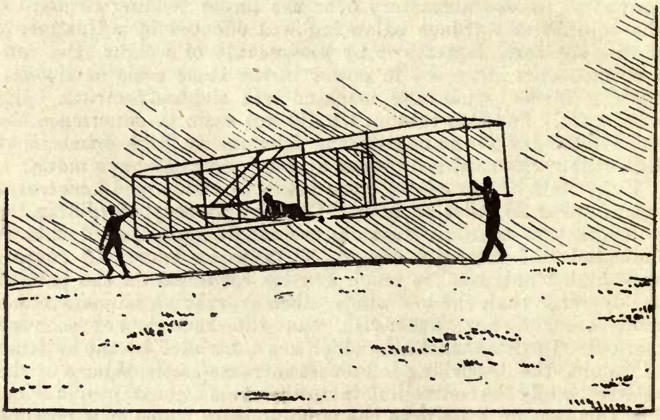


Fig. 17.—Starting a flight.

During a period of five weeks, glides were made whenever the wind 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 six miles an 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 speed of at least 18 miles an 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 six miles we did not usually attempt to practise; but when the wind rose to 20 miles an hour, gliding was real sport, for starting was easy and the labour of carrying the machine back up hill 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 exhaustion than resulted from 20 or 30 glides on days when the wind was light.

No complete record was kept 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 1,000. The longest glide was 622½ft., and the time 26sec.

The prime object in these experiments was to obtain practice in the management of a man-carrying machine, but an object of scarcely less importance was to obtain data for the study of the scientific problems involved in flight. Observations were almost constantly being made for the purpose of determining the amount and direction of the pressures upon the sustaining wings; the minimum speed required for support; the speed and angle of incidence at which the horizontal resistance became least; and the minimum angle of descent at which it was possible to glide.

To determine any of these points with exactness was found to be very difficult indeed, but by careful observations under test conditions it was possible to obtain reasonably close approximations. It was found that a speed of about 16 miles an hour would produce a pressure sufficient to support machine and operator, but the angle of incidence was too great for general gliding purposes. At 18 miles, the angle of incidence was about 8 degrees, and the machine would glide on the Little Hill, descending at an angle of a little over 7 degrees. Although the wings were inclined slightly above the horizon, the machine continued to glide without loss of velocity. With a speed of 22 miles an hour, the angle of incidence required for support was 4 or 5 degrees, and the angle of descent a little less than 7 degrees. At this speed, the surfaces were inclined several degrees below the horizon. As the speed became greater, the angle of incidence continued to grow less, but the angle of descent became greater again, thus showing that the point of minimum resistance had been passed. Scores of glides were made at angles of descent under 6 degrees, and, in a few cases, we reached 5 degrees. 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

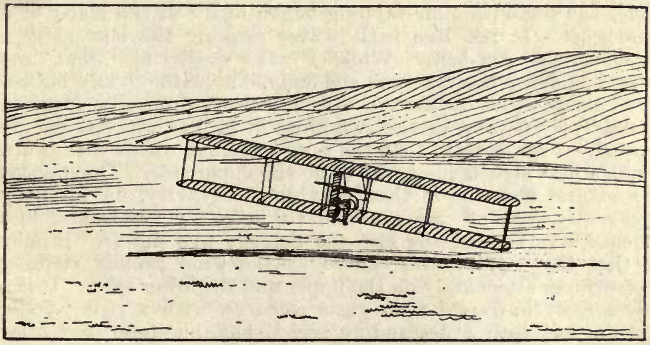


Fig. 18.—Making a turn to the right.

mark, and four trials were made. Twice the machine landed on the same spot. The distance was 156½ft., and the angle of descent exactly 5 degrees. Time, 6½sec. From a point higher up the slope, the best angle was 5 degrees and 25min. for a glide of 225ft. Time, 10¼sec. The wind was blowing about nine miles an 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 30lb., as computed by multiplying the total weight, 250lb., by the tangent of the angle of descent. This resistance remained nearly constant at speeds between 18 and 25 miles an hour. Above or below these limits, there was a somewhat rapid increase. At 18 miles, the power consumed was 1½h.p.; at 25 miles, 2h.p. At the lower speed, 166lb. were sustained for each horse-power consumed; at the higher speed, 125lb. per horse-power. Between 18 and 25 miles, the horsepower increased almost in exact ratio in 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 10ft., 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. Toward 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.

Irregularities of the wind are most noticeable when the wind is high, on account of the greater power then exhibited, but light winds show almost equal relative variations. An aviator must expect to encounter in every flight variations in velocity, in direction, and in upward or downward trend. And these variations not only give rise to those disturbances of the equilibrium which result from the travel of the centre of pressure due to the changed angle of incidence, but also, by reason of the fact that the wind changes do not occur simultaneously or uniformly over the entire machine, give rise to a second series of disturbances of even more troublesome character. Thus, a gust coming on very suddenly will strike the front of the machine and throw it up before the back part is acted upon at all. Or the right wing may encounter a wind of very different velocity and trend from the left wing and the machine will tend to turn over sideways. The problem of overcoming these disturbances by automatic means has engaged the attention of many very ingenious minds, but, to my brother and myself, it has seemed preferable to depend entirely on intelligent control. In all of our machines the maintenance of the equilibrium has been dependent on the skill and constant vigilance of the aviators.

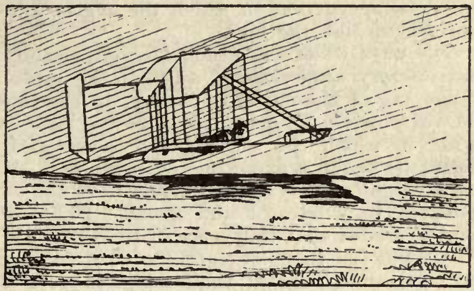


Fig. 19.—*Skimming the ground.*

In addition to the work with the machine we also made many observations on the flight of soaring birds, which were very abundant in the vicinity of our camp. Bald eagles, ospreys, hawks, and buzzards gave us daily exhibitions of their powers. The buzzards were the most numerous and were the most persistent soarers. They apparently never flapped except when it was absolutely necessary, while the eagles and hawks usually soared only when they were at leisure. Two methods of soaring were employed. When the weather was cold and damp and the wind strong, the buzzards would be seen soaring back and forth along the hills, or at the edge of a clump of trees. They were evidently taking advantage of the current of air flowing upward over these obstructions. On such days they were often utterly unable to soar, except in these special places. But on warm, clear days, when the wind was light, they would be seen high in the air soaring in great circles. Usually, however, it seemed to be necessary to reach a height of several hundred feet by flapping before this style of soaring became possible. Frequently a great number of them would begin circling in one spot, rising together higher and higher till finally they would disperse, each gliding off in whatever direction it wished to go. At such times other buzzards only a short distance away found it necessary to flap frequently in order to maintain themselves. But when they reached a point beneath the circling flock, they began to rise on motionless wings. This seemed to indicate that rising columns of air do not exist everywhere, but that the birds must find them. They evidently watch each other, and when one finds a rising current the others quickly make their way to it. One day, when scarce a breath of wind was stirring on the ground, we noticed two bald eagles sailing in circling sweeps at a height of probably 500ft.

After a time our attention was attracted to the flashing of some object considerably lower down. Examination with a field glass proved it to be a feather which one of the birds had evidently cast. As it seemed apparent that it would come to earth only a short distance away, some of our party started to get it. But in a little while it was noticed that the feather was no longer falling, but, on the contrary, was rising rapidly. It finally went out of sight upward. It apparently was drawn into the same rising current in which the eagles were soaring, and was carried up like the birds.

The days when the wind blew horizontally gave us the most satisfactory observations, as then the birds were compelled to make use of the currents flowing up the sides of the hills, and it was possible for us to measure the velocity and trend of the wind in which the soaring was performed. One day four buzzards began soaring on the north-east slope of the Big Hill at a height of only 10ft. or 12ft. from the surface. We took a position to windward and about 1,200ft. distant. The clinometer showed that they were 4½ to 5½ degrees above our horizon. We could see them distinctly with a field glass. When facing us, the under side of their wings made a broad band on the sky, but when, in circling, they faced from us, we could no longer see the under side of their wings. Though the wings then made a little more than a line on the sky, the glass showed clearly that it was not the under side that we saw. It was evident that the buzzards were soaring with their wings constantly inclined about five degrees above the horizon. They were attempting to gain sufficient altitude to enable them to glide to the ocean beach three-fourths of a mile distant, but, after reaching a height of about 75ft. above the top of the hill, they seemed to be unable to rise higher, though they tried a long time. At last they started to glide toward the ocean, but were compelled to begin flapping almost immediately. We at once measured the slope and the wind. The former was 12½ degrees; the latter was six to eight metres per second. Since

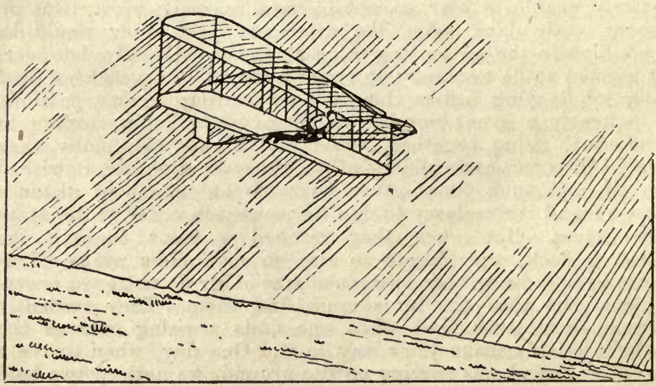


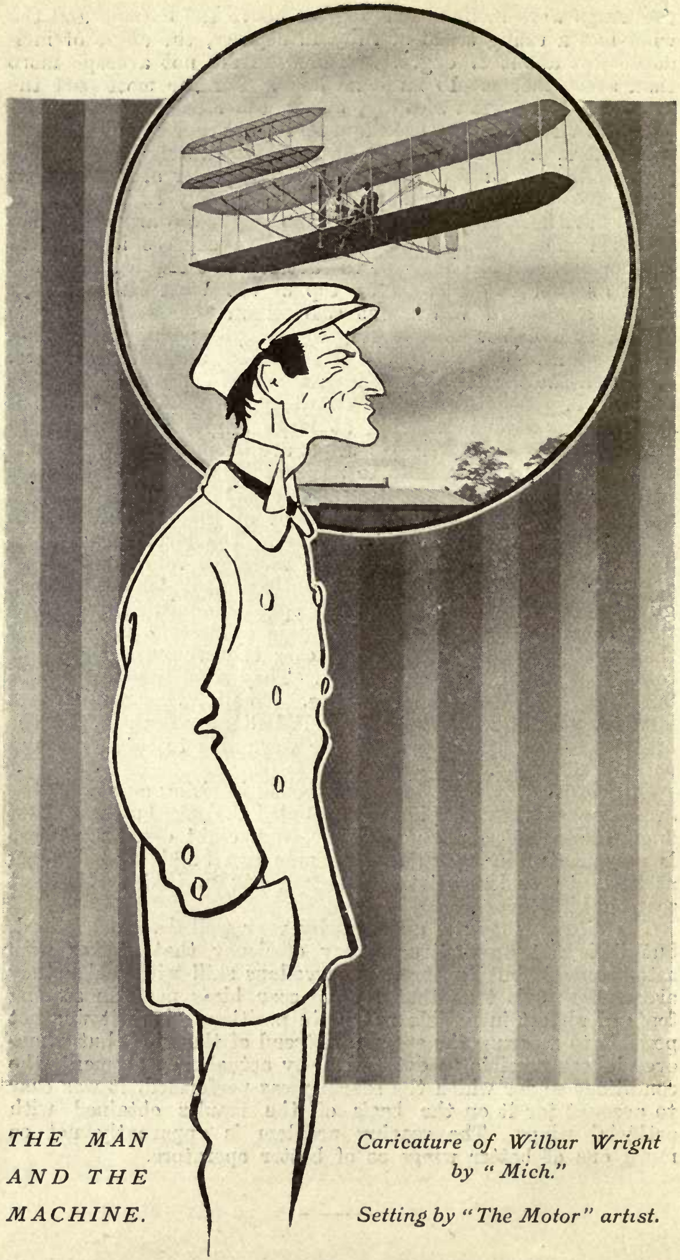
Fig. 20.—One of the most satisfactory flights.

the wings were inclined five degrees above the horizon and the wind had a rising trend of fully 12 degrees, the angle of incidence was about 17 degrees. The wind did not average more than seven metres—15 miles an hour. For the most part the birds faced the wind steadily, but in the hills they were compelled to circle or glide back and forth, in order to obtain speed sufficient to provide support. As the buzzard weighs about .8lb. per square foot of wing area, the lifting power of the wind at 17 degrees angle of incidence was apparently as great as it would have been had it been blowing straight upward with equal velocity. The pressure was inclined five degrees in front of the normal, and the angle of the descent was 12½ degrees.

On another day I stood on top of the West Hill, directly behind a buzzard which was soaring on the steep southern slope. It was just on a level with my eye and not more than 75ft. distant. For some time it remained almost motionless. Although the wings were inclined about five degrees above the horizon, it was not driven backward by the wind. This bird is specially adapted to soaring at large angles of incidence in strongly-rising currents. Its wings are deeply curved. Unless the upward trend amounts to at least eight degrees, it seems to be unable to maintain itself. One day we watched a flock attempting to soar on the west slope of the Big Hill, which has a descent of nearly nine degrees. The birds would start near the top and glide down along the slope very much as we did with the machine, but we noticed that whenever they glided parallel with the slope their speed diminished, and when their speed was maintained the angle of descent was greater than that of the hill. In every case they found it necessary to flap before they had gone 200ft. They tried time and again, but always with the same results. Finally, they resorted to hard flapping until a height of about 150ft. above the top of the hill was reached, after which they were able to soar in circles without difficulty.

On another day they finally succeeded in rising on almost the same slope, from which it was concluded that the buzzards' best angle of descent could not be far from eight degrees. There is no question in my mind that men can build wings having as little as, or less relative resistance than, that of the best soaring birds.

The bird's wings are undoubtedly very well designed indeed, but it is not any extraordinary efficiency that strikes with astonishment, but rather the marvellous skill with which they are used. It is true that I have seen birds perform soaring feats of almost incredible nature in positions where it was not possible to measure the speed and trend of the wind, but whenever it was possible to determine, by actual measurement, the conditions under which the soaring was performed, it was easy to account for it on the basis of the results obtained with artificial wings. The soaring problem is apparently not so much one of better wings as of better operators.



THE MAN AND THE MACHINE.

Caricature of Wilbur Wright by "Mich."

Setting by "The Motor" artist.

THE PRINCIPLES UNDERLYING HUMAN FLIGHT.

There are three stages in which the study of the principles of aviation must be taken, whether the investigation be experimental or theoretical. It is necessary first to discover means whereby the weight which is to be carried can be supported in the air. Secondly, the machine must be so designed that, when in the air, it will not capsize if its direction is altered slightly or if the velocity of the wind changes. Lastly, when an efficient glider has been evolved, the question of a suitable propelling agency has to be considered, or in the words of Lilienthal, " stability first, propulsion afterward."

Everyone is aware of the force with which the wind can blow and of the pressure that it can exert on buildings and walls exposed to the fury of its blast. To utilise this force for lifting any weight into the air, some sort of exposed surface must be employed in such a manner that the wind, in blowing against it, exerts an upward supporting force.

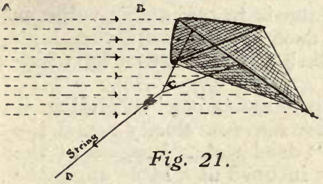


Fig. 21.

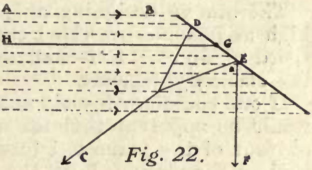


Fig. 22.

An ordinary kite is an example of the way in which this principle is put into practical use. Let the kite be represented as in Fig. 21, with the wind blowing as shown by the arrows in the direction A B, and with the string by which the kite is flown being pulled in the direction C D. If the weight be far enough back and the string properly fixed, the kite will be inclined at an angle to the wind, which, blowing upon the surface, will then exert a lifting force upon the kite. A diagram of the forces acting on the kite is given in Fig. 22. There are the downward pull on the string in the direction D C, the upward pressure of the wind, which may be considered as acting at the " centre of pressure " of the kite surface, and the weight of the kite. The force due to the latter acts downward at the centre of gravity. When the kite is being flown in the air, these three forces are balanced, the tail supplying the steadying effect.

Thus far, it is the question of a wind blowing against a stationary surface that has been considered, but a similar lifting effect can be obtained if the air be still and the surface be moved through it. The only necessary condition is that the air must meet the surface at such an angle that a downward velocity be given to it after the plane has passed over it. The actual velocity of flight that is required will depend on the amount of weight that has to be carried, and on the supporting surface that is used. The greater the weight or the less the surface, the greater must be the speed of the machine, and vice versâ.

Just as in flying a kite in the air a considerable pull must be exerted on the string by which it is flown, so in an aeroplane or glider which is in flight there must be a force exerted to push it through the air. This force has to overcome the resistance caused by pushing the framework, etc., of the machine through the air, and is similar in effect to that which has to be exerted to drive a car at high speeds. It is usually termed the "drift," as distinguished from the upward or lifting force called the "lift." Both lift and drift will vary considerably with different types of machines, with the loads carried, and with the speeds of flight. If, however, the area of supporting surface and the weight that has to be carried both be limited, it is evident that, by trying all manner of shapes of plane with varying cross-sections and thicknesses, different values for the drift will be obtained, supposing that in each case the area were sufficient to support the weight. The most efficient shape would be that requiring the least force to push it through the air, that is it would have the least drift. For this plane the ratio of lift/drift would be the highest.

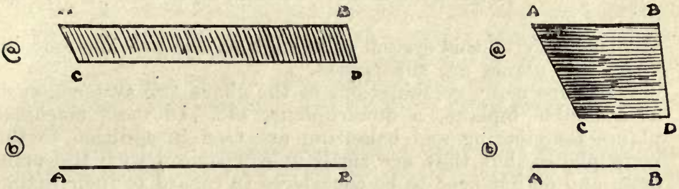
The aim in designing an aeroplane is to make this value as high as possible, provided that it does not involve a very high speed of flight. It is well to investigate the factors on which the efficiency depends.

If one could see the air as the plane meets it when gliding, it would be apparent that the air does not flow closely round the contour of the plane but forms a "dead water" region at the back of the plane. With the plane inclined at a large angle the effect is much more pronounced, usually resulting in turbulence, i.e., a churning up of the air all round the surface of the plane. This turbulent effect requires energy to set it in motion, so that if one obtains a certain lift with a plane the drift will be much less if the turbulence can be eliminated. This is effected by making the cross-section of the planes such that it is of "stream line" form, so that the air flows evenly around with a minimum disturbance.

The pioneer work in the experimental investigation of the best form to be used for plane cross-section was carried out by Horatio Phillips, whose dipping front edge forms are treated in a separate chapter in the book.

Phillips also advocates the use of wood for plane surfaces, because it forms a hard polished surface, offering much less resistance than a surface formed of canvas stretched over a frame. For Phillips's machine (described on page 46) wood was, no doubt, the best substance, but, for the modern aeroplane, its weight would, probably, be excessive.

In addition to the cross-section of the planes there is still the plan form to be considered, and this, too, has a considerable effect on the efficiency. The ratio of the spread of the planes to the fore and aft depth is usually termed the "aspect ratio" of the plane. It has been found experimentally, with a plane in which the span or spread is large compared with the fore and aft depth, or in other words with one where the aspect ratio is large, that the efficiency is much greater than where the span is smaller and the depth greater. The reason for this will be easily understood from a consideration of Figs. 23 and 24, where there are shown planes of small and large span.



Figs. 23 and 24, showing aspect ratios.

The air meets the "cutting edge" A B of the large span plane (Fig. 23) and is deflected downwards at the angle at which the plane is placed, causing a difference of air pressure between the upper and lower surface of the plane. This pressure difference between the air above and below the plane tends to set up a flow of air from below to above, with a greater loss of energy in the case of the small-span plane with its wide ends than in the case of the narrow plane. In addition, practically the whole of the narrow plane surfaces is effective in acting on the air, whereas with the wide plane the rear edge is to a certain extent shielded by the front and exerts very little effect on the air, to which a downward velocity has already been imparted.

Many of the modern aeroplanes have one, two, three, and sometimes more surfaces arranged in various ways according to the inventor's design.

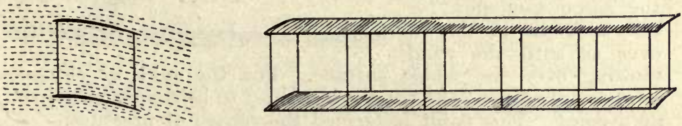
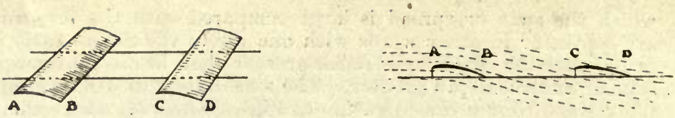


Fig. 25.—Superposed biplane.

The single surface or monoplane acts upon air which is undisturbed both above and below the plane. Where two planes are superposed as in Fig. 25, even if they be spaced a good distance apart, the lifting effect is not twice that of the single one, for they both act to a certain extent on the same cushion of air. With a triplane or multiplane this relative diminution of lifting effort is even more pronounced.

Instead of fitting the planes one above the other they may be placed in tandem, as shown in Fig. 26. Fig. 27 shows the end view and how the air would flow round such an arrangement. The back plane would be in the wash of the front plane, and, if placed at all close to the first one, would have to be inclined at a much greater angle to have any effect at all. It is doubtful if



Figs. 26 and 27.—Tandem biplane.

the efficiency of this system is as high as the previous one, in which the planes are superposed.

There are many combinations of the above two systems, such as a double biplane, a quadruplane, etc. In most machines planes for steering and balancing are used in addition to the main planes, but they are small in comparison with the main ones, and do not need to be considered in regard to their lifting effect.

The stability of the machine when in the air depends on the movement of the "centre of pressure" of the supporting surface, and it will be well to consider this factor, which has already been mentioned above.

If, as in Fig. 28, there is a wall A B exposed to the force of the wind which is blowing in the direction D A, a certain pressure is exerted on the wall tending to blow it over. Instead of supposing the air to be rushing against the whole surface of the wall, it can be imagined to concentrate in one strong jet. By choosing the point on the surface where this jet should then act, there could be obtained just the same tendency for the wall to be blown over as with the wind blowing over the whole surface. For the sake of clearness the pressure due to the wind is imagined to be concentrated thus at a point. This point is termed the centre of pressure.

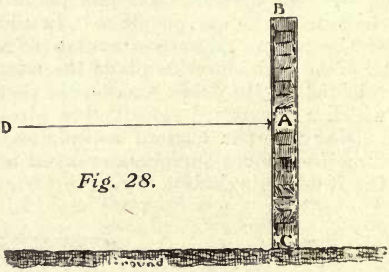


Fig. 28.

Turning to the study of an aeroplane in the air, there are two forces acting upon it: the upward lift due to the air and the force due to the weight acting downward. The upward lift will act at the "centre of pressure" and the other force at the centre of gravity. Fig. 29 represents this diagrammatically. A B is the end view of the aeroplane, E C is the direction of the upward force acting at the centre of pressure C, and D F is the weight acting downward at the centre of gravity D.

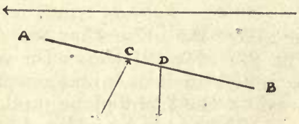


Fig. 29.

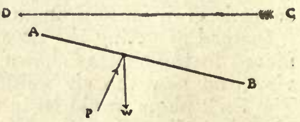


Fig. 30.

Neglecting the question of propulsion for the moment, these are the only two forces that need be considered, and if they are balanced there will be no tendency for the machine to capsize. As shown in Fig. 29, the centre of pressure is ahead of the centre of gravity, and if this state of affairs were allowed to continue the front of the machine would tip right over. Some means must therefore be employed whereby if the machine is balanced when the aeroplane is inclined at a certain angle, the aeroplane will come back to the correct angle if the latter is altered. There are two ways of effecting this, one being by hand control as in the Wright machine and the other being more or less automatic.

In the Wright machine the tips of the planes are flexible and their angle of incidence to the air can be altered by a controlling device operated by the aeronaut. This, in conjunction with the rudders, is continually in operation by the aviator, so that the centre of pressure of the planes is made always to coincide with the centre of gravity.

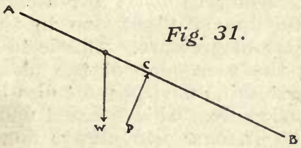


Fig. 31.

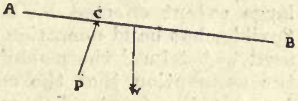


Fig. 32.

Automatic stability depends for its action upon the movement of the position of the centre of pressure when the angle of incidence varies. It is found that, as the angle of incidence decreases, the position of the centre of pressure moves forward towards the front edge of the plane, and vice versâ. This does not hold good for one or two shapes of planes if the angle is less than 10 degrees, as will be explained later. When the angle of incidence increases, the reverse takes place, the centre of pressure moving backward away from the front edge.

Let it be supposed that there is a plane A B (see Fig. 30) moving through the air in the direction C D shown by the arrow. Let it also be supposed that the whole arrangement is balanced for the speed at which it is travelling, i.e., the positions of the centres of pressure and gravity coincide. At any moment it is possible that the speed of the wind may suddenly increase, and at that instant the machine, which will still be travelling at the same speed relatively to the earth, will meet the air at a greater velocity. The lifting effect is increased and the nose of the machine will rise in the air. The angle at which the surface meets the air is now greater and the centre of pressure will move back to some point (C) as shown in Fig. 31.

From this diagram it will be seen that the force due to the weight is trying to pull the nose down and the upward pressure is trying to push the tail up. The result is that the angle of incidence will be altered, until it takes the original value as indicated in Fig. 30, where the positions of the centres of pressure and gravity coincide.

The opposite effect is shown in Fig. 32. If a wind were

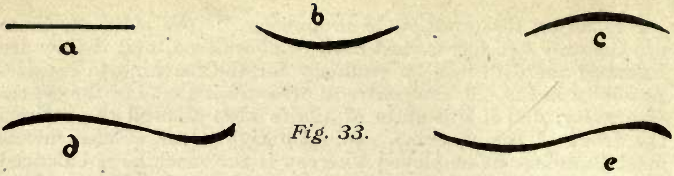


Fig. 33.

blowing when the machine was travelling in a balanced state and then suddenly dropped, the speed of the machine relatively to the air would not be sufficient for support. The front edge would drop, the machine tending to dive to get up the necessary speed. The angle of incidence is diminished and the centre of pressure moves forward. There is then the upward pressure acting at some point (C) tending to push the nose up, while the weight is tending to pull the tail down. The net result is that the machine, having got up speed, resumes the position of equilibrium shown in Fig. 30.

It is evident that, in a wind which is constantly changing and gusty, some auxiliary device is necessary to damp any oscillations that may take place in the line of flight due to the changes in the position of the centre of pressure. This is to a large extent effected by making the rear edge of the plane flexible, but hand operation of the steering devices must also be used to "trim" the machine occasionally. This is based upon the assumption that the centre of pressure will always move towards the front edge as the angle of incidence decreases. This, however, is not the case with every type of plane. It has been found experimentally that, of the planes with cross sections as shown in Fig. 33, this change in position of the centre of pressure only occurs with those of section similar to (a), (b) and (d). If the planes are of the cross section (c) or (e), the centre of pressure moves forward until a certain critical angle of incidence is reached, and after this it moves backward. If one wish to make the plane stable without any auxiliary device, its cross section must be shaped similar to (a) (b) or (d).

The lateral balance of the machine in the direction of line of flight can be made to a certain extent automatic by inclining the two sides of the plane at a dihedral angle as in Fig. 34 (a),

Fig. 34.

or by turning up the tips of the wings as at (b) or (c). The addition of a keel also improves the stability.

The proper shaping of the cross section of the planes so as to make them of "stream line" form greatly increases the efficiency, and every part should be torpedo-shaped, which allows the air to flow round the body with a minimum disturbance. It is also necessary to have the surface of all exposed parts as taut as possible. Wherever there is a looseness, the covering will bag and little pockets will be formed, all tending to increase the resistance of the machine.

BRIEF HISTORY OF THE AEROPLANE MOVEMENT.

I.—Early History.

To Leonardo da Vinci, the versatile Italian genius, famed equally for his work in painting, sculpture, music, architecture, mathematics and physical science, belongs the honour of having first set on paper some rational notions of human flight. Several remarkable principles are to be found in da Vinci's manuscript. He shows very clearly that he understood the relation between the centre of pressure and the centre of gravity, for he states that a bird which finds itself in equilibrium with the centre of resistance of the wings more forward than the centre of gravity will descend with the head inclined downwards.

This he wrote after a note on " The kite and other birds which beat their wings little, go seeking the course of the wind, and when the wind prevails on high, then will they be seen at a great height, and if it prevails low they will hold themselves low. When the wind does not prevail at all, then the kite beats its wings several times in its flight in such a way that it raises itself high and acquires a start, descending afterwards a little and progressing without beating its wings, repeating the same performance time after time."

An even clearer exposition of the principles of flight is shown by his note that the bird that wishes to rise " will raise its shoulders so that the air may press between its sides and the tip of the wings, so that the air will be condensed and will give the bird the movement towards the ascent and will produce a momentum in the air which will push the bird upward."

Further, this remarkable genius of the 15th century states that when, without the help of the wind, the bird remains in the air without flapping its wings, this shows that the centre of its resistance coincides with its mass centre. In referring to his classical illustration of a man in a flapping-wing machine, he foresaw that the chief difficulty in gliding or soaring is to keep the centre of gravity at all times in the right place. In one of his notes he wrote that the man in the flying machine should " be free from the waist upwards in order that he might keep himself in equilibrium as one does in a boat, so that the centre of his gravity and that of the apparatus may set itself in equilibrium and change, when needful, as the centre of resistance changes."

Leonardo da Vinci, born in 1452, died in 1519, and there can be no doubt that this extraordinary man was the first to recognise, as he was certainly the first to enunciate, the elementary principles of flight, and he should be given foremost rank in the annals of aeronautics. The only picture of him which exists is a peculiar proof of his versatility, the picture having been drawn by himself in red chalk; it now hangs in the Royal library at Turin.

The Italian master's work is generally prefaced by a reference to the legends of Dedalus, Icarus and others, which merely show how the problem of human flight captivated the imagination of men from the earliest times of which records exist. In every country, also, the folk-lore is rich in tales of flying men, but in none more than in the Scandinavian countries. These tales it is hard to accept as well-founded.

There may, perhaps, be truth in the legend of Simon the Magician, who during the reign of the Emperor Nero attempted

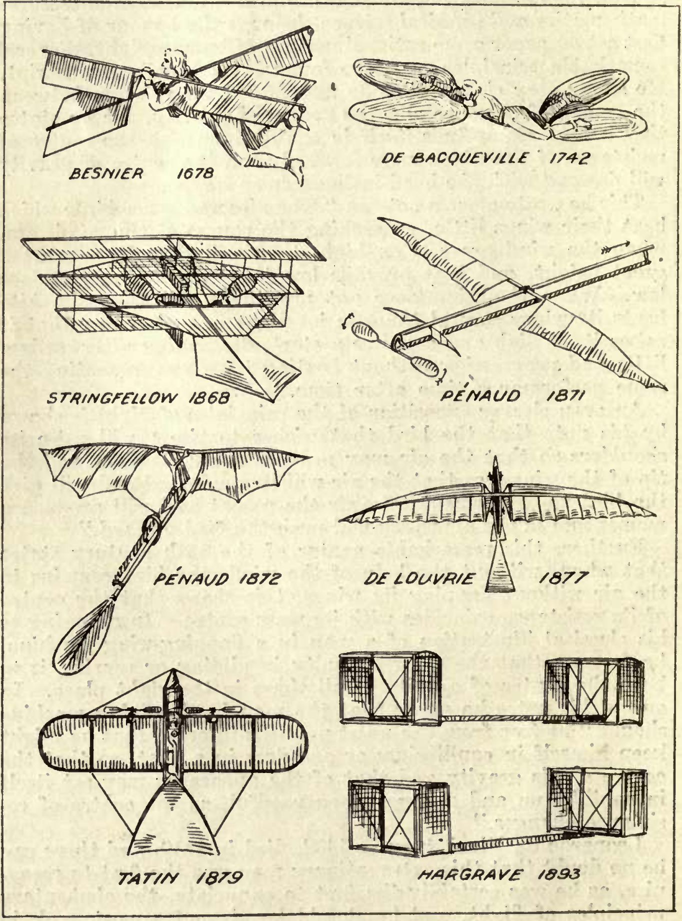


Fig. 35.—A page of early history.

"to rise towards heaven." The legend recounts that Simon rose in the air "through the assistance of Beelzebub," but that St. Peter offered up a prayer, the power of the demon was crushed and the magician fell to earth and was killed by the fall. It is possible that the man used a large plane surface and that he discovered, by accident or otherwise, that he could in that manner be lifted from the earth if he made use of a rising current of air. In the southern countries the vertical air currents are very much more frequent than they are in this country, for which reason the soaring birds are in those regions far more common.

An English Benedictine monk, Elmerus or Oliver, of Malmesbury, appears to have used wings (whether flapping or fixed the tradition does not state), and to have sprung from the top of a tower against the wind. He is said to have actually glided for some distance and then to have experienced a sudden fall, which broke his legs, preventing further experiments. That was in the 11th century, and the flight may just as well have taken place as that of the Saracen who towards the end of the 12th century glided from the top of a tower in Constantinople. The account given in the history of Constantinople by Cousin very clearly describes the apparatus used. The man was clothed in a white robe, the folds of which were stiffened by willow wands, to serve as sails for the wind. Evidently he was making use of rigid surfaces in place of the flapping wings which earlier legends record. In the presence of the Emperor the Saracen waited until he caught a favourable wind, and then "rose in the air like a bird," but, like most of the early investigators of flight, he fell and broke his bones, the accident causing considerable merriment, so the historian relates.

Towards the end of the 14th century Dante, the Italian mathematician, is recorded to have flown with artificial wings over Lake Trasimene. Later he tried to improve upon this experiment by jumping from the top of the highest tower in his native city of Perugia. He sailed over the crowd in the public square beneath, and was supported for a long time stationary in the air, but the iron forging which controlled his left wing is said to have broken and to have been the cause of his unchecked drop upon the roof of a neighbouring church. Having broken one leg in the experiment, he abandoned his efforts to solve the problem of flying.

There is, until the beginning of the 19th century, no further interesting history to relate, the numerous attempts at flight that were made in France (especially at the courts of Louis XIV. and Louis XV.) showing no proof of any great genius, all the investigators—of whom those that did not kill themselves were at least seriously injured—being men of ambition who sought the favour of the French kings. Most of them used four wings, some operated respectively by the hands and feet, as that of Besnier.

II.—In England: From Cayley to Maxim and Pilcher.

At the commencement of the 19th century there arose another great student of flight, Sir George Cayley, whose writings might be read with benefit by many at the present day, for he certainly had very clear notions of what was required and how it had to be done.

Sir George Cayley was the first to point out that two planes at a dihedral angle form a basis of stability. For, if the machine heel over, the side which is required to rise gains resistance by its new position, and that which is required to sink loses it, the operation very much resembling what takes place in an ordinary boat. In dealing with the principle of stability in the direction of the path of the machine, he pointed out that experiments showed that in very acute angles with the current the centre of resistance in a plane does not coincide with the centre of its surface, but is considerably in front of it. As the obliquity of the current decreases these centres approach and coincide when the current becomes perpendicular to the sail. Hence, any heel of the machine backward or forward removes the centre of support behind or before the point of suspension, and operates to restore the original position by a power equal to the whole weight of the machine acting upon a lever equal in length to the distance the centre has moved. To render the machine perfectly steady and to enable it to ascend and descend in its path it becomes necessary, he wrote, to add a rudder in a similar position to the tail in birds.

In 1809 he made a machine with a surface of 300 sq. ft., which was accidentally broken before there was an opportunity of testing the effect of its propelling apparatus. Its steerage and steadiness were perfectly proved, so he relates, and when any person ran forward with it at full speed, taking advantage of a gentle breeze in front, it would frequently lift him up and convey him several yards. For his motive power he endeavoured to obtain a steam engine working at a very much higher pressure than the couple of pounds per square inch which was usual in those days, and he also invented a gunpowder engine. It is probable that it was simply owing to the fact that there was at that time no light prime mover that his experiments did not lead him further.

He fully recognised the importance of eliminating every possible rib or strut that could offer any resistance to the air, the poles that were used in his wings being covered with the cloth that formed the plane. He was also aware that the shape of the after part of any body offering resistance to motion through the air was of as much importance as that of the front portion.

It is said that some ten years later he succeeded with mechanical power in raising a man from the ground with his apparatus, but this has not been properly authenticated.

From that time most of the serious work connected with human flight in heavier-than-air machines was carried out in England until Lilienthal made his famous experiments in Germany.

About 30 years after Sir George Cayley first made public his researches into the problem of flight there came Henson, who patented a large aeroplane of canvas, stretched upon a rigidly-trussed frame and propelled by screws operated from a steam engine. In his patent specification he gave the surface of the planes as measuring 4,500 sq. ft., that of the tail being 1,500 sq. ft. extra, and with a total weight of 3,000lb. he intended to use an engine of 25h.p. His drawings show the main surface to have been about 150ft. in spread by about 32ft. in length, but Henson never completed such a machine. With his friend, Stringfellow, he completed in 1845 a model of 70 sq. ft., weighing just under 30lb. It is evident from the accounts of these experiments that the machine lacked stability and was never able to make any flight. Stringfellow later, on his own account, made a much more stable model, which he found was able to sustain itself in the air in an enclosed space, but not out of doors.

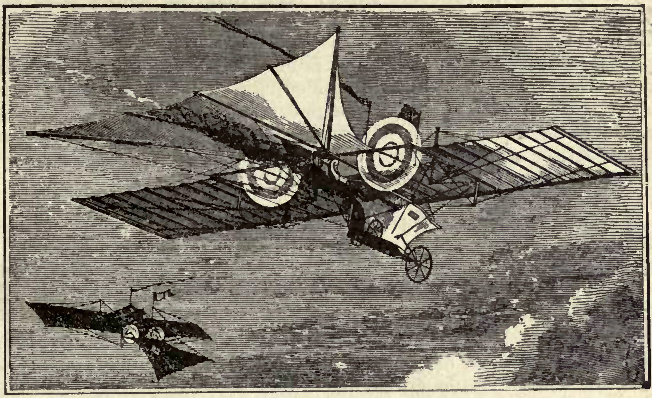


Fig. 36.—Henson's projected aeroplane of 1814.

The most important contribution to aeronautical knowledge before the modern era of flight commenced was afforded by Mr.

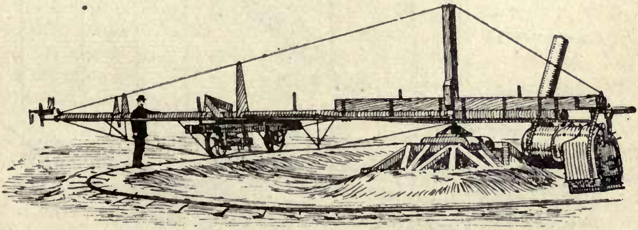


Fig. 37.—Phillips's whirling machine for testing the lifting power of planes.

Wenham in 1866. He was the first to point out that the supporting surface of an aeroplane could be best utilised by disposing it in such a manner that it offered a broad spread with little fore and aft depth, instead of arranging it with considerable depth. He entirely repudiated all imitations of natural wings, but considered that a successful flying apparatus could be constructed. He actually made a large model of a kite or glider sufficient to carry the weight of a man, the supporting surface being arranged in six narrow planes after the fashion of a venetian blind. His diagram shows that he intended the operator to lie prone, just as the Wright Brothers did in their early experiments. He found that when the wind approached 15 or 20 miles per hour the lifting power of this apparatus was all that was required, but the capricious nature of the ground currents was a perpetual source of trouble. Wenham is also notable for having first used the hyperbole of a man skating over thin ice, the ice not being deflected in any way so long as rapid motion is maintained. This same illustration was later used by Langley.

Wenham, like most other capable students of flight, based all his theories upon the soaring powers of birds, and his great theory was published in this form: "Having remarked how thin a stratum of air is displaced between the wings of a bird in rapid flight, it follows that, in order to obtain the necessary length of plane for supporting heavy weights, the surfaces may be superposed or placed in parallel rows with an interval between them. A dozen pelicans may fly one above the other without mutual impediment, as if framed together, and it is thus shown how 2cwt. may be supported in a transverse distance of only 10ft."

Phillips, who, in 1884, patented the dipping-edge section of planes, expended a considerable amount of time and money with a peculiar form of flying machine previous to 1893. The apparatus had the appearance of a huge venetian blind with the slats open, the total number of slats or sustainers being 50,

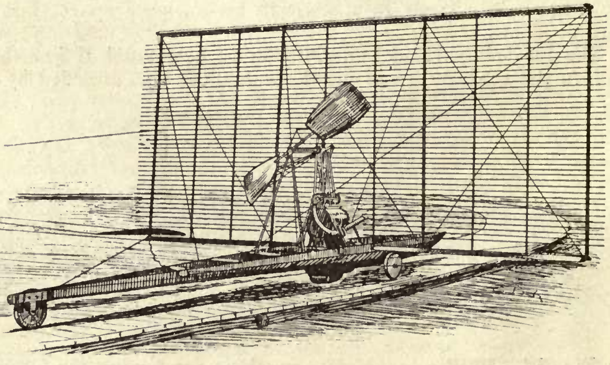


Fig. 38.—Phillips's steam-driven multiple plane captive flying machine.

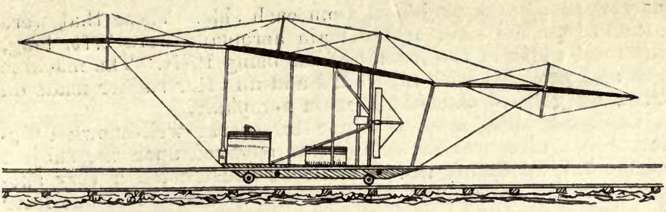


Fig. 39.—Maxim's aeroplane of 1893.

each 1½in. wide and 22ft. long, fitted 2in. apart; the total supporting area thus obtained was 136 sq. ft. The frame holding these slats was fitted on a light carriage mounted on three wheels, each 1ft. in diameter, one in front and two at the rear. A small boiler and compound engine, with a two-bladed screw turning at 400 revolutions per minute, was employed for the motive power. The machine followed a circular path of wood of 200ft. diameter, and wires were carried from different parts of the apparatus to a central pole in order to prevent erratic flights. This notion for testing a machine originated with Tatin in 1879.

The forward wheel was so balanced that it would never leave the track and served, therefore, as a guide, carrying less than 20lb. of the weight, the remainder being on the hind wheels. With 72lb. dead weight added, the hind wheels of the machine rose a couple of feet clear of the track when the apparatus was set in motion. Whilst, therefore, the ability of the machine to raise itself from the ground was amply demonstrated, the net results of the experiments were of little value, for no provision was made for maintaining equilibrium on such a machine in free flight.

About this time Sir Hiram Maxim was carrying out his experiments on a full-sized machine; the total lifting surface of his apparatus was 6,000 sq. ft., and the total weight with 600lb. of water in the tank and boiler, and with naphtha and three men on board was no less than 8,000lb. Two compound engines were specially designed for the work (one of these is to be seen at the present day in the South Kensington Museum). Weighing only 310lb. each, they each developed 180h.p., using steam at 320lb. to the square inch. A lifting effect of 3,000lb. to 4,000lb. was obtained at a speed of about 40 miles an hour. The apparatus was not allowed to rise from the ground, but ran over a track. The wheels on which the machine was carried ran over steel rails of 9ft. gauge, and the safety track of 3in. by 9in. Georgia pine, placed about 2ft. above the steel rails, was 30ft. gauge. Maxim calculated that the lifting effect upon the machine on the occasion when it got off the rails and was badly smashed could not have been less than 10,000lb.

Maxim's experiments with the large machine extended from 1890 to 1893, and were abandoned only owing to their costly nature. The main aeroplane was 50ft. wide and 47ft. long in the direction in which the machine travelled. Five long and narrow aeroplanes projected from each side. Those that were attached to the sides of the main aeroplane were 27ft. long, the total width of the machine thus being 104ft. The machine was also provided with a forward and an after rudder made on the same general plan as the main aeroplane.

Lawrence Hargraves, the inventor of the well-known cellular or box kite, was for some years engaged upon the subject of mechanical flight, and in 1892 he constructed a very successful model. He employed at first compressed air, but later adopted steam. The general idea of the model was that two fixed wings were carried at a very obtuse angle on the main keel, while in front were two flapping wings, which afforded the propelling power. The wings were driven by a little engine. One of the models, when compressed air was used, flew 343ft. in 23 seconds. These experiments were apparently discontinued.

A clever young engineer, Pilcher by name, commenced in 1895 to work on Lilienthal's system. His first glider, with which he made many flights between 50ft. and 350ft. in length, weighed 50lb. and gave a sustaining surface of 150 sq. ft. A larger machine, double-decked, which he constructed in the following year, he found difficult to control. A third and somewhat lighter machine in 1896 made many good flights. It was equipped with wheels for grounding. In gentle winds his method was to rise into the air like a kite, the glider for this purpose being towed by a horse, the tow rope passing over a pulley block which made the glider travel five times as fast as the horse. At any desired altitude, Pilcher cast off and glided to earth. He designed in 1899 an aeroplane to be driven by a 4h.p. petrol motor of his own design, but a rib of one of the wings of his glider broke during a trial in the same year, and falling from a height of 30ft., he broke his collar-bone and succumbed within 24 hours.

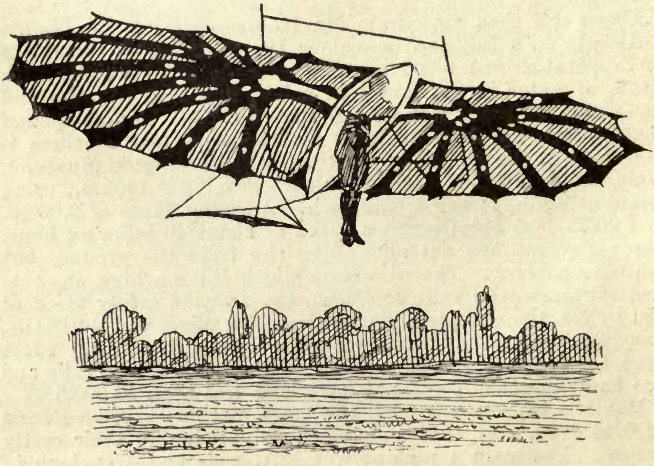


Fig. 40.—Pilcher making a gliding flight in 1895.

III.—In Germany: Lilienthal, the Founder of the Modern School.

Otto Lilienthal has undoubtedly inspired all the modern efforts which have finally led up to the conquest of the air. As a boy of 15 this distinguished engineer, who for so many years spent his spare time in the study of aviation, showed an early desire to investigate the mysteries of bird flight. His name appears first in aeronautical annals in 1889, when he published his famous book "Bird Flight as a Basis of the Flying Art." In this treatise he gave to the world the practical result of 25 years research and study. Much of his early attention was devoted to the flight of sea birds—Otto Lilienthal in the course of his work having been occupied on sea work; he was the inventor of a fog-horn adopted for German lighthouses. Later he spent a great deal of time in following the movements of storks, which are to be found in great numbers in the south of Germany, where their soaring feats are regarded as commonplace. In much of this work Otto Lilienthal was aided by his brother Gustav, but the brother's help was probably seldom sought, for the 1889 book bore the name only of Otto Lilienthal.

When he satisfied himself that curved surfaces such as birds apparently use would be essential to human flight, he was still uncertain about the ability of man to lift himself by flapping wings. This problem he solved in an interesting manner: he suspended himself by a rope counterpoised over a pulley supported from a beam projecting from a house. He equipped himself with three pairs of wings to be operated by his own muscular efforts, using both hands and feet, with the wings opening and closing like venetian blinds. The total weight of the wings and of Lilienthal himself amounted to 176lb., and after a few experiments he employed a counter weight of 88lb., and with considerable effort lifted himself in this wise 30ft. from the ground. This satisfied him that flapping flight was

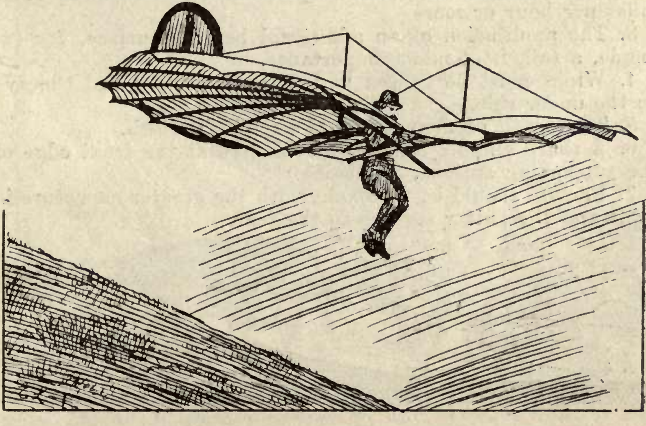


Fig. 41.—Lilienthal gliding in 1891 with his first model.

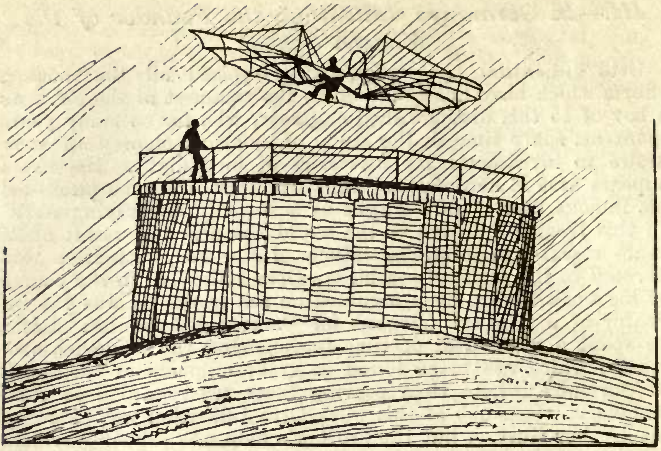


Fig. 42.—Lilienthal's starting tower.

out of the question, but he was encouraged to proceed further, and for the investigation of the supporting power of curved surfaces he made almost countless experiments with a whirling table, the invention of which, though often attributed to him, seems rightly due to Professor Marey, who employed such a device about the year 1870. Lilienthal enumerated in his book a number of conclusions which he drew from his 25 years' experience. The most important of these were that:

1. The construction of machines for practical operation is independent of the development of a light and powerful motor.
2. Hovering flight is impossible by man's unaided strength, but can be attained by means of proper surfaces in winds of 22 miles per hour or more.
3. The application of an additional bearing surface, for example, a tail, is of minor importance.
4. Wings must be curved in transverse section and concave on the under side.
5. The depth of flexure should be 1-12th width.
6. A sharp cutting edge should be used at the front edge of the supporting surface, if possible.
7. Flexure should be parabolic, with the greater curvature in front and the flatter surface to the rear.

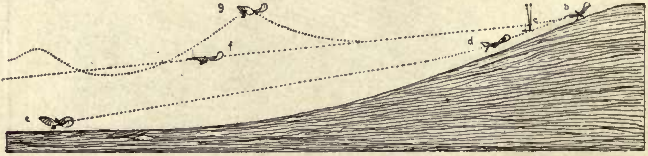


Fig. 43.—Trajectories of three of Lilienthal's flights.

In 1890 Lilienthal commenced a series of experiments that must, and will be, for ever regarded as classical. In the following year he made his first trials with gliders, and in 1893, with a glider weighing 44lb. and measuring 150 sq. ft., he went cautiously to work to lift his own weight freely in the air. He started in his garden by jumping from a spring board 3ft. high, and gradually increasing the height of the board to 8ft., and taking bounds from it, he satisfied himself that he could come safely to earth. He then built a low tower on a hill, and from the top of this made many successful glides. Later he was led to construct an artificial hill 50ft. in height near Gross Lichterfelde, near Berlin. In 1895 he adopted two superimposed planes each 18ft. broad and of 100 sq. ft. area, the upper surface being about three-quarters of the breadth of the lower. He wanted to fly in a wind of 10 metres per second. Previously he flew nearly horizontally in winds measuring from 6-7 metres per second. In a strong wind he

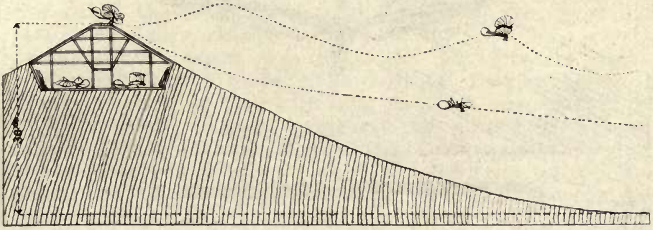


Fig. 44.—Trajectories of two Lilienthal flights from his later artificial hill with shed at summit.

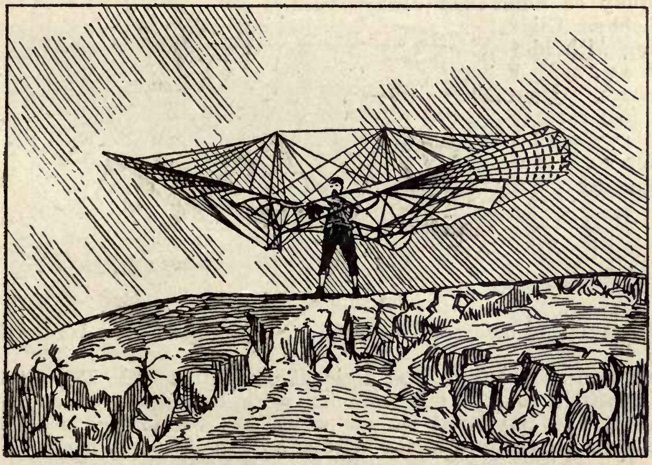


Fig. 45.—Lilienthal's glider of 1893, made to fold for portability.

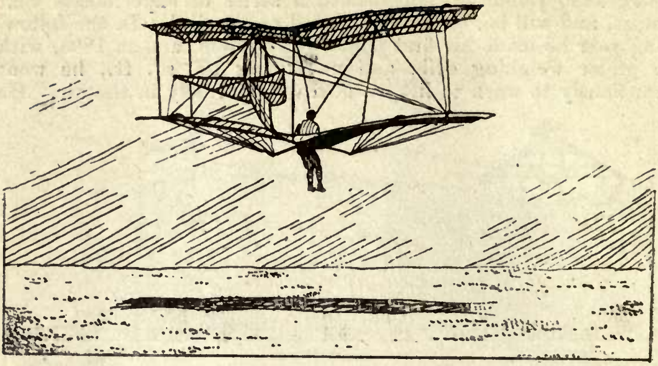


Fig. 46.—Lilienthal's double-deck glider of 1895.

frequently allowed himself to be lifted from the top of the hill without the necessity for running down the slope, and oftentimes he found himself higher than the top of the hill. To take longer glides, he went in 1896 to the Rhinerow Hills, where he had been in 1893 for a fair time. From the top of some hills there 250ft. high he glided sometimes 750ft. or more. Unfortunately, in the search for that soaring flight which seemed to fascinate him, he was caught in an awkward current, and the machine, losing its equilibrium, carried him plumb to the ground, breaking his collar bone, from which injury he died within 24 hours. With him the study of flight had always been a hobby. Gliding with him became a sport. How much further he would have progressed had he been spared from that accident on August 12th, 1896, it is impossible to say, but from his work has proceeded all the great and important success which has within the last few years been attained in the art and science of human flight.

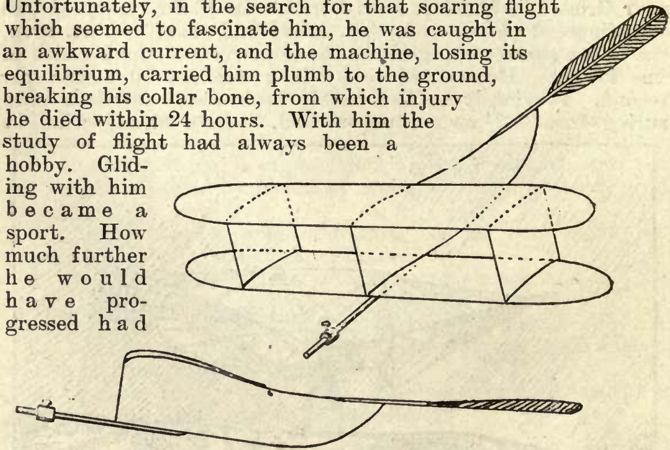


Fig. 47.—The model arrived at by Lilienthal just before his death.

From his pupils Herring, Pilcher and Ferber have grown the schools of America, England and France, respectively.

IV.—In America: Langley and Chanute.

The history of the American aeroplane resolves itself in the popular mind to the doings of the two Wrights. However, it must be borne in mind that, though these two clever inventors accomplished the feat of flying before anyone else, they had a vast amount of work already done for them.

Langley—with whom was associated Dr. Graham Bell—Chanute and Herring were first in the field; Langley and Bell, who were working on their own lines, had been co-operating for two years before Chanute came on the scene, for Langley started in 1893. Chanute began with the assistance of Herring, who had been a pupil of Lilienthal, and, while in no wise discounting the Americans' achievements, we see in Lilienthal the groundwork of Chanute's success. But Langley and his adviser Bell, Chanute and his engineer Herring were all handicapped by the absence of light motive power such as that of the petrol engine. They all stopped, because progress was impossible until the day of the light efficient engines.

Langley is recognised as being one of the first to make an aeroplane that would actually fly. In making his report on the subject, Langley modestly stated that, "to prevent misapprehension, let me state at the outset that I do not undertake to explain any art of mechanical flight, but to demonstrate experimentally certain propositions in aerodynamics which prove that such flight under proper directions is possible."

Langley recognised that to try to imitate the action of a bird was useless, and in his endeavour to master the problem of flight he employed an aeroplane, or, as he called it, aerodrome. To assist him in his pioneer work he used the whirling table. With this he was able to prove that the figures prepared

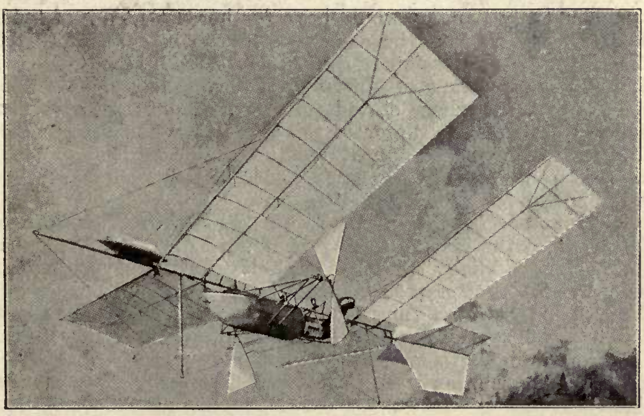


Fig. 48.—Langley's mode devised in 1893 and first flown in 1896.

by a well-known French mathematician were wrong, likewise Newton's rule for finding the resistance to advance through air. Otherwise, as he pointed out, the swallow would have to be nearly as strong as a man to enable it to travel at 60 miles per hour. Since he first propounded his famous theory, well known as Langley's law, he has qualified the remarks to the extent that, though it still reads as it did at first, to the effect that less power is spent in making a plane surface travel fast through the air than would be spent in making it travel slowly, that statement applied only to the ideal condition of a frictionless plane, and not to an actual flying machine.

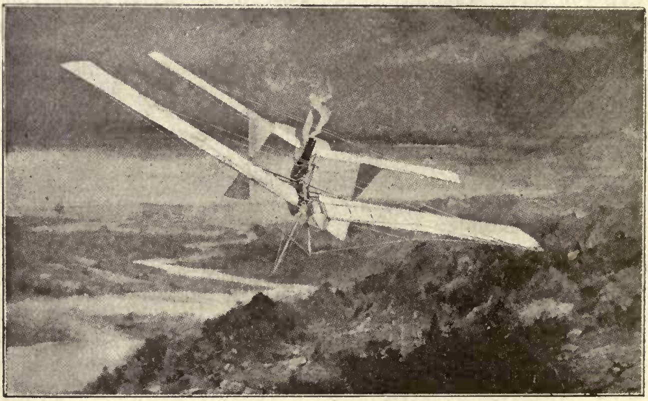


Fig. 49.—The Langley model in actual flight, May 6th, 1896.

Undoubtedly Langley would have furthered that art of flying if he could have had the assistance of the petrol motor. He experimented with compressed air, carbonic acid gas, electricity and other means of obtaining power. Finally, he settled upon steam, though he stated that he thought the gas engine would be the motive power of the future. When using steam he was terribly handicapped, for the engine, generator, etc., weighed 7½lb. per h.p., and his water supply would only last long enough for a flight of 1½ minute.

The innumerable difficulties that he had to overcome can be gauged from the fact that it was not until May 1st, 1896, that his machine actually flew, although it was three years previously that he first started his experimental work.

As the illustration shows, Langley's aerodrome was shaped like a butterfly, and consists of a main girder lying in the direction of flight, to which the four plane surfaces are attached fore and aft, the power unit and propellers being placed immediately behind the front pair of wings. Langley claimed that with this model he had proved flight to be possible.

Herring and Chanute were very closely allied in aeroplane work, though together they never got beyond the experimental

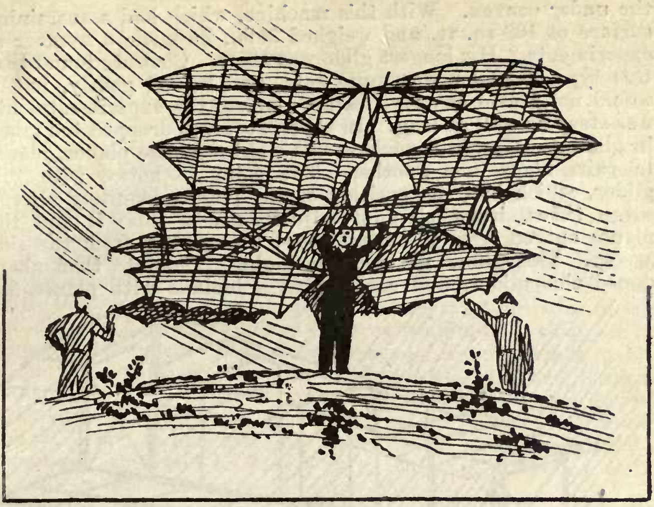


Fig. 50.—Chanute's experimental multiplane glider.

stage in gliders. Herring was a pupil of Lilienthal, but he soon broke away from the lines of the German engineer. He brought to Chanute's notice the German inventor's discoveries, and appears to have really started the latter's interest in gliding experiments as a means towards the conquest of the air, so that in 1895 he and Chanute constructed a glider like Lilienthal's, though slightly modified. This glider was shaped like the outstretched wings of a bird, the top surface being concave and

Fig. 51.—Chanute's final form without vertical planes.

the under convex. With this machine, which had a sustaining surface of 168 sq. ft. and weighed 36lb., he made a number of experiments. His longest glide was 168ft. Chanute found that this type of glider was quite safe, and landed gently, but it would not travel any real distance unless the experimental hill was steep as well as long. In other words, it dropped too much in gliding. His next machine had eight separate planes, placed in pairs above one another. The point to notice with this glider, which had the position of the planes definitely altered seven times, irrespective of adjustment, is this: it had the planes curved from the front view, though flat from the side aspect. This glider gave longer flights. Chanute then abandoned this glider, and constructed a biplane with planes flat from the front aspect, but arched from the side. This was a most important step. The result was that he immediately doubled the length of his flights. With the biplane he had a certain amount of unsteadiness that he had not previously experienced, and which he does not account for. However, he overcame that by attaching a vertical rudder to his glider some distance at the rear and on the same level as the load.

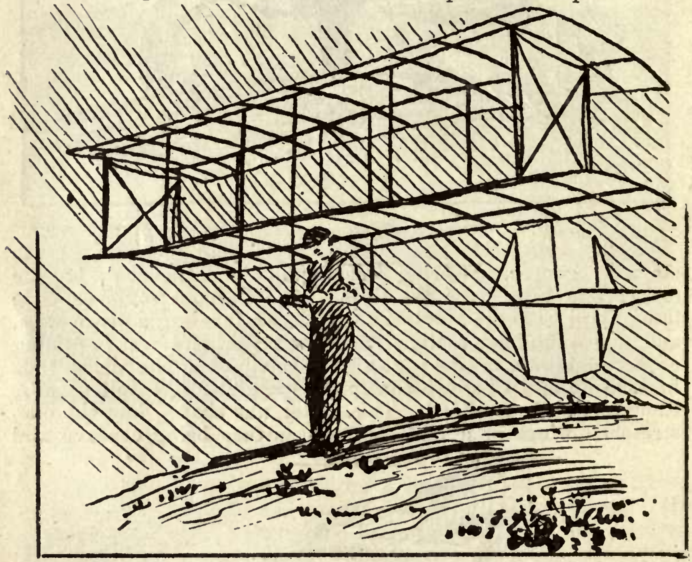


Fig. 52.—Chanute's penultimate form of double-deck gliding machine—the side planes were finally abandoned.

Chanute was of the opinion that not much was to be learned from studying the action of flying creatures, because they vary so in the amount of their supporting surface. He thinks that his most valuable discovery was when he found that a plane presenting a flat appearance from the front and arched from the side had the greatest lifting capacity.

IV.—In France: From Ader to Wright.

Although the aeronautical research work undertaken in France seems to have been very meagre until the last half of the nineteenth century, the work of Tatin and Penaud with models in the 'seventies and 'eighties was not insignificant.

It is necessary to go further back than that first flight of Santos-Dumont, made at Bagatelle on the afternoon of October 23rd, 1906, and popularly regarded as the starting point of the aeroplane in France, to get at the true beginning of this revolutionising movement. Before that first soar could be made, years of patient experimenting had been carried out, and Santos-Dumont should be more correctly regarded as the happy instrument than the originator of the first real flight made in France. The rapid rate of progress since that October afternoon, and the immense enthusiasm in France prove that there was a wealth of activity unknown to the ordinary observer.

Ignoring the small army of inventors, who dreamed of discovering the secret of the birds and worked towards that end to receive no other reward than the title of "Fools," the first person in France directly connected with the present movement is Ader, who, in 1892, started practical experiments with flying machines, and in 1897 made the first known flight in Europe. Ader had succeeded in interesting the Government,

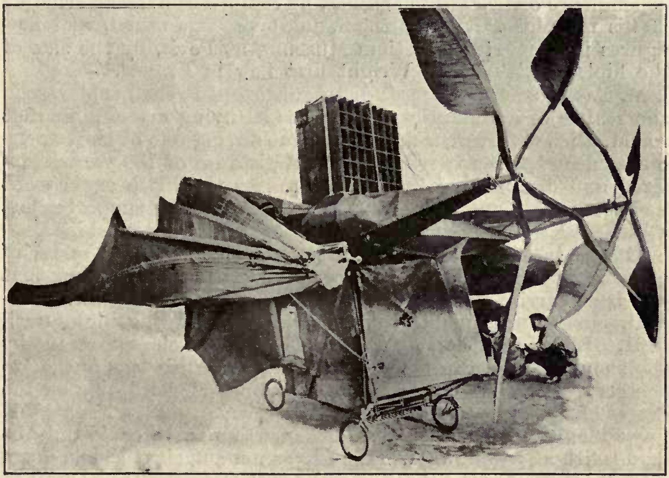


Fig. 53.—The Ader, the first power-propelled aeroplane.

Fig. 54.—Experiments at Issy with a glider in 1900, power being obtained by towing the glider with a car.

and after a very short flight on October 12th, 1897, on the Satory ground, in the presence of General Mesnier, a demonstration was ordered to be made the following day before a military commission. October 14th, which was later fixed as the date of the trial, was a gusty autumnal day most unfavourable for aeronautical experiments, and although Ader was able to rise from the ground, his machine was incapable of struggling against the strong wind, and made such a poor display that the Government lost interest in the matter. Ader was abandoned, and, discouraged after 40 years' labour and the expenditure of two million francs, he commenced the destruction of his machines. One of them, however, was saved, and now figures in the Arts et Metiers Museum, at Paris, by the side of the biplane with which Wright first flew in France.

M. Tatin, one of the most distinguished of French explorers in the realms of aeronautics, built a model flying machine in 1896 for M. Richet. The machine flew, but during one of the experiments near the sea it travelled for a distance of 150 yards, capsized and disappeared in the water. As the little experiment had cost nearly one thousand pounds sterling, the supporter lost all interest in flying with the disappearance of the machine.

It was in 1899 that Captain Ferber began a long series of experiments with gliders, endeavouring to take up the work that had been carried on with so much success by the German Lilienthal, but he was unable to make the least gliding flight until 1901. Like Lilienthal, he attached himself to the apparatus by the shoulders and arms, steering by carrying his legs ahead, to the rear, or to left and right, but was not able to glide on the layers of air as had been done by his German master. In 1901, he suddenly perceived that flights of this nature could only be made with an ascending wind. It was not sufficient to run down a gentle slope, for the speed of 3ft. to 6ft. a second thus obtained would be altogether insufficient to support a man on such an unbuoyant element as air. A horizontal head wind was altogether unfavourable, for if it caught the wings on the upper surface the effect would be to hold the apparatus down to earth. On the other hand, if the apparatus were at such an angle that the wind struck the under surface, the apparatus would be raised, but would not be able to advance in the face of the wind, and, after a flutter in the air, would be driven backwards towards the ground. With the wind blowing up the slope, it was possible for the aviator to run down, with the front of his apparatus inclined towards the ground, in what would appear to be in the face of the wind; the upward current of air, however, would have a lifting effect which would allow the experimenter to glide ahead, gradually descending all the time.

Captain Ferber, in France, kept in touch with the work being done in America by Chanute, Herring and Avery, as well as with the earlier experiments of the Wright Brothers, with the result that progress was being made simultaneously on each side of the Atlantic. The "Ferber No. 5," of the Chanute and Wright type, after a few unsuccessful initial attempts, made satisfactory gliding flights at Beuil, in 1902. The experiments were continued the following year at Conquet, in Finisterre, with equal success, the apparatus, which had then a very strong resemblance to the one being used on the other side of the Atlantic by Wilbur and Orville Wright, making numerous gliding flights with perfect stability. It was considered so satisfactory that the problem of driving it mechanically was taken into consideration.

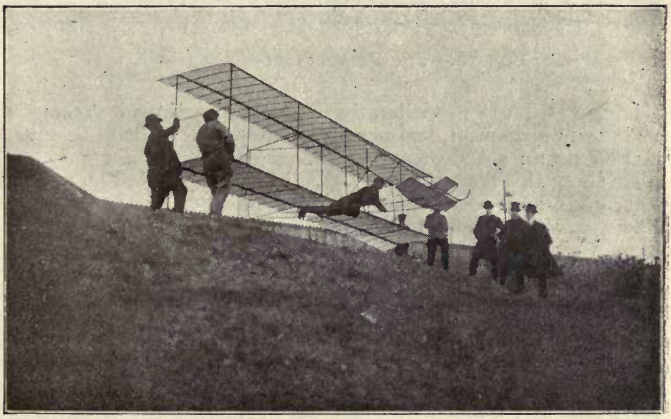


Fig. 55.—Experiments in gliding in 1900-1902 by M. Ernest Archdeacon and Gabriel Voisin.

Captain Ferber estimated that the weight of engine he could put on the machine was 220lb. In 1903 all the power he could obtain for this weight was 6h.p., delivered by a Buchet petrol motor. A new biplane, known as "No. 6," was built on the same lines as the preceding one, fitted with the Buchet engine

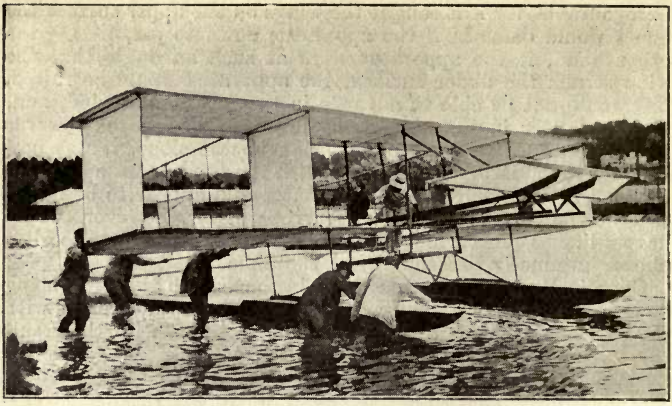


Fig. 56.—The Voisin float-borne glider.

driving two large propellers in opposite directions by means of a kind of differential, and arrangements made for it to be tested in 1903 on an aerodrome at Nice.

He hung this from an arm 100ft. in length pivoted on a tower 60ft. high, and drove the machine round, but the power available was not sufficient to sustain the machine in the air, centrifugal force prevented a high initial speed, and, further, the propellers were much too large for the engine. Afterwards experiments were made with the aeroplane hung on a cable and running upon it, to be released and shot into the air, but the aeroplane merely glided, the motor failing to keep it aloft. A larger motor was ordered, but before further work could be attempted the Government required the shed in which the aeroplane was housed, and the experiments came to an end.

Captain Ferber went on half-pay immediately after this, and was not able to rebuild his apparatus until the spring of 1908. In July of that year, it was tested at Issy-les-Moulineaux, flying the full length of the ground after a few slight adjustments. This result, which might have been obtained in 1905, but for the lack of War Office sympathy, passed unnoticed, for in the meantime Farman, Delagrange, Bleriot, and Santos-Dumont had all made flights.

While Captain Ferber was carrying out the most important experimental work in France, M. Ernest Archdeacon was no less active in the capacity of aeronautical evangelist, seeking to arouse enthusiasm in the subject of flight by lectures in various parts of the country, and by financial and moral encouragement to all experimenters in this field. Mr. Chanute having visited France in 1903, and given particulars of the wonderful success achieved by the Wright brothers with gliders during the years 1900, 1901, and 1902, M. Archdeacon had a machine of a similar type constructed at Chalais-Meudon. The possession of the machine, however, was not sufficient, and, in view of the lack of experience in its handling, as well as the different conditions under which it had to operate there, nothing practical was done in this line.

Gabriel Voisin was introduced to M. Archdeacon in January, 1904, and less than three months later the two were making gliding flights together at Berck-sur-Mer.

Gabriel Voisin, who mounted the apparatus, was at first unable to make a flight, and it was only after Captain Ferber had been brought from Nice to explain that they must operate in an ascending wind, that practical results were obtained. Berck-sur-Mer was not an ideal spot for gliding experiments, and in order to be nearer their workshops, the party returned to Paris, where, for want of a hill on which to make glides, the aeroplane was towed by a motorcar across the military drill ground at Issy-les-Moulineaux. The method of operation was to place the aeroplane, without motor, but with a pilot on board, on suitable rails, attach it by means of a tow-rope to the motorcar, and pull it until it rose in the air in the same way as a kite. It was not a very satisfactory arrangement, and after an accident on March 25th, 1905, when the machine flopped to the ground and was completely destroyed, these experiments were abandoned. Fortunately, on this day the pilot had been replaced by a sack of sand.

Believing there was less danger on the water, the aviators abandoned Issy and took up their headquarters at the Surcouf establishment at Billancourt, on the River Seine. The most remarkable performance was made on June 8th, 1905, when the aeroplane, mounted on two long floats, piloted by Gabriel Voisin, and towed by the motor-boat "Rapière," rose to a height of 55ft. and covered a distance in the air of not less than 160 yards. The apparatus had then very closely approached the form to be adopted later by the aeroplane with which Farman was so

Fig. 57.—Gabriel Voisin in his glider towed over the Seine by a fast motor-boat.

successful. It had two main superimposed planes, about 60in. apart, united by four vertical planes to give lateral stability. In the rear was a tail, composed in the same manner, but of much smaller dimensions than the main bearing surfaces. In the front was a single horizontal plane forming the functions of elevation rudder.

It was not long before experiments on water were proved to be even more dangerous than those on land. Six weeks after the experiment just mentioned, Voisin again tested the Archdeacon aeroplane on the Seine with but moderate results, and a few hours later took out a new apparatus which he had built for M. Louis Bleriot. While being towed by the motor-boat "Antoinette," the aeroplane suddenly dived under the water, taking Voisin with it. The aviator only succeeded in extracting himself from under the planes at the end of 20 seconds, which appeared to be 20 minutes to the anxious spectators. A little later, M. Archdeacon removed to the Lake of Geneva, hoping there to get a powerful motor boat which would tow him constantly head on to the wind, a thing which was practically impossible on such a narrow river as the Seine. A suitable boat could not be found, and the only practical result of the visit was a little experiment made by Gabriel Voisin when the aeroplane was lying at anchor on the lake. In a very strong wind Voisin discovered that he could cause the aeroplane to rise from the surface of the water merely by operating the elevation rudder, and remain in the air, struggling at its cable until a lull in the wind or the manipulation of the rudder caused it to descend.

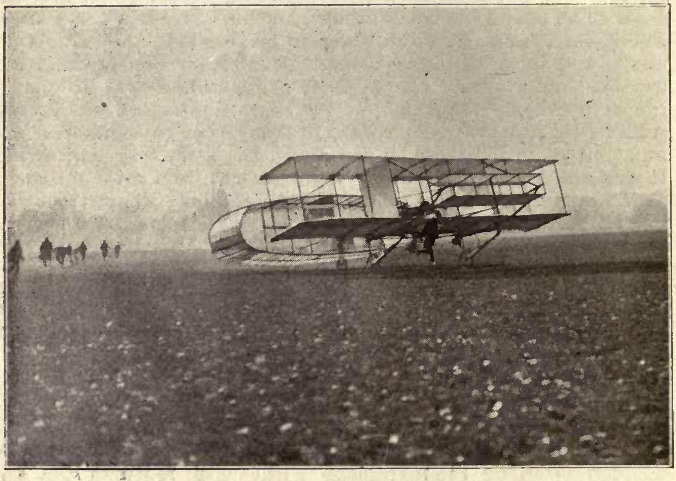


Fig. 58.—Bleriot "9bis" running over the ground in 1906.

The year 1906 opened with tremendous activity among French

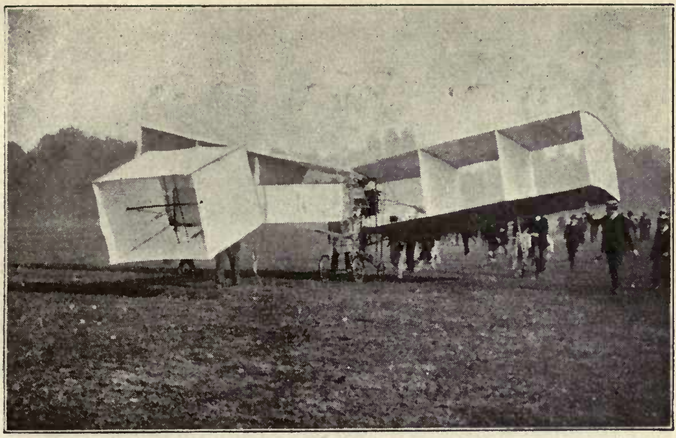


Fig. 59.—Santos-Dumont's famous aeroplane "14bis" coming up for the start of its first flight. The elevation planes were carried at the forward end of the body.

aeronauts, and a firm belief on the part of enthusiastic inventors that the day was very near when a mechanically-driven machine would rise from the ground and maintain itself in the air, a feat which had never been accomplished in Europe, with the exception of the brief and almost-forgotten soar of Ader in 1897. The Wright brothers claimed to have made flights the previous year varying from 25 to 38 minutes' duration, and, although their statements were far from being generally accepted in France, the mere possibility of the Americans having made a flight at all incited everyone to increased efforts on this side of the Atlantic.

Gabriel Voisin had joined Louis Bleriot in business as aeroplane constructors, and, together, the aeroplanes Nos. 3 and 4 were built and experimented with on the lake at Enghien, near Paris, and at Issy-les-Moulineaux.

Santos-Dumont's first idea was to build a helicoptere; several technical advisers persuaded him that this would be a waste of time and energy, and, in consequence, an aeroplane of the Hargreave box kite type was constructed and shown to the members of the Aero Club in July, 1906. The first Santos-Dumont aeroplane, known as the "14bis," was attached to No. 14 dirigible balloon, the young Brazilian sportsman at that time not having sufficient confidence in the heavier-than-air type of flying machine to attempt a flight from the ground in the generally accepted manner. It was immediately seen that the dirigible balloon was more of a hindrance than a help, and other aids were looked for. After various experiments with an inclined cable and, later, with an inclined wooden track, the machine was sent away over the Bagatelle ground on its four wheels and under the effort of its 24h.p. Antoinette motor.

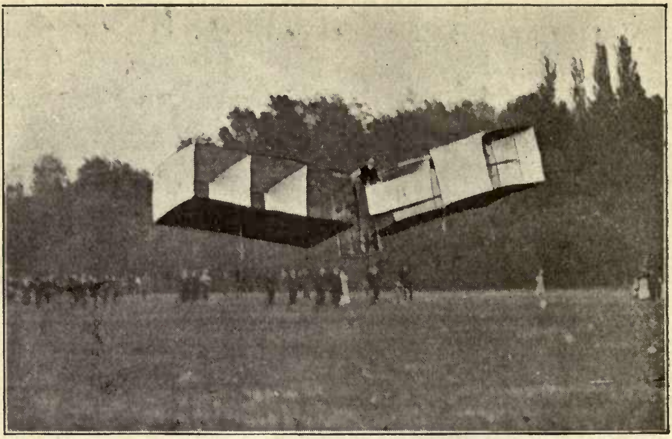


Fig. 60.—The starting-point of the aeroplane movement in France. The flight of Santos-Dumont's "14bis" at Bagatelle, October 23rd, 1906.

There was an immediate improvement, and it was not many days before the apparatus was running about in all directions. The motor was changed for a larger one developing 50h.p., while, longitudinal stability having proved to be perfect, the two rear wheels were abandoned, leaving the front ones only. From July to October had been spent in experiments; but so rapid was the progress that, on the 23rd of that month, Santos-Dumont called together the Aviation Commission of the Aero Club of France, and at 4.45 in the afternoon won the Archdeacon prize for the first flight of not less than 25 metres. Excitement was at such a high pitch when this huge motor-driven box kite rose from the ground, that the Commission forgot to measure the distance covered in the air. Although officially given as 25 metres, it was generally recognised that the actual distance was not less than 70 yards. The first flight ended with the breaking of the wheels of the aeroplane, for, the apparatus having set up a slow lateral roll while in the air, Santos-Dumont switched off the ignition and allowed his machine to descend abruptly, instead of guiding it down gently.

A month later, the flying record had been carried to 220 metres, and enthusiasm in French aero circles had reached its height. Among the general public, however, the belief was prevalent that the so-called flights were only jumps, comparable to the leaps that could be made by a man running at high speed, or even by a motorcar when driven fast. Santos-Dumont's first success was not rationally followed up, and, after various unsuccessful attempts with small area high-speed flyers, the young Brazilian abandoned the aeroplane to endeavour to construct an apparatus to travel at 100 kilometres an hour on water.

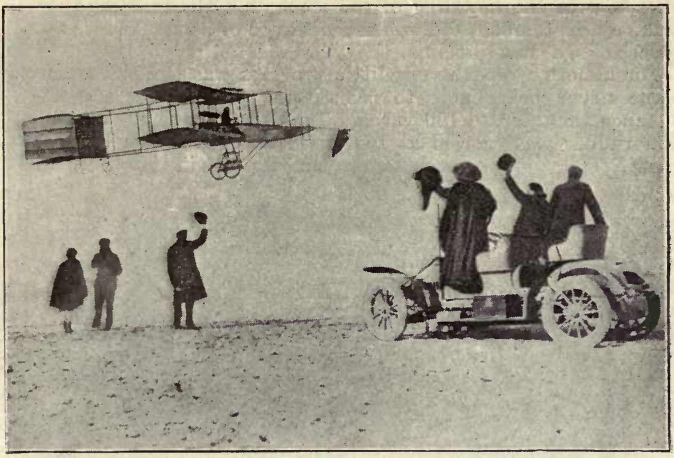


Fig. 61.—Henry Farman wins the Archdeacon-Deutsch prize of £2,000, by covering a triangular course of one kilometre, on January 13th, 1908.

Gabriel Voisin, who, during 1906, had dissolved his partnership with Bleriot and been joined by his brother Charles, had developed his own type of aeroplane while working out the ideas of his customers. He discovered, however, that inventors who were willing to pay for aeroplanes wished to have them according to their own ideas. It was not until the Parisian sculptor Leon Delagrange came forward in the early part of 1907 that he could find anybody to accept the machine produced as the result of the gliding flights at Berck-sur-Mer, and the experiments on the Seine and elsewhere. The first Voisin machine, known as the " Delagrange No. 1," was tested at Vincennes on February 28th, 1907, Charles Voisin mounting it. It was so lightly constructed that the backbone of the machine broke. A fortnight later it was out again at Bagatelle, but failed for lack of lateral balance. Finally, on March 30th, still on the Bagatelle ground, the machine went into the air for a magnificent flight of 60 yards.

Instead of continuing his training after this very satisfactory début, Leon Delagrange abandoned the Voisin machine to carry out experiments with M. Archdeacon on the Lake of Enghien. In June, Henry Farman came forward with a request for a machine, and the " Henry Farman No. 1," differing from the " Delagrange No. 1 " in the method of attachment of the wheels only, was supplied to him.

With true Anglo-Saxon thoroughness, for Henry Farman is of British parentage, the new recruit set to work for a thorough training. A shed was built on the edge of the Issy-les-Moulineaux ground—the first of its kind—and for a whole month Farman scurried over the ground thoroughly familiarising himself with the handling of the machine. The first flight was made on September 30th, when a distance of about 90 yards was covered in a straight line.

For almost a month very little progress was made, the aeroplane never being able to remain in the air for a greater distance than 100 to 150 yards. The fault was that the elevation rudder was carried at too great an angle from the horizontal, and, as the machine rose in the air, it lost speed and fell. This was soon remedied, and on October 26th Farman made another record by a flight of 843 yards. On every possible occasion during the months of November and December Farman trained on the Issy-les-Moulineaux ground, making numerous modifications in the machine and familiarising himself with the handling of it. By January he was sufficiently skilled to attempt a complete turn, and on the 13th of that month called together the Commission of the Aero Club of France, in view of an attempt to win the Deutsch-Archdeacon prize of £2,000 for a circular flight of one kilometre.

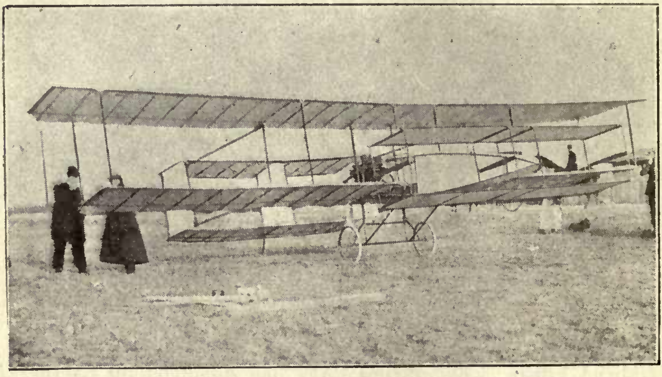


Fig. 62.—Kapferer's aeroplane (built by Voisin Freres) at Issy in 1907.

The conditions of the flight were that the machine should fly over a given line, 50 yards in length, follow an imaginary line at right angles to the starting line, rounding a flagpost 546 yards ahead, then return and recross the starting line. Obviously it was much more than a kilometre that must be covered, for the distance from the starting point to the flagpost and return alone equalled that distance. It was a perfectly calm January morning when Farman started up his Antoinette engine, and, after a preliminary soar, shot over the line, rounded the flagpost, and in 1min. 28sec. was back again at the starting point, the winner of the Deutsch-Archdeacon prize.

It was an epoch-making day, for those sceptics who had previously maintained that aeroplanes were huge jumping machines, capable of making wild leaps in the air, but were altogether incapable of a real flight, were silenced for ever. That circular flight of roughly one mile had proved to the world that the aeroplane was a practical machine.

Soon after the winning of the Deutsch-Archdeacon prize, Leon Delagrange returned to the Voisin biplane, and commenced training with such ardour that on March 14th he covered 328 yards; two days later he had covered twice that distance; towards the end of the month he began to attempt circles, and on April 11th won the Archdeacon Cup by a circular flight of nearly 2½ miles.

The first half of the year 1908 was a period of friendly rivalry between Farman and Delagrange, first over very short distances, then for comparatively long periods. Farman, whose long experience as a motorist stood him in good stead, and who also owed much to his regular methods of training, at first had the advantage, being able on several occasions during the month of May to make short flights with M. Archdeacon on board. While giving demonstrations in Rome, Delagrange took the lead by making a flight lasting 15min. 25sec., and on June 22nd, at Milan, remained in the air for 16min. 30sec. Had these flights been made in France, he would have been entitled to the Armengaud prize of £400 for the first machine remaining in the air not less than a quarter of an hour, which had been coveted by both aviators for several months. It remained, however, for Farman to secure this prize, and at the same time to break the flying record by a flight lasting 19min., on the evening of July 6th on the Issy-les-Moulineaux ground.

Up to this time the only other aeronaut in France who had made flights of any important was Louis Bleriot. Several types of machines had been constructed, but it was the No. 5, a monoplane modelled after Professor Langley's machine, which first proved successful. After this had made several short flights and been the cause of a sensational fall, it was abandoned for another type of monoplane, the Bleriot No. 8, embodying

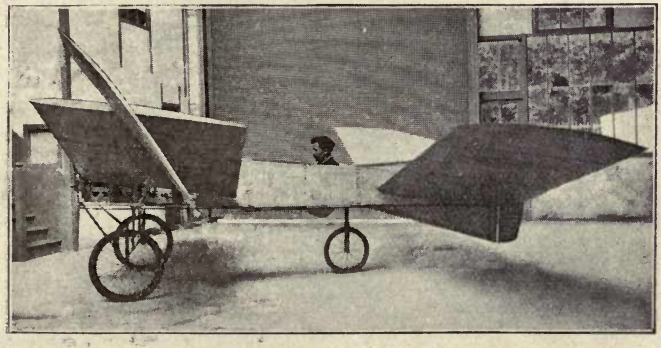


Fig. 63.—Bleriot's double-winged aeroplane of 1907. The angle of the ends of the forward planes can be altered.

Fig. 64.—*Capt. Ferber's later experiments at Issy in July, 1908.*

many of the ideas of M. Tatin, which proved to be the most successful monoplane then known in France. The morning that Farman won the Armengaud prize Bleriot made a flight of 8min. 24sec., his progress only being stopped by the failure of the pressure in the petrol tank.

Activity, however, was not confined to these three. But the score or so who were endeavouring to fly had not been able to realise anything more important than trips lasting a few seconds. In 1906 Vuia had left the ground on a monoplane for a distance of five or six yards, lengthened a year later to a flight of 60 yards; Robert Esnault-Pelterie flew as early as October, 1907; Comte de la Vaulx flew 60 yards in November of the same year; De Pischoff flew a kilometre on a biplane in December, 1907, and Gastambide-Mengin made his first flights with an Antoinette monoplane in February, 1908. Paul Cornu's helicoptere managed to rise from the ground to a height of about 16in. on

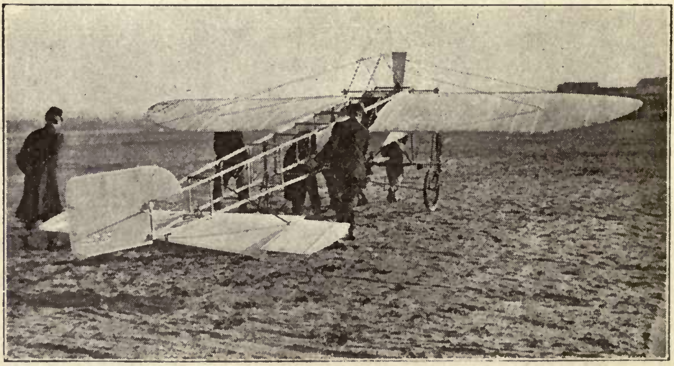


Fig. 65.—Bleriot No. II. at Issy.

March 16th, 1908, and the Breguet gyroplane, in July of the same year had attained a height of 14ft. and travelled a horizontal distance of about 20 yards. The success of the leaders had already attracted a host of experimenters and imitators, with the result that flying machines were being built and tested on all sides, not always with any degree of success.

The situation in France was entirely changed by the arrival of Wilbur Wright during the month of July, 1908, with the object of fulfilling conditions imposed by a syndicate of which M. Lazare Weiller was the head. The syndicate undertook to pay to Wilbur Wright the sum of 500,000 francs on condition that he made two flights of not less than 50 kilometres (31 miles) each with a passenger on board and sufficient petrol for a flight of 200 kilometres. The syndicate secured the sole rights to construct and sell the Wright type of aeroplane in France and her colonies.

Wilbur Wright made his first flight on the Hunaudieres racecourse at Le Mans on August 8th, 1908. It was the first time the machine had been brought out since May of the previous year, and, in view of his lack of training, the American aeronaut was content to remain in the air 1min. 45sec. It would have been a triumph for his detractors but for the fact that during those 105 seconds the machine readily rose to a height of 36ft. and described a couple of circles in a manner that was altogether unknown to Europe.

The flights were continued on the following days, and gradually lengthened, until, on August 13th, the machine remained in the air 8min. 13$\frac{2}{5}$sec. Naturally, these experiments had

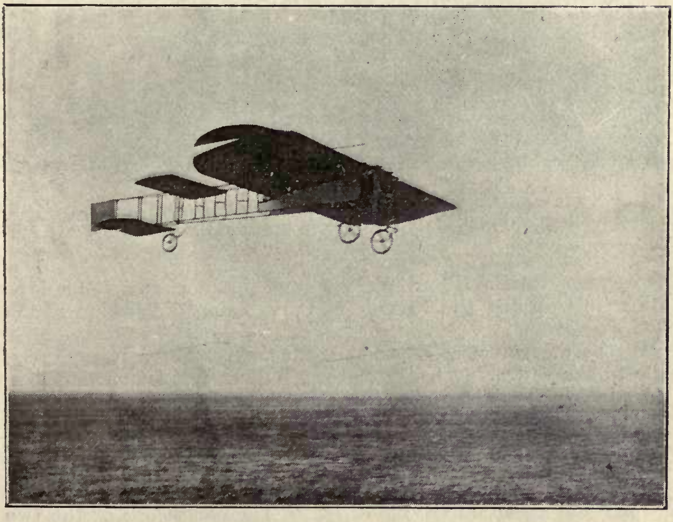


Fig. 66.—One of Bleriot's innumerable flights.

attracted enormous crowds of spectators, much to the annoyance of Wright, who had innocently imagined that, after the first two or three flights, he would be left to work alone. A removal was therefore made to the Camp d'Auvours, a vast pine-bordered plain about seven miles out of town, difficult of access and unused except for military manœuvres.

Almost immediately after the arrival at the Camp d'Auvours, the flights were lengthened, Wilbur Wright remaining in the air 19min. 48⅖sec. on September 5th, almost equalling the distance covered by Delagrange and Farman in the previous month. But there were still more important flights in store, and, after a soar of 2min. 20sec. with M. Ernest Zens as passenger, on September 16th, Wilbur Wright sent in his entry for the Michelin Cup and the Prix de la Commission d'Aviation of the A.C.F.

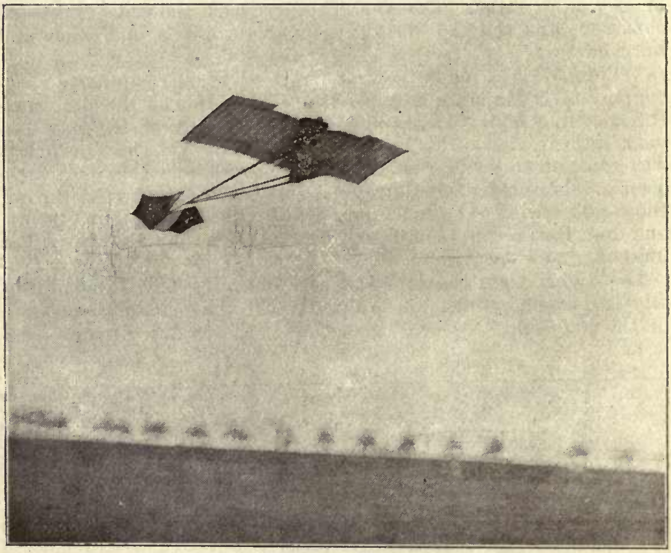


Fig. 67.—" La Demoiselle," Santos-Dumont's miniature flying machine at St. Cyr in the autumn of 1908.

In the afternoon of September 21st, after three false starts, due to the rail being badly placed, Wilbur Wright remained in the air for 1hr. 31min. 25⅘sec., thus creating a world's record for both time and distance, and provisionally securing the Michelin Cup and the Commission d'Aviation's prize. As he stepped from the machine amid the tremendous excitement of the mass of spectators gathered on the ground, he remarked: "That will cheer up Orville a bit." The conditions of the two prizes were that the flight should take place before sunset; thus

Wright was only credited with 19 rounds of the triangle, or a total distance of $23\frac{1}{2}$ miles. The actual distance covered, however, was more than 55 miles, equal to three times the crossing of the Channel from Calais to Dover. That this could have been considerably lengthened was shown by the fact that only $4\frac{4}{5}$ gallons of petrol out of a total of 11 had been used, and but three pints of water had been lost out of the radiator containing $2\frac{1}{4}$ gallons. On September 24th another attempt was made for the Michelin trophy, with the result that the official distance was carried from 38 to 39 kilometres (24 3-10 miles). The total distance, however, was less than on the previous occasion, the flight having to be arrested owing to the rising wind and the invasion of the ground by over-eager spectators. Four days later the distance for the Michelin Cup and Aviation Commission's prize was increased to 48 kilometres 120 metres (30 miles), this latter being won outright, and on the same day Wilbur Wright took a passenger for the second time, flying for 11min. $35\frac{2}{5}$sec. with M. Paul Tissandier by his side. Finally a flight of 7min. 45sec. was made with Comte de Lambert.

On October 3rd, after certain modifications to the machine, and interesting demonstrations of flying so low that the runners touched the top of the heather and coarse grass of the military ground, Wilbur Wright invited Franz Reichel, the representative of the "Figaro," to fly with him. Although the sun had set when the flight began, the machine did not settle down again until 55min. $32\frac{1}{5}$sec. later, thus creating a new record for flights with a passenger on board. On October 4th this record was broken by a flight of 1hr. 4min. $26\frac{2}{5}$sec., with M. Fordyce on board, and on October 5th this record in turn was beaten by one of 1hr. 9min. $45\frac{2}{5}$sec., the passenger being M. Painleve.

In view of the remarkable results obtained by Wilbur Wright, French aeronauts had almost ceased to exist for the general public, and it needed the remarkably daring trip of Henry Farman on October 30th to prove that the American was not the only man who knew how to fly. Farman, who had been

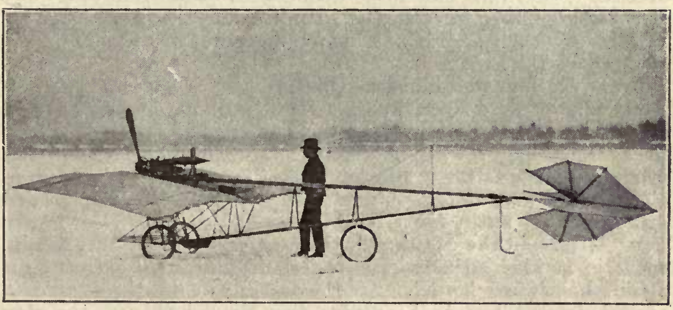


Fig. 68.—The snow-covered plain at Issy in the winter of 1908-9, when Santos-Dumont continued his experiments with "La Demoiselle."

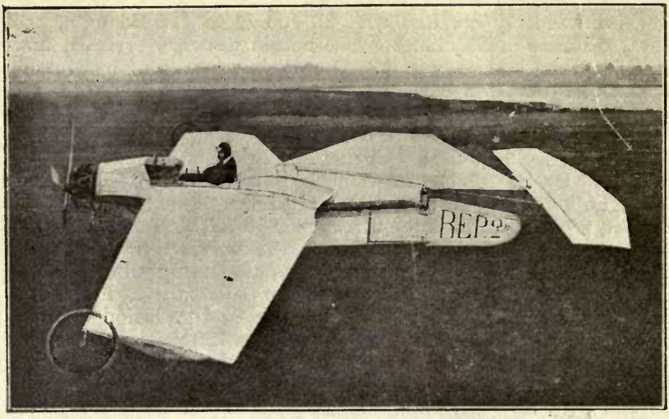


Fig. 69.—The R.E.P. aeroplane "2bis." Mr. Esnault-Pelterie is an advocate of the monoplane.

training for some time on the vast plain near Chalons, started a little before four o'clock on a cross-country flight, his destination being Rheims, about 17 miles away. The machine, the one which had won the Deutsch-Archdeacon prize in January, was immediately carried up to a height of over 130ft., in order to be absolutely certain of clearing the tall poplar trees, telegraph wires, and other obstacles. In a few minutes the aeroplane was lost to sight, and was not long in getting clear away from the motorcars which attempted to follow it. Exactly 20 minutes from the time he started, Henry Farman descended on the military ground just outside the city of Rheims, having made the first cross-country flight at a speed of 45 miles an hour, and at an average height of 130ft. It had been intended to return in the same manner, but, owing to certain adjustments being necessary, this idea had to be abandoned. The following day Farman competed for the height prize of the Aero Club of France, and succeeded in passing over a couple of balloons placed 80ft. above the ground.

Louis Bleriot, who alone had been devoting attention to the monoplane type of flyer, was not to be outdone by the Farman exploit, and, on October 31st, set out on a round trip from Toury to Artenay and return, a distance of about 19 miles. The machine used was the "Bleriot VIII.," equipped with a 50h.p. eight-cylinder Antoinette engine. In 11min. the machine passed over Artenay, but a few seconds later had to descend owing to irregularities in the working of the magneto. After 1hr. 30min. spent in making adjustments, the monoplane went into the air again, homeward bound. After covering about three miles a second descent had to be made; this time, however, the stop was only of a few minutes' duration, and, on going up again, the machine flew remarkably well until it reached its starting-point, where a descent was made. The first round trip across country had begun at 10.5 a.m. and ended at 5 p.m. A few days later, while making trials near Toury, the Bleriot monoplane was smashed through striking a hillock when running over the ground at high speed. The pilot, who had had more tumbles than any other aeronaut in France, fortunately escaped with his usual good luck.

The last flying competition in 1908 was for the Michelin Cup, to be awarded to the aviator making the longest flight during the year. Since his cross-country flight, Henry Farman had considerably modified his machine, with a view to beating Wright's record for the Michelin prize. Several different makes of motors were tried, whilst the structure of the aeroplane was also changed, the most important modification being the addition of another plane making the machine a triplane. It was impossible, however, to make the aeroplane as satisfactory as the Wright apparatus, and, although Henry Farman made some clever flights towards the end of the year, he never seriously threatened Wilbur Wright's supremacy. Early in January Farman sold his aeroplane to an Austrian syndicate, and, having broken with the Voisin Frères, commenced business as an aeroplane constructor on his own account.

Although Wilbur Wright practically had the field to himself, he did not in the least relax his effort to make a record flight. On December 18th he covered an official distance round a triangular course of 99 kilometres (61½ miles), his time in the air being 1hr. 53min. 59⅗sec. The actual distance covered was not less than 75 miles, and his actual time 1hr. 54min. ⅖sec. On the same day Wilbur Wright competed for the height prize of the Aero Club of France, the minimum for which was 328ft. Although a strong wind was blowing, this was won with ease, the small balloons being passed with a good margin, the actual height being given as 377ft. Even this did not satisfy the American aeronaut, and he declared he would try again the next day, but was prevented by rain.

As if afraid that the Michelin trophy would escape from him at the last moment, Wilbur Wright made another attempt to beat his own record on the last day of the year, and admirably succeeded. Well wrapped up to withstand the biting breeze—for the thermometer was at freezing point—the aeroplane left its rail just after two o'clock, and did not settle down again until sunset, having remained in the air 2hr. 20min. 23⅕sec. His official distance for the Michelin Cup was 123 kilometres 200 metres (76½ miles), while the actual distance covered was estimated at 93 miles.

THE MILITARY VALUE OF AIRSHIPS AND AEROPLANES.

Imagination necessarily playing the chief part in criticism of any new and untested force, we always get extremes. The truth as to the potentialities of the airship and aeroplane in war probably lies midway between the popular novelist's high-coloured pictures of uncontrolled—and uncontrollable—carnage and devastation, and the unimaginative, placid citizen's belief that comparatively little danger can come from the air—at least for many years. The latter is ignoring the lessons of the motor's remarkable progress and modern military utility, the equally rapid developments in air craft and the significant competition among continental military powers for machines: the former is ignoring the lesson taught by history that new weapons of destruction are always curbed by nearly corresponding improvements in defensive armaments. Brain combats brain, thus

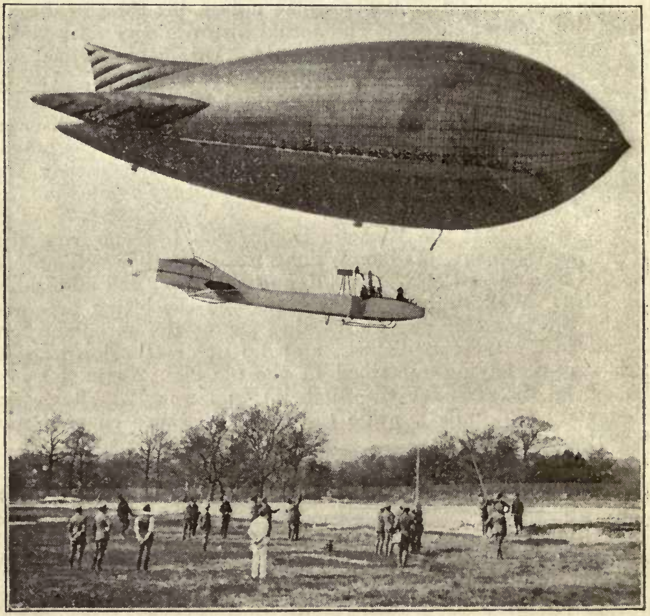


Fig. 70.—"Baby," the War Office dirigible made in the spring of 1909.

equalising matters. The future will probably prove the aeroplane's propensities for death-dealing to be as capable of limitation as the torpedo's; it will also prove that all such appliances are two-edged!

Whatever happens, a nation's war strength will continue to be measured by its financial resources—its capacity to keep ahead of its rivals in regard to the number and quality of new destructive engines; war could only reach the height of unrestrained holocaust portrayed by the novelist if a nation were powerful and rich enough to make a "corner" in any new and secret murderous machine—though it is more probable that this would mean the end of bloodshed, either because any such country could dangle its diabolical invention, like the sword of Damocles, over the heads of its rivals and exact any terms it chose, or because all other nations would combine to prevent the use of such a weapon. The alarmist may rest assured that the airship and aeroplane do not come within this category.

Probably the greatest misconception exists in regard to invasion viâ the air. A German councillor has gone so far as to state in public that a fleet of airships could land an army of 100,000 men on the Kentish coast in half-an-hour. Some 30 men can be carried on a Zeppelin airship, so that over 3,000 of

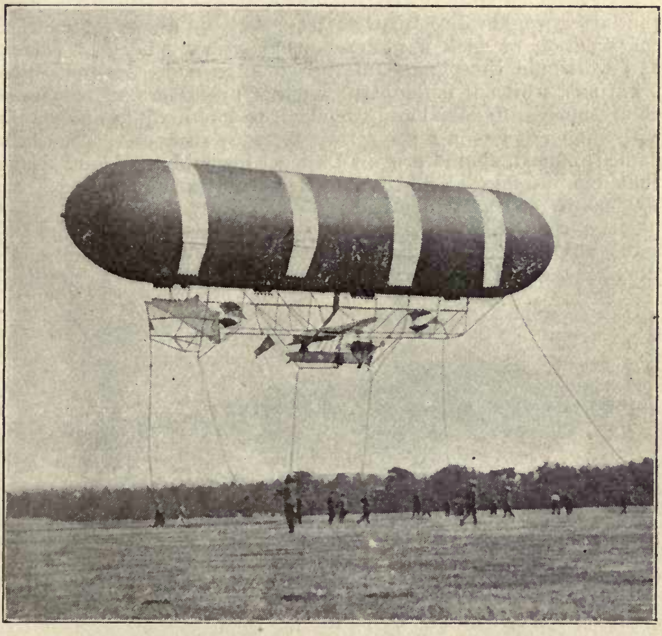


Fig. 71.—Dirigible No. 1 (the ill-fated "Nulli Secundus") of the British Army.

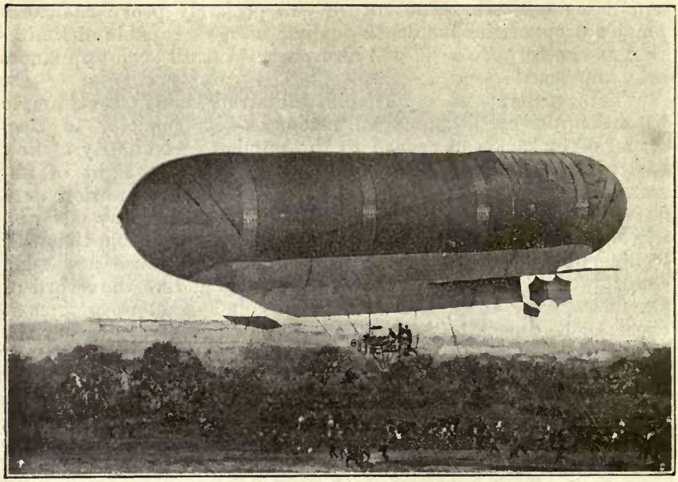


Fig. 72.—The rebuilt and enlarged "Dirigible No. 1."

the latter would be required to transport the above force. The construction of such a number could scarcely be kept secret, and we would thus have time in which to make adequate preparations, whilst it is doubtful whether even Germany possesses the resources, financial and chemical, to build, equip and supply with sufficient gas in a short time so many machines. The last-named, indeed, should prove an almost insoluble problem, seeing that one airship of the above type requires anything from 350,000 to 400,000 cubic feet of gas. But a more important point is that only an airship of such size as to be almost unmanageable in bad weather could take heavy supplies and munitions, or guns of any size; and without ample cavalry or artillery

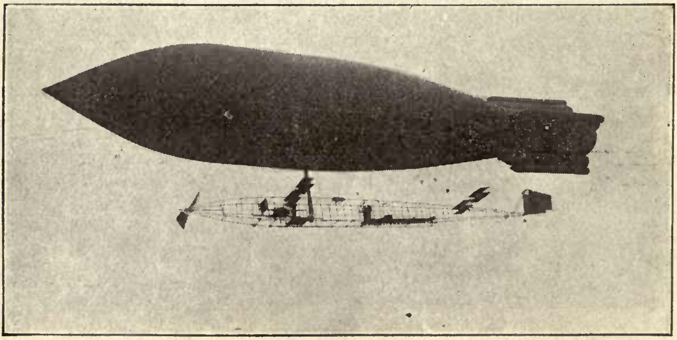


Fig. 73.—The "Ville de Paris" attached to the French Army.

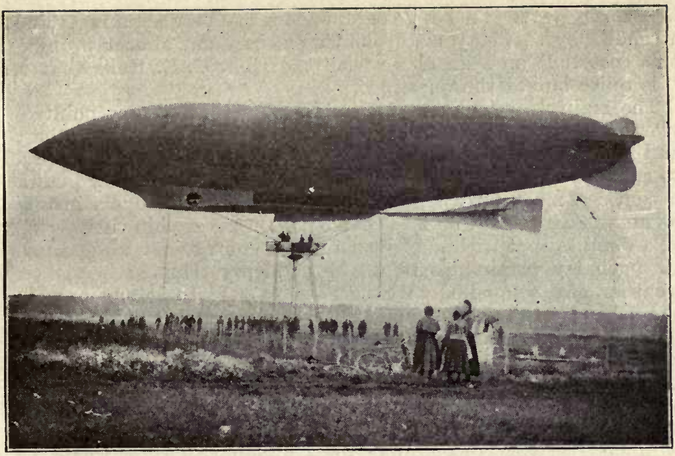


Fig. 74.—" La Patrie," the dirigible which, in 1907, was blown away into the Atlantic.

an infantry force of the strength mentioned would be dangerously handicapped in a strange country—if not comparatively useless. Machine guns might be brought over; indeed, one of the latest French airships is fitted with two guns of the Hotchkiss type; but they lack the range and moral effect necessary to cover the advance of infantry. Invasion by airship would

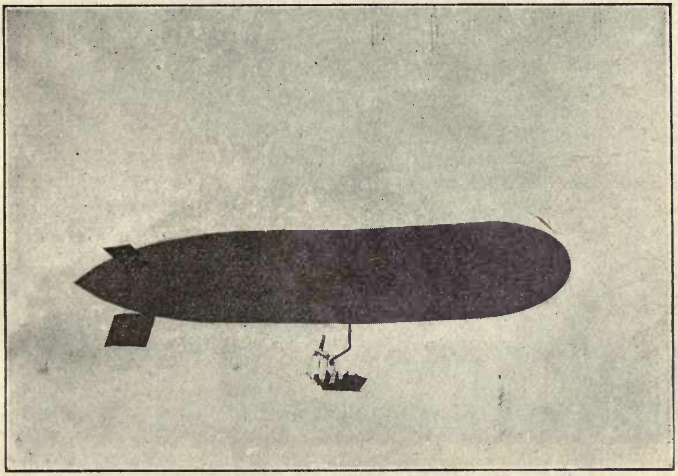


Fig. 75.—The new Parseval dirigible.

in short, prove to be so stupendous an undertaking, and attended by so many risks, contingencies, and almost prohibitive cost that one can agree with the Hon. C. S. Rolls that it "is quite out of the question."

The main drawback to the airship from the military point of view is that it cannot be implicitly relied upon in all weathers and under all circumstances. This terrible uncertainty would, to some extent, put all commanders on a level; military genius becomes a mockery when one is at the mercy of one's instruments. There could be no dependence on an airship turning up at a definite spot within a given time; a commander whose main strength lay in airships might be suddenly crippled in violent weather and compelled to capitulate to a force strong only in the field. Military commanders might shun such machines, preferring to put their trust in the unmatchable resource, adaptability and intelligence of human beings. Air craft will be indispensable adjuncts to an Army, but of secondary importance only. The construction of gun carriages that will admit of fire almost up to the zenith is only a question of time, and, properly equipped in this respect, our forts and naval bases would be able to bring such a sustained bombardment to bear on any hovering airships as to make the latter's position absolutely untenable. The failure of recent experiments of this kind at Gibraltar need cause no uneasiness; for much better results

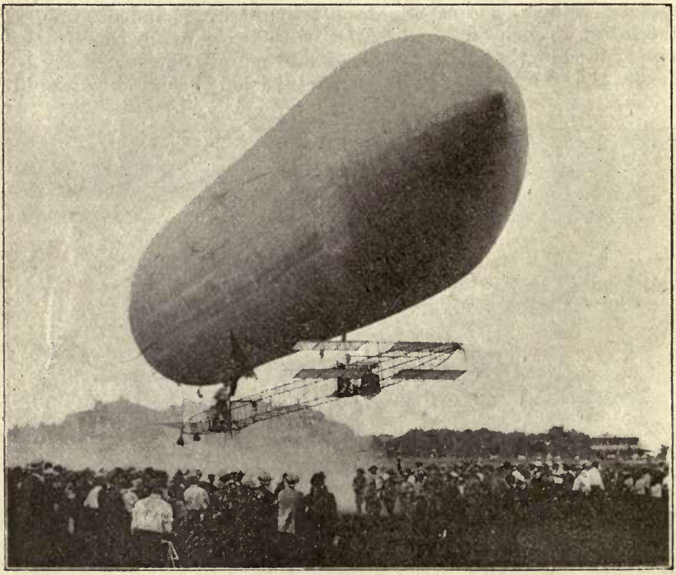


Fig. 76.—The Baldwin dirigible attached to the American War Department.

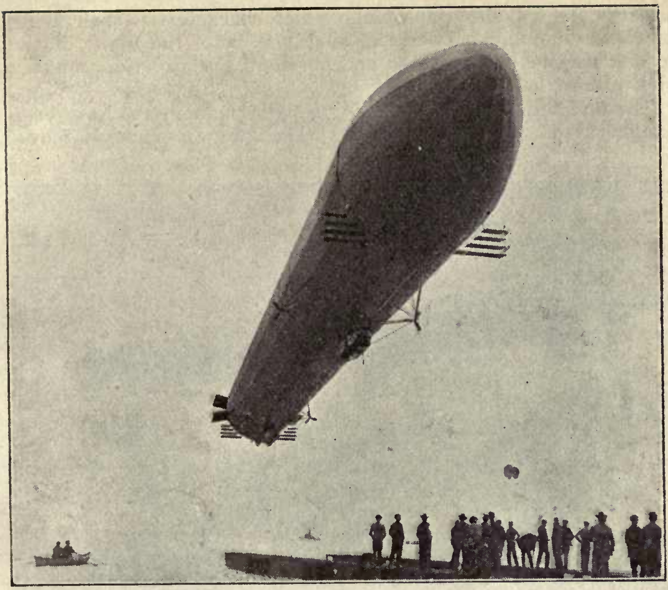


Fig. 77. – The Zeppelin airship manœuvring before the Kaiser.

have been obtained in France and Germany, and Rear-Admiral Sir Percy Scott is said to have all but solved the question.

For serious offensive purposes the airship can rely on no greater degree of accuracy than is to be attained in the dropping of explosives, which needs no little practice. But buildings and thoroughfares cannot be readily recognised from a height, and to aim with certainty an airship would have to approach comparatively close to the earth and hover above its objective for a few moments—which might prove fatal if picked marksmen were on the look-out in favourable positions. There is a doubt, moreover, whether an airship can always be got in a position exactly over any comparatively small spot and at the necessary height, and, as magazines are usually situated in obscure and isolated spots it would be not only difficult to locate them, but their destruction would involve little more than a monetary loss; for we do not station soldiers in magazines, and the chief constituent in the latter, cordite, merely burns away with a sort of fizz, so long as it is not rigorously confined. Sir Hiram Maxim has pointed out that an added danger for those on land will be from the falling shells fired at airships; but to balance this we have Captain Tulloch's very pointed reminder in the " Nineteenth Century " that explosives exert their force upwards, thus constituting a very real danger to the airship that drops them! It is doubtful, however, whether our garrison gunners will ever be able to exhibit the mathematical accuracy towards the travelling aeroplane which characterises their firing at rapidly-moving battleships, simply because the flight of the former may be both vertical and horizontal in direction, making of it a most baffling target.

The possibilities of the airship on night manœuvres have been exaggerated. It could place no check on an enemy's movements, seeing that only the darkest nights are chosen for surprise attacks. Under such circumstances it would neither be able to observe and report the operations nor to make a counter-attack. If all lights on land were extinguished it would have nothing but a compass to rely on. On the other hand, it would be clearly visible against the sky on a moonlight night, and thus a positive source of danger to its main force. The one great disadvantage of the airship in actual campaigning is that it would disclose the whereabouts of an opposing force, and the direction it was taking. Even on the blackest nights, powerful electric searchlights could sweep the sky and disclose the position of any hovering airships. When certain developments have taken place in regard to the former, another check will have been placed on the destructiveness of airships. The latter will supplement railways for the more direct conveyance of dispatches, members of the staff, special supplies, and so on, but will never supplant them. For airships will be unavailable for heavy goods, and they will be too dependent on weather conditions, and for this reason they can never equal the railways or motor when the rapid concentration of troops at any given point is desired.

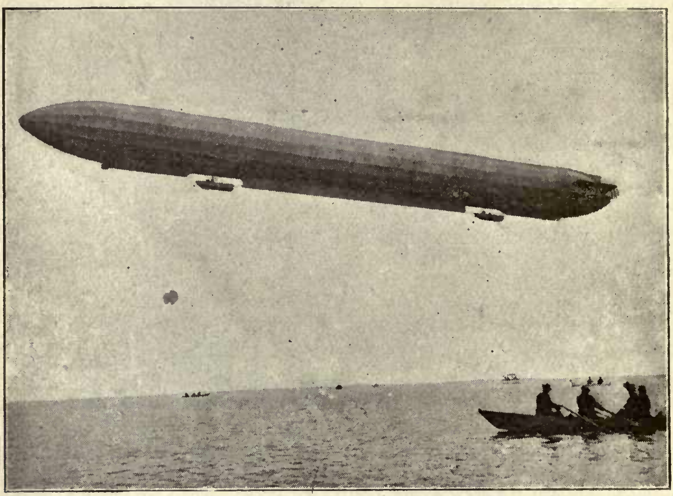


Fig. 78.—The Zeppelin over Lake Constance.

No one will dispute for a moment the airship's utility for reconnaissance work, observing the effects of artillery fire, photographing positions, making rough maps of the country, and so on; but the military captive balloon has answered all these purposes for over a hundred years, and the airship has the same limitations, namely, fairly calm weather is essential for making careful observations, and in a very mountainous country the range of outlook is restricted, for if the reverse slopes of hills be steep they can effectually conceal an enemy's position. The difficulty of communication has also yet to be satisfactorily solved, for, unless airships can be relied on to keep in direct touch with headquarters, and, perhaps more important, with one another, the commander must leave them entirely out of his calculations as being irresponsible and useless. Wireless telegraphy will in due time doubtless step in here with complete success, though it is claimed that the aeroplane is not so well adapted for the installation as the airship, and that even in the latter case there is some risk of fire. The latter's superiority over the aeroplane in yet another military requisite is worthy of note, for it can in certain circumstances rise direct from an enclosed space, descend at any desired spot, and manœuvre more easily.

The airship and aeroplane bid fair to revolutionise gunnery, musketry, and even the uses of cavalry, in the future. There can be no forecasting the composition of the army of the future —supposing such things are still in existence. Nor, apparently, would the present-day rules of strategy answer. For commanders will have to take the weather into consideration, as being an additional weapon to use against airships, to an extent hitherto undreamed of. Campaigning may consist of protracted manœuvring, mere dilly-dallying so as to ensure that battles are fought on days when the climatic conditions place the enemy's airships at a grave disadvantage. A snowstorm, which will practically kill an airship, will be one of the few occasions when contending armies will have an equal chance.

The real war value of airships lies, as Captain Tulloch has graphically portrayed, in their unlimited capacity for incendiarism. With everything carefully mapped out beforehand, they could operate over dense commercial districts and harbours, where untold stores of combustibles, such as oil, timber, and gas could be found. These are also, in regard to population, the most congested centres; and it needs little imagination to picture the black ruin, desolation, and mad, reckless, fatal panic that might be brought about in a few short hours by a group of airships in skilful, determined hands. Mr. H. G. Wells has driven this truth home with ghastly realism in his vivid description of the destruction of New York in "The War in the Air." "As the airships sailed along they smashed up the city as a child will shatter its cities of brick and card. Below, they left ruins and blazing conflagrations and heaped and scattered dead." In the same book he anticipates, too, the recent remark made by Lord Montagu of Beaulieu at the Mansion House, to the effect that "the little island in the silver seas" is near the end of its immunity, its insularity. To make that good by the establishment of a two-power standard in airships is the only solution of the problem for politicians. There is only one way in which a great city can hope to escape wholesale destruction under the above circumstances, namely, by levelling all its fortifications and withdrawing its troops; for according to the Law of Nations no unfortified and undefended town should be bombarded; but history proves that rather than suffer such a blow to their patriotism and pride the inhabitants of a beleaguered town will endure anything.

In conclusion, it may be said that airships will probably prove of greater assistance in naval than in military warfare. For it is common knowledge that when one is over the sea at some altitude with the water smooth it is usually possible to see to the bottom, and thus the presence of mines and submarines could be detected and reported. Airships could serve as eyes and signal-stations to a fleet, as guides in long-range bombardments, and as pilots in low-lying fogs.

A figure carved on the tomb of Rameses III. in the Louvre Museum, Paris.

DIRIGIBLE BALLOONS.

The Zeppelin Airship.

The Zeppelin airship comes within the category of rigid dirigibles. No matter whether deprived of the lifting gas or not, its contour remains unaltered, determined, as it is, by an aluminium framework, or skeleton, covered by an outer skin. Apparently cylindrical in form, with obtuse cones fore and aft, the airship is really a 16-sided prism, the framework consisting of a series of polygonal rings, trussed from stem to stern, and kept severally expanded by steel wires, which, starting from each angle of the polygon, converge on a small central ring, just as the spokes of a wheel concentrate in the hub. Each polygonal ring, therefore, possesses 16 converging stays or, to preserve the wheel metaphor, as many spokes. From the inside ends of the longitudinal trusses, which also number 16, cords of ramie stretch from ring to ring, and form a network separating the lifting power from the outer skin.

The source of lifting energy is hydrogen gas, enclosed within 16 separate cells, 12 in the cylindrical section and two in each of the forward and after cones that constitute the stem and stern respectively of the airship. This separate-cell system is a distinctive characteristic of the Zeppelin. The Count, it may be observed, was the first to place separate gasbags inside a rigid frame. Destruction of any one cell, consequently, does not necessarily involve the collapse of the airship.

Between gas-cells and outer skin there is, as stated above, an air-space, which plays an important part in the system, namely, to counteract the effects of varying temperature on the gas, air, as every student of physics knows, being an extremely poor conductor of heat. Naturally, the counteraction is only one of degree. The Zeppelin, with its metallic framework and more or less rigid skin, always presents a good steering surface, its form being altogether independent of the state of the gas-cells—a point noted in the opening sentence.

The weight of the framework and inter-connections makes it absolutely necessary that the airship should have large dimensions. "Zeppelin I." measures 446ft. in length, and has a diameter exceeding 38ft., the volume working out at some 12,000 cubic metres, or 211,900 cubic feet. On the other hand, thanks to the low conductivity of the air-space between the cells and frame-cover, the density of the gas is less affected than in the case of dirigibles constructed on other principles. Hence, the aeronauts need less ballast as such, although this advantage becomes neutralised by the airship's huge dimensions, which necessitate the carrying of more fuel.

With the object of stiffening the frame, Zeppelin has added a keel, of triangular cross-section and covered with rubbered

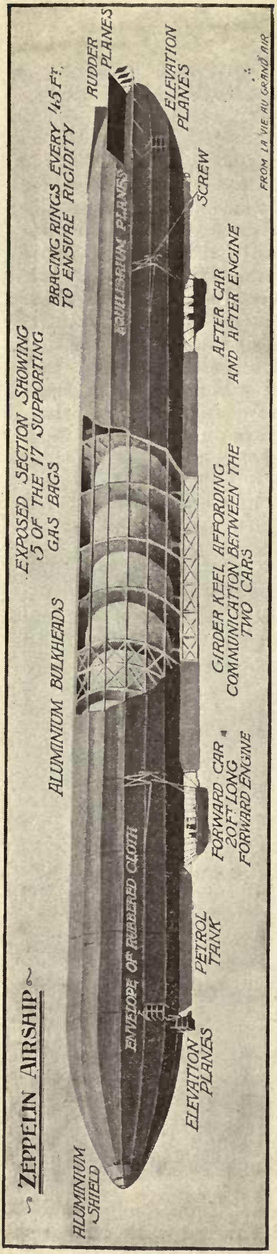


Fig. 79.—The Zeppelin airship and its constructional details.

cloth to reduce resistance. About a fourth of the whole length from each end the keel is interrupted to admit of attachments for two boat-shaped cars of aluminium and steel tubing, connected by a gangway containing, amongst other things, a wagon, which runs on rails and can be hauled to and fro by wire cable, for preserving equilibrium. The cars have pneumatic shock-absorbers underneath. Each car is over 26ft. in length, and hangs within 7ft. of the outer skin, a proximity tending to obviate oscillation.

"Zeppelin I." has two sets of horizontal-steering planes, fixed high up, towards the middle of the stern cone, at the rear end of two laterally-placed steadying planes, and operated from the cars through an ingenious arrangement of gear, wire and wheel. Each set consists of three parallel planes of about 43 sq. ft., hanging, like ship's rudders, almost perpendicularly to the large steadying planes, each over 300 sq. ft. in area. The frames of steering sets and other planes are composed of aluminium rods, over which canvas is stretched, wires holding the surfaces in position.

Change of altitude is effected by means of two pairs of plane-sets, the one forward and the other astern, each set being made up of four parallel planes, attached laterally, just over the keel, to the first ring of the cylindrical section. Of course, their planes of position are identical with that of the airship's axis, or at a tangent with the body. As each of the parallel planes terminates outwardly in a line with the others of the same set, they differ in length, being shorter according as they approach the centre of the balloon's transverse curvature. The pairs can be worked alone or together. They have severally an area of about 240ft. Turned aslant, they act like a kite, the airship gliding upwards or downwards as their position may determine. With these altitudinal planes, in fact, the ship can rise dynamically under the power of its propellers; in other words, it can rise in spite of being at the time somewhat heavier than air, like an aeroplane. Two four-cylinder engines of 85h.p. each supply the propelling power, which gives the monster an independent velocity of over 30 miles an hour. Its propellers are four in number, resting on supports fixed to the framework of the cylindrical section and high above the two cars, one on each side. They are three-bladed, about 10ft. in diameter, and act at a point where they can be most effective. Power is transmitted from the motor through bevel gear, propellers and motors corresponding in revolutions per minute.

The French Airships.

The first really successful airship in France was appropriately named "La France," and was designed and constructed by the late Colonel Renard and Commandant Krebs. Starting from the military establishment of Chalais-Meudon, in the suburbs of Paris, on August 9th, 1884, "La France" sailed a distance of several miles to the intersection of the Versailles and Choisy-le-Roi road, described a circle, reversed, and went through various manœuvres, then returned to its starting point in safety, the return journey of five miles being made in 23 minutes.

Santos-Dumont was the first in France to adapt the petrol motor to a balloon. His early attempts may be passed over, for it was not until No. 5 was produced that anything like success was achieved. This was a long, small diameter balloon, 111ft. in length, but of only 19,000 cubic feet capacity, to which was

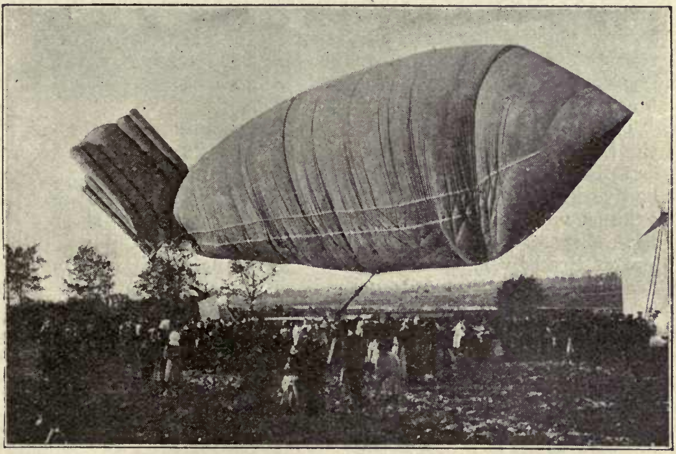


Fig. 80.—A loss of symmetry! Deflation of "La Ville de Paris.'

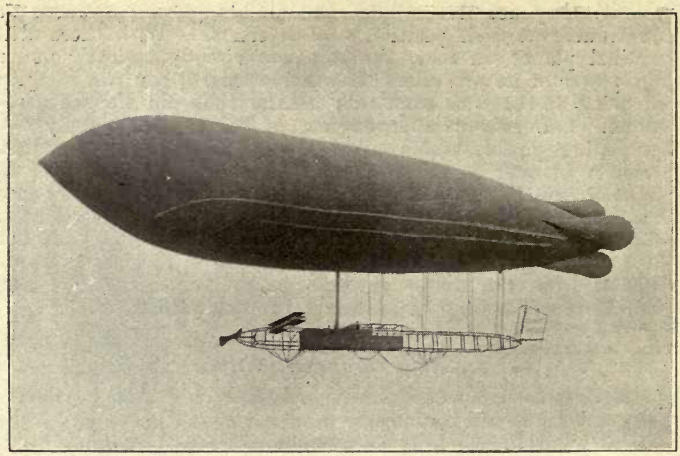


Fig. 81.—"Clement-Bayard," a very successful ship.

attached a rough sort of platform receiving a four-cylinder 16h.p. petrol motor driving a large propeller. The accommodation for the pilot was very mean, there being no car properly speaking, but merely a bicycle saddle, with two pedals as on a motorcycle, allowing the engine to be started up. It was a delicate construction, and needed the audacity of a Santos-Dumont to mount it.

The first important experiment was made on July 12th, 1901, when the airship went up from St. Cloud, crossed over the Seine, and came down on Longchamps racecourse less than a mile away. On October 19th of the same year Dumont successfully rounded the Eiffel Tower on his No. 6, returning in safety to his starting point at St. Cloud, the winner of the Deutsch de la Meurthe prize of 100,000 francs.

There was a temporary set-back to the airship movement by the fatal accidents the following year to "Pax," piloted by the Brazilian Severo, and to the Bradsky airship. "Pax" was badly designed in respect to the position of its motors, the exhaust valve of the envelope being so near to one of the motors that a mass of gas formed outside the balloon and was fired. Baron Bradsky, who used a non-rigid type of airship, met his death, together with his companion, by the car breaking away from the balloon when sailing over the suburbs of Paris.

Black as was the year 1902, it was nevertheless the starting point of the practical airship movement in France, for at the end of that year the Lebaudy dirigible was produced, and made more than 50 journeys between October, 1902, and November, 1903, when it was wrecked by colliding with a tree during landing operations in a heavy wind. This was followed by "Lebaudy I.," even more successful than the first one, and which served as a model for future military airships, among others the famous

"Patrie." "La Republique," now placed at a station on the eastern frontier, was the direct successor of "La Patrie."

The French have never favoured the rigid type of balloon, all their present airships being of either the semi-rigid or of the non-rigid type, "La Patrie," "La Republique," and "La Democratie" belonging to the former class, and "La Ville de Paris" and "Clément-Bayard" to the latter. The semi-rigid type is stiffened by the use of a metal keel, which at the same time serves as an attachment for the car that carries the engine and passengers. In the non-rigid type the shape of the balloon is maintained entirely by the pressure of the gas within the envelope, no metal being employed at all. The objection put forth against the semi-rigid type is that the long keel makes a descent difficult, if not impossible, except under favourable conditions. The pilots of "La Patrie," for instance, it is said, hesitated to let the gas out of their balloon when it was in danger merely because it was of the semi-rigid type; had it been non-rigid, it might still have been in existence.

Fig. 82.—Forward framing and tractor screw of "Clement-Bayard."

One of the best examples of the non-rigid type of balloon is "Clément-Bayard," a description of which will suffice also for "La Ville de Paris," "La Ville de Bordeaux," "La Ville de Nancy," etc. Being 185ft. in length, 35ft. greatest diameter, with a cubic capacity of 124,000ft., "Clément-Bayard" is a big balloon, though small in comparison with the huge Zeppelin. The envelope, or gas bag, is of rubbered cloth, the qualities of which must be light weight with the greatest strength, together with an ability to hold such a light gas as hydrogen for the greatest possible length of time.

Within the outer envelope is a small second bag, or ballonet, which is filled with pure air maintained at a certain pressure by means of a pump worked by the engine. Both the main gas bag and the ballonet are fitted with automatic valves opening when a certain pressure is attained. The valves allowing the hydrogen to escape are at the rear of the balloon in order to prevent any danger of this gas accumulating in the region of the motors. The valves in the ballonet open under a much lower pressure than those of the gas bag proper. When the balloon mounts in the air the expanding gas, being unable to stretch the envelope, seeks an escape. The same applies to the air in the ballonet, and under the pressure the automatic valve opens, allowing some of the air to escape, decreasing the size of the ballonet, and giving greater space for the hydrogen gas. When the ship descends the contrary takes place, the hydrogen gas contracting to such an extent that the balloon is in danger of losing its rigidity. This is prevented, however, by more air being pumped into the ballonet, thus constantly maintaining the rigidity and form of the balloon. This contraction and expansion with difference in volume of the ballonet is constantly going on, the volume of the gas being effected not merely by altitude but by the condition of the weather, a hot sun expanding the gases, while passing under clouds causes contraction. In "Clément-Bayard" the balloon valves open under a pressure of 40 millimetres of water, the ballonet valves opening under a pressure of 30; the valves can also be controlled by hand.

At the tail of "Clément-Bayard" are four cylindrical gas bags, two at each side, one above and one below, and all communicating with the main gas bag. The object of these additions is to give longitudinal and horizontal stability. It will be noticed that the greatest diameter of the balloon is not at the centre of its length, but some distance further forward. This is necessary because of the fact that under the pull of the propeller the balloon has always a tendency to lift its nose in the air, this tendency being capable of increasing until the machine capsized, as once happened with Henry Giffard. The four cigar-shaped additions assure stability to the airship in both directions, correcting the tendency for the balloon to lift its nose in the air and at the same time suppressing all roll.

The car on a modern balloon is generally a steel structure, the size depending on the work for which the airship has been built. Thus on "Clément-Bayard," an aerial pleasure craft, it is much longer than on "La Republique," a fast war cruiser. The engine of "Clément-Bayard" is a 120h.p. racing car model carried on a chassis which is attached to the framework by semi-elliptic springs in order to reduce vibration to a minimum. The propeller is placed at the front, as on practically all the modern French balloons, and is geared to turn at 300 revolutions with the engine running at 1,200 revolutions. The vertical rudder is composed of two parallel steel planes having a total surface of 172 sq. ft. The airship has, in addition, a horizontal rudder composed of three superimposed planes at the front of the steel car.

A type of dirigible balloon that has recently become popular in France is known as the Zodiac. It is a small airship capable of carrying either two or four passengers, and so designed that it can be readily deflated and packed with much more ease than a "Clément-Bayard." Naturally it is of the non-rigid type.

PILOTING A VOISIN AEROPLANE.

It would be an exaggeration to say that anybody can drive a Voisin aeroplane, but it is not going beyond the confines of truth to declare that any sportsman, especially a man familiar with motoring, cycling, ballooning, or yachting, can learn to fly in half-an-hour. The designers have made their apparatus as automatic as possible, trying to eliminate the human element, and thus giving the machine the maximum of security.

Consider what happens when a flight is made. The pilot has taken his seat behind the steering wheel, the engine has been started up, and the attendants are holding the apparatus, which threatens to drag them along with it over the ground. Having given a little more gas and advanced the spark, you raise your hand as a signal to those in the rear that you are ready. The men release their hold and you are off, running over the ground at a speed that soon increases to 30 miles an hour. Of course, there is a right and a wrong way to start, or rather one right way and many wrong ways. The correct manner is to have your machine with its nose in the wind, if any wind is blowing, and the front edge of the elevation rudder pointing upwards, this position being obtained by pulling the steering wheel towards you. The object of raising the rudder at the start is not to rise in the air immediately, but to prevent the machine falling on its nose. Before the aeroplane has run a dozen yards over the ground the tail will have lifted and the machine will be running on its two front wheels only. In such a condition, if the elevation rudder were kept in a horizontal position, the tendency would be for the tail to overbalance the front portion and bring the machine to a brusque stop by falling on its nose.

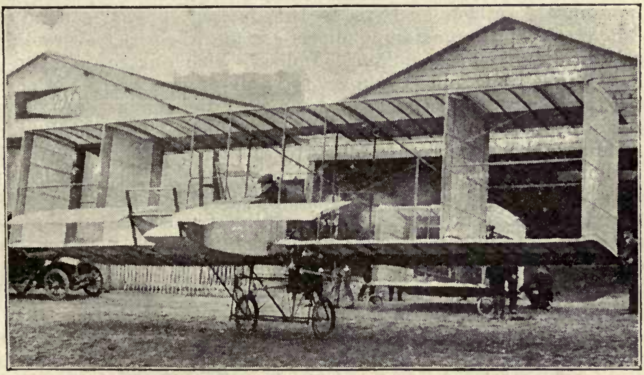


Fig. 83.—Mr. J. T. C. Moore-Brabazon on his Voisin aeroplane at Issy, November, 1908.

As the aeroplane gains speed it will rise from the ground. You may not know at exactly what moment the wheels cease to touch, but you are very soon aware of a very different sensation, an almost indescribable sensation, in which the feeling that you have got rid of a lot of superfluous weight is uppermost. You realise that some invisible force has lifted you clear of the ground, and the change is so great that you almost imagine your legs had formerly been trailing on the ground and had now been lifted into still air. For there is also this difference: that, whereas 30 miles an hour on the ground seemed a giddy speed, the same rate of travel in the air is very gentle motion. With the ground several feet away and no objects near at hand to indicate speed, the sense of motion is almost lost.

But it is necessary to pay attention to the control of the aeroplane, or the gentle sailing motion will quickly transform itself to a rough encounter with the ground. As soon as the apparatus has got clear of the earth, the angle of the front elevation rudder must be diminished, for, in its inclined position, it is offering resistance and, if maintained in this position, will diminish speed to such a degree that the aeroplane will rapidly fall. Therefore, push the steering wheel slightly forward, so that the front edge of the rudder is only slightly pointing upwards; this will still allow you to rise without offering the same resistance to forward direction as formerly.

One of the difficulties of all learners is to understand that the movements must be made gently, even leisurely. Unlike the motorcar, which responds immediately to a touch of its steering wheel, the aeroplane answers very slowly. In this respect, the control is much more like that of a sailing yacht than an automobile, a turning movement beginning gradually, increasing in strength and falling off gradually. On the ground there is a somewhat violent pull on the steering wheel, but, as soon as the aeroplane gets into the air, a very gentle pressure is exerted on the horizontal plane and, in consequence, the effort required of the pilot is very slight. The plane is placed in a horizontal position as soon as the desired height is attained, but, even then, no attempt must be made to correct every slight oscillation of the aeroplane. Indeed, with our present knowledge, it is impossible to do so, for a manipulation of the elevation rudder to correct a slight downward dip, for instance, would certainly come too late to be of any effect. The point to remember, therefore, is to operate the front elevation rudder without any brusqueness whatever. Emphasis has been laid on this because the operation of the elevation rudder is generally found to be the most difficult, doubtless from the fact that the sense of movement in a vertical direction has not yet been developed in man.

The operation of the rear vertical rudder, giving movement in a lateral direction, is a much more simple matter: a turn of the wheel to the left and the aeroplane will move in that direction; a turn to the right and a curve will be made to the right. The lateral rudder has also the effect of correcting lateral balance. The machine, for instance, has a tendency to heel over to the left, caused, naturally, by the wind striking

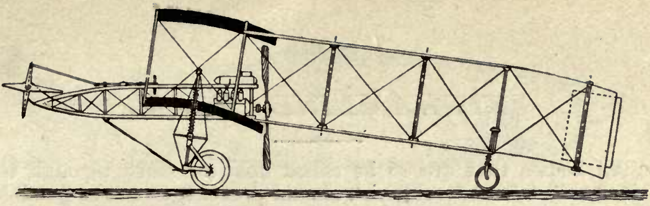


Fig. 84.—Elevation of a Voisin aeroplane.

it on the right. This would be corrected by turning the steering wheel in the direction it is desired to bring the aeroplane, in this case to the right, bringing the nose of the machine into the wind and putting it on an even keel. These movements also should be made without any harshness, nor must the pilot tug at the wheel if the aeroplane does not answer immediately. The vertical planes give so much lateral stability that it is practically impossible, under ordinary conditions, for the aeroplane to take such a list that it will capsize.

In order to make a turn, it is necessary that the machine should be inclined, and, as soon as the pilot has realised that there is no more danger for him to heel over in the air than there is for a cyclist to be inclined when riding on a banked track, turning on an aeroplane will not be difficult. Having realised that the machine must be inclined, the point is to turn at a sufficient height to prevent any possibility of the inside tip of the wing touching the ground. In making a turn, there is a slight loss of speed and a certain amount of fall of the aeroplane, which must be guarded against by commencing the turning movement at a reasonable height.

There are two correct ways of settling down: one, generally adopted by Farman and other expert pilots, being to stop the engine when not less than 15ft. from the ground, keep the elevation rudder horizontal, allowing the machine to advance through the air, at the same time gradually falling until the speed has decreased to such a degree that the last few inches of its flight are a vertical drop, but so gently that the wheels do not suffer any damage. The other method is to lower the elevation rudder gradually until the machine is brought near the ground, with its engine still running. The ground must be struck almost horizontally and, as soon as it is felt that the wheels have touched, the front elevation rudder should be slightly raised in order to relieve the apparatus from shock. At the same moment the engine must be stopped, and after running along for a few yards the entire apparatus will come to a standstill. An important point in connection with a descent is to attempt it, whenever possible, with the wind full ahead. It can be readily understood that, if there is merely a gentle breeze astern of the aeroplane when a descent is made, it may be driven a considerable distance before being brought to a complete stop. A side wind would tend to get the machine out of the control of the pilot, swinging it round violently, but a head wind steadies the machine, while at the same time acting as a brake.

STREAMLINE FORM.

All bodies that are to be called upon to move through the air should take a form which should prevent, as far as possible, the mutilation of the stream lines. It has been shown by a study of the form suitable for bullets and for torpedoes and submarines (although information about the latter is not readily available) that a discontinuous flow of the fluid in which the body is moving must be avoided if that motion is not to be

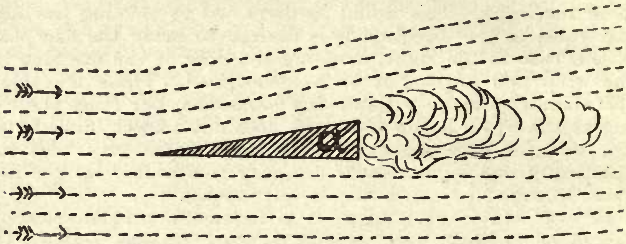


Fig. 85.—Discontinuity of flow due to the shoulder (a).

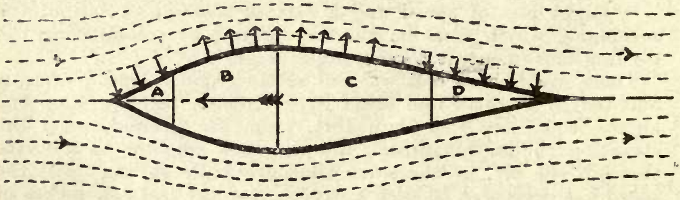


Fig. 86.—The pressures showing the forces acting on and outward from a streamline body.

A is the head of the body, B the shoulder, C the buttock, and D the tail.

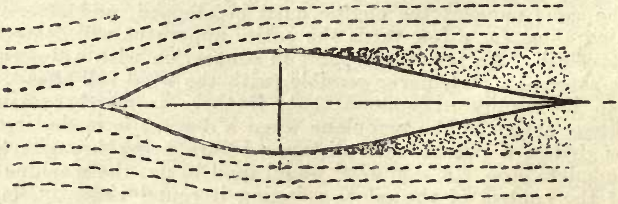


Fig. 87.—Discontinuity caused by removal of buttock and tail portions.

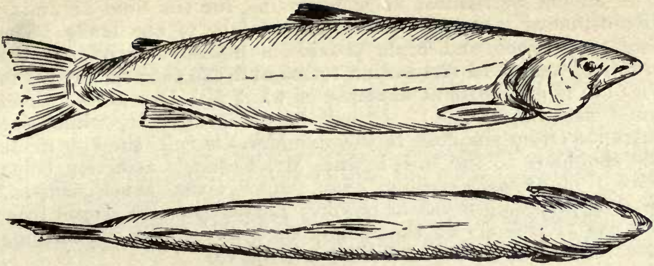


Fig. 88.—The salmon, a fish with typical streamline body.

affected by undue resistance. If a cylindrical body (say, for instance, a round stay or strut) be moved rapidly through a fluid—the air, for example—there will be an excessive pressure on the surface presented to the direction of motion, and, as the air has not time to close in round the rear portion or run, there is a diminished pressure in that region. If the body takes the form of a cone (Fig. 85) the air will shoot off past the sharp edge at the shoulder at (*a*), and, behind the shoulder, the fluid will break up into a vortex of small eddies. Maxim has found that the air in this case will have a tendency to press the body at (*a*) downwards. If, however, the body in motion be of perfect streamline form there is no resistance due to work done upon the fluid, for the late Mr. W. Froude has shown that the applied forces—the pressure inward at the head and at the tail and the pressure outward at the fullest part of the body—balance each other (Fig. 86), and there will be no resistance to its motion through the fluid. The viscosity of the fluid must, however, be allowed for, and it may approximately be represented by the tangential resistance of the exposed area as determined for a flat plate of the same general proportions. If the perfect streamline body be cut in half at the beginning of the run (shown by the vertical line on the body in Fig. 87) the flow of the fluid will again be discontinuous, and a void will be formed behind the moving body, as indicated by the stippling in the figure. It is highly important in the case of a propeller blade, for example, that the cavitation, as it is termed in that

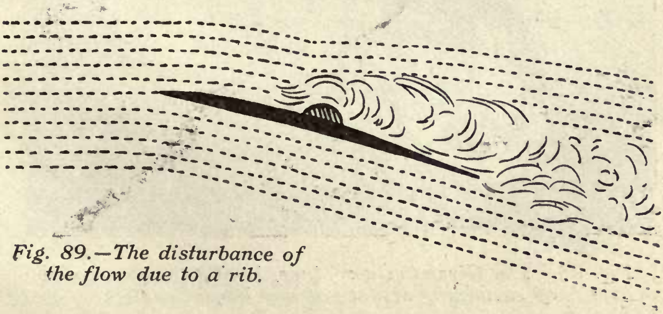


Fig. 89.—The disturbance of the flow due to a rib.

case, should be reduced to a minimum, for the fluid becoming discontinuous, ceases to follow the surface of the blade. The bodies of fishes and birds provide a means of studying the practical aspect of streamline form, and the salmon (shown in Fig. 88) is an excellent example of what Mr. Lanchester terms the "fish-shaped fish." It will be observed that, whilst the entrance (from the nose to the shoulders) is full, the run (from the shoulders to the tail) is fine, Mr. Froude's assertion being that "blunt tails rather than blunt noses cause eddies," thereby involving a loss of power. Losses can also accrue from the use of ribs across the surface of a plane, Fig. 89 showing how the air is disturbed behind a cross rib.

An accurate streamline form should, therefore, be adopted in connection with each constructional detail of an aeroplane. The form of the machine as a whole should be based upon this requirement, and every item in its construction should be considered with the same end in view—that of offering as little resistance as possible to the air. The section of the approximately-perfect plane offers a streamline aspect, the nose being blunt and the tail end fine. Stays and struts require the fullest care in designing, not only in order that head resistance shall be reduced to the minimum, but that the effect of a side wind upon them shall also be minimised. The body of an aeroplane generally presents a number of small surfaces to the direction of motion in the shape of struts, stays, and mechanical details, and considerable advantage can be gained by closing in a body of that character, although care must be taken not to allow the covering to form a scoop, or it will be ripped from its, generally, insecure fastenings.

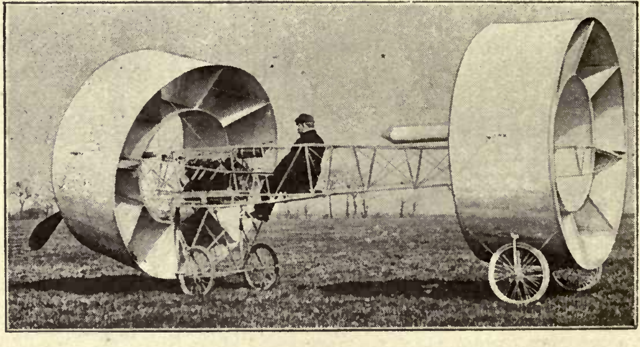


Fig. 90.—The Givaudan-aeroplane, having the same area of sustaining surface at any lateral angle.

THE DIPPING FRONT EDGE.

A fact that seems to have escaped observation until within the last quarter of a century is that the front edge of a bird's wing is of arched form or dipped. This dipped front edge is, according to those who have of recent years closely studied this peculiarity, characteristic of the wing form of all birds that are able to sustain a flight. As an example of this dipped front edge, Lanchester gives a section of the wing of the herring gull (Fig. 91), and, assuming that the bird is making a horizontal flight, the wing would take the form shown by the full lines, whilst the dotted line gives the form shortly after the bird has been killed.

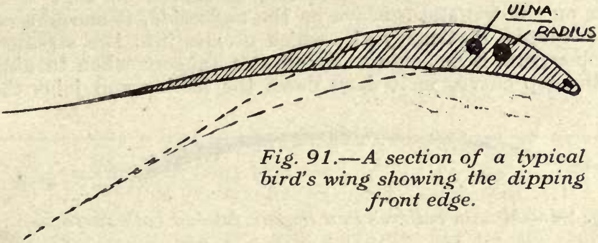


Fig. 91.—A section of a typical bird's wing showing the dipping front edge.

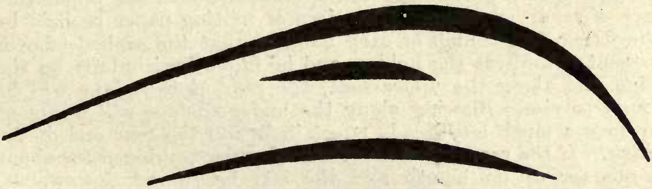


Fig. 92.—The arched wing sections discovered by Horatio F. Phillips and patented by him in 1884.

The dipping edge was, so far as all records show, first discovered by Mr. Horatio F. Phillips, who patented his discovery in 1884 (patent No. 13,768), and the wing sections which he showed in his specification are reproduced in Fig. 92, whilst his later patent of 1891 (No. 13,311) gives the modified form

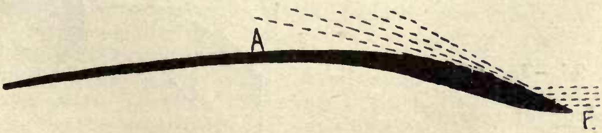


Fig. 93.—Phillips's modified wing form patented in 1891.

shown in Fig. 93. It is considered likely that Lilienthal, who used an arched wing section in his experiments commencing in 1890 and continuing until 1894, did not know of Phillips's work, whilst at about the same time Lanchester evolved the arched form, as he says, from theoretical considerations and without any knowledge of the work of either Phillips or Lilienthal. Phillips assumed that a current of air striking the forward edge (E) (Fig. 93) at an acute angle would be deflected upwards by the forward part of the surface creating a vacuum (or partial vacuum) over the greater part of the upper surface (A), but Lanchester considers that this theory is inadequate. Maxim explains that when a plane is curved so that it is convex on the top and concave on the underside, it encounters, as it advances, stationary air, which divides into two streams. The top stream is not able to fly off at a tangent when turning over the top curve, so it flows down the incline and joins the current which is flowing over the lower horizontal surface. The angle at which the combined stream of air leaves the plane is the resultant of these two angles. Thus, the plane finds the air in a stationary condition and leaves it with a downward motion, so that the plane itself must be lifted.

Fig. 94.—Maxim believes that the air follows both surfaces.

But there is some evidence to support the theory of Horatio Phillips that a partial vacuum is created above the upper surface of a curved plane. If a piece of writing paper be held by the finger and thumb of each hand so that the arched edge is presented towards the holder, and he blows horizontally on the edge and along the upper face, the rear of the plane will be found to rise. Blowing along the under surface will be found to have a much less steady effect in lifting the rear end of the plane. If the rear end of the sheet of paper be hinged for about a quarter of its length and the end be curved downwards, blowing along the upper face of the plane will be found to lift the rear hinged portion almost vertically in the air and

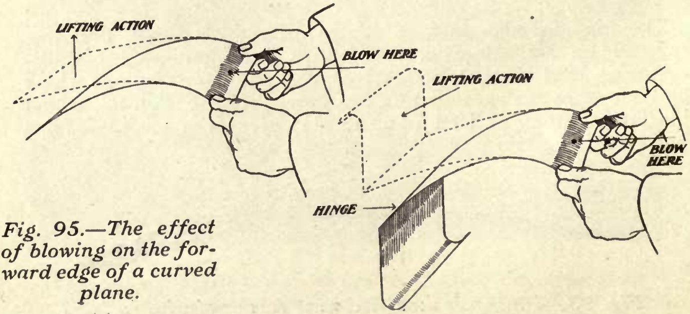


Fig. 95.—The effect of blowing on the forward edge of a curved plane.

seemingly right in the face of the current of air, whereas if the hinged portion be kept flat it will not lift, and if its rear end be curved upward it will merely vibrate and act as a drag upon the lifting of the plane forward of the hinge.

Whatever may be the real explanation, however, there is no question about the superiority of a curved plane. Maxim has found in the course of a long series of experiments that if a plane, convex on the top and perfectly flat on the bottom side, be mounted in the air so that the bottom side is perfectly horizontal, it will, if a current of air be passed over it, produce a lifting effect, no matter in which way it may be run. Maxim's experiments led him to assert that the practical shape and the practical angle, 1 in 10, of an aeroplane are as set out in Fig. 96, and he thinks that the air striking the underside of the plane will not move forward and curl over the top of the plane, being compressed and leaving a large eddy in the rear as in Fig. 97. He points out that the theory upon which this diagram was based does not provide that the air travels downwards after the passage of the plane, and that the lifting effect upon a plane is, therefore, not explained by this theory. Lanchester points out that, if the dip of the front edge be insufficient, the upward current will not strike the edge conformably, and the result will be a small pocket of dead air just

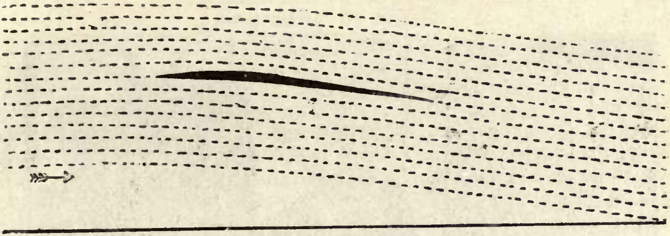


Fig. 96.—The air leaving both sides of a plane in a downward direction exerts a lifting effect on the plane.

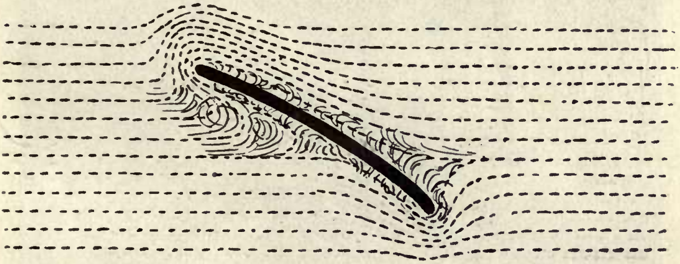


Fig. 97.—The disturbance in the vicinity of a moving plane according to some experimenters.

above the forward edge, whilst if the insufficiency of the dip be serious, then a very large pocket, practically extending over the whole of the upper surface of the plane, will occur. If the dip be too great, the pocket of dead air will be below the plane, and the pressure region occupying the upper surface, a condition of instability arises and the new system of flow inaugurated produces a downward instead of an upward reaction.

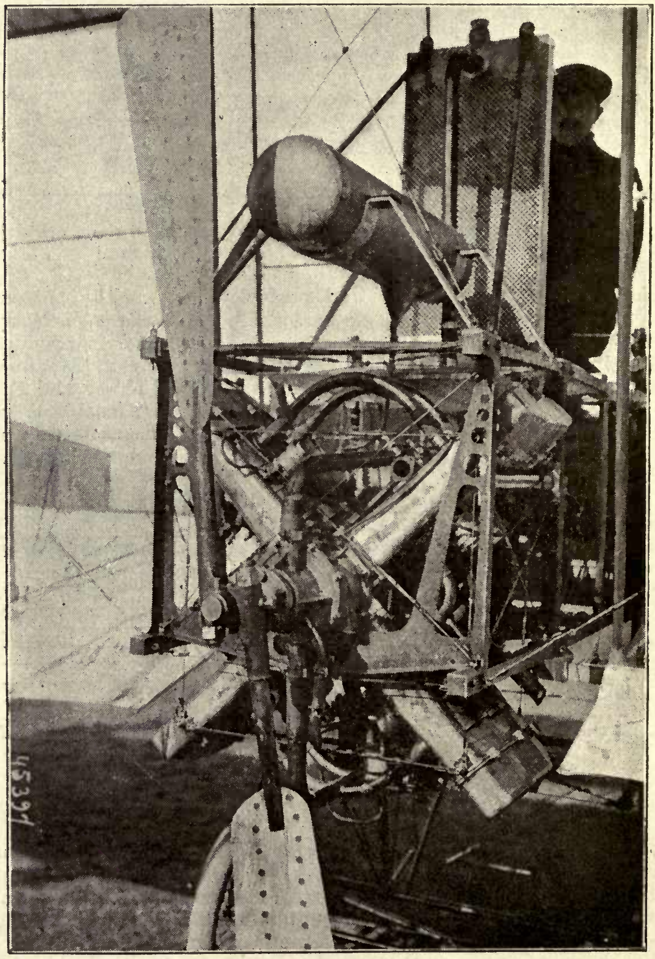


Fig. 98.—The installation of the Gobron engine and the propeller on Baron de Caters's aeroplane.

GLIDING AS A SPORT.

How to Construct a Glider. Instructions for Learning to Glide.

There is an exhilaration about gliding which cannot be obtained in any other sport. The sense of floating through the air, of being of the earth but above it, of conquering a barrier that Nature had for centuries drawn against man, gives a feeling of exultation and delight that can be found in no other pursuit of pleasure. There is also in gliding a splendid school for the training of quick judgment, of calm reflection but rapid decision, and of precision of movement, which stimulate the brain and develop those qualities which flag in our modern life. And with the work that comes from the necessity of carrying the machine again and again to the top of the hill, or, as Chanute once put it, winding up the gravity spring, there is all the exercise associated with other out-door sports.

In gliding there is no danger, if one be not ridiculously imprudent, and provided one is strong enough to suffer a few shocks without hurt. The art must be learnt in easy stages, caution being the insurance against harm. And who, in trusting himself to the element which since the beginning of the world has seemed, and even now seems, to defy man's skill and ingenuity, will not proceed warily? No man who cannot swim would throw himself into an unfordable stream, expecting to reach the other side. He would first set himself to master the ability to progress a few feet through the water, and by gradual stages learn to swim. So must it be with gliding. A few feet at first; then further and gradually further; until, with intelligent and capable control of the machine a glide of a hundred feet or more can be taken. From Wilbur Wright's lecture of 1901 and from the later one of 1903, both read before the Western Society of Engineers, let a lesson be taken in caution. If ever there were men who exercised patience and self-restraint they were the Wright brothers during the experiments that led them to the conquest of the air by mechanical flight. Impatience, rashness, and precipitation are of the very essence of peril, whilst, on the other hand, calmness, self-possession, patience and self-restraint will carry the gliding devotee safely and unscathed through thousands of flights.

Beyond those who will indulge in gliding as the nearest approach that their purse permits to controlled flight, everyone who takes to aeroplaning should previously indulge in a course of glides. The present-day great masters of flight, the Wrights, Farman and the Voisins, have learnt their elementary notions of equilibrium in the air from gliding experiments. Chanute, with his assistant, Herring (whose work has not yet been accomplished), Capt. Ferber, Archdeacon, and others have practised the art, not primarily for sport sake, though enjoying the sport, but for education and instruction.

The first and ruling qualification for the sport of gliding is the accessibility to a suitable slope. The ground should be open and free from trees, with no bushes or gorse—heather does not matter—to cause obstruction when alighting. Heather, in fact, is an advantage, just as sand is, because of the "cushioning" it affords should a glide be prematurely terminated. How smoothly the glider comes to ground at the natural termination of a flight can be gathered from the fact that the Wrights assumed a prone position during all their gliding trials. The slope should be from 1 in 10 to 1 in 7, and should be from 150ft. to 300ft. or 400ft. long. Such slopes are not to be found in many parts, and it should therefore be the first concern of the would-be gliding exponent to discover a suitable ground, which should also be at least 150ft. wide. Trees in the proximity do not matter, if they are planted in regular order, and if the machine does not approach them too closely.

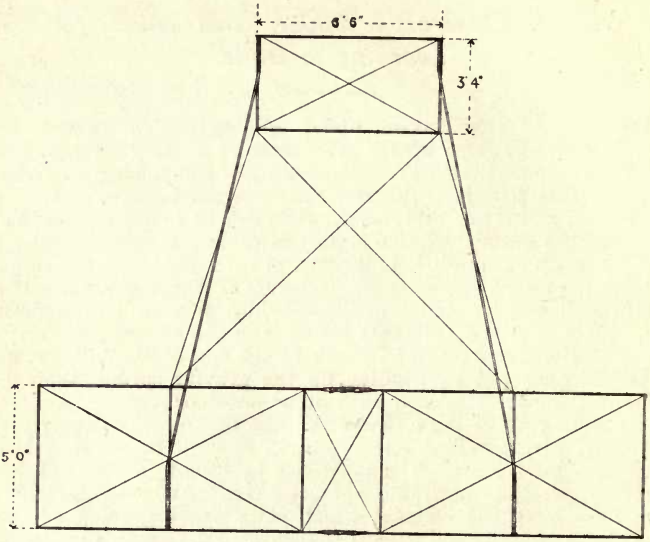
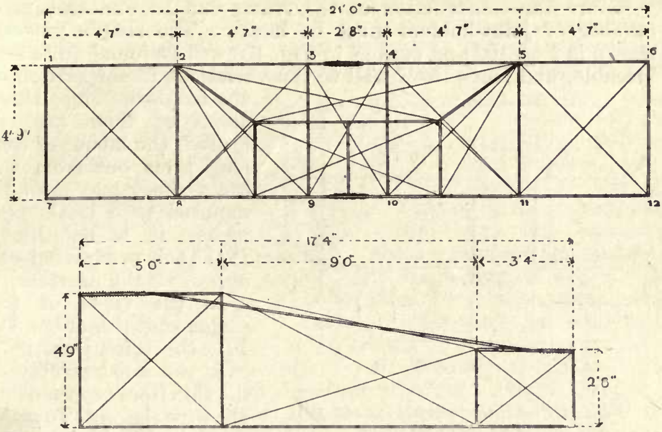


Fig. 99.—Plan of glider, giving dimensions of tail and width of main planes.

For the novice no better material will be found for the framework than bamboo, which can be obtained selected for the job. In respect of its section, it is not all that can be desired for the reduction of wind resistance, but this is not of much importance at the speeds which the glider attains. Providing strength with lightness, bamboo possesses the additional advantage that it requires no working. It is ready for use in the state in which it is bought, only a saw being required to cut it to the correct length. Owing to the fractures that are sure to occur during the initial glides, it will be useful to lay in some spare lengths over and above those actually required for the frame in the first instance.



Figs. 100 and 101.—Dimensioned elevation plans of glider.

The quantities and materials that must be taken into stock for the construction of the glider are:—

1. Bamboo: 135yd., in lengths of 6½ft., 14ft., and 18ft., and of 1¼in. diameter.
2. Piano wire: 175yd. of silver-plated .056in. dia. (No. 17 S.W.G.).
3. Nine dozen Hope rigging eyes or about 7ft. of No. 20 Imperial wire gauge copper tubing (3-16in. external diam.).
4. Calico: 25yd. of double width.
5. Brass sheet: 1 sq. yd. of 24 B.W. gauge.
6. Screws and nuts: a gross of 3-16in. (1in. long).
7. A ball of cord.

Though variations in prices will be found in different localities, especially with the bamboo, it may be taken that the average cost of the materials will accord with the following estimate:—

	£	s.	d.
1. Bamboo	1	12	0
2. Piano wire		12	6
3. Copper tubing		2	0
4. Calico		14	0
5. Brass sheet		9	0
6. Screws and nuts		6	9
7. Cord		1	0
Total	3	17	3

No account is taken of the cost of labour, nor are the necessary hand tools priced, the assumption being that the glider is to be made by an amateur already possessed of the pliers, hacksaw, and wood saw that form the small outfit required.

Before the construction of the frame can be undertaken, a number of joint-holders must be made. The simple pattern shown in Fig. 102 and used as in Fig. 103 will be found quite serviceable, and lends itself well to the variations in the section of the bamboo. Since three dozen of them are required, the labour of cutting them out from the brass sheet may well be deputed to a local engineer. It is not likely that their production will appeal to the amateur.

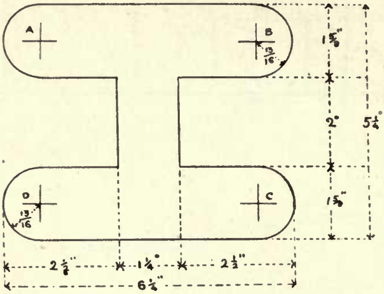


Fig. 102.—Sheet metal as cut for making joint-holders.

In the views of the glider shown in Figs. 99-101, the thick lines indicate the wood structure, the thin lines representing the wire rigging. To make a start with the job, take two lengths of bamboo each 11ft. 6in. long and well matched. Cut a plug to fit the ends, and, dipping this in white lead or varnish, use it as a dowel for the butt ends of the bamboo (see Fig. 105). Although the joint could then be bound up, a better job can be made if some bamboo splints are laid along the butted ends. These splints can be obtained by splitting a short piece of bamboo and tapering off the edges. Using three of these, bind the joint up with wire at four points, as illustrated in the diagram on next page. The ends of each binding wire should be crossed under the turns of wire in the spacing between two splints and twisted on each other above. The binding can then be tightened by driving wedges into the spacing between the splints, means being employed to fasten the wedges. This will make a strong and workmanlike joint, neat and tidy. If desired, the joints in the bamboos can be rasped down nearly flush without weakening the sticks. Lay out another 21ft. length in the same manner, and bend a half-dozen joint-holders over each at intervals corresponding to the positions of 1, 2, 3 . . . . . 11, 12 in the drawings, remembering to turn the lap of the joint towards the inside. Cut a dozen lengths of 5ft., and, laying the two 21ft. poles on the ground, fit the short pieces horizontally into the joint-holders. This will give a stiffened

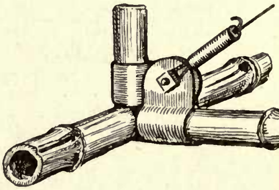


Fig. 103.—A joint-holder bent to shape and placed in position.

rectangle, which will form one of the main planes. Into the tops of the joint-holders should next be fitted a dozen lengths of 4ft. 9in., on the free ends of which must be placed the upper main plane, constructed in the manner just described for the lower one. At this stage the frame will present the appearance of a cage, as shown herewith; though possessing the elements of rigidity, it will need bracing.

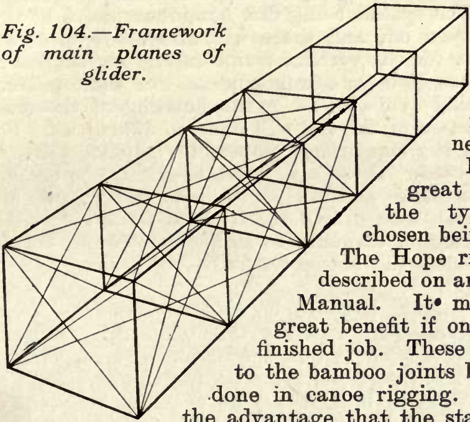


Fig. 104.—Framework of main planes of glider.

Even for this no great skill is required, the type of fastening chosen being of the simplest. The Hope rigging eye is fully described on another page in this Manual. It may be used with great benefit if one desires a neatly-finished job. These eyes can be lashed to the bamboo joints by light wire, as is done in canoe rigging. This method has the advantage that the stays will seldom require to be tautened, but there is the disadvantage that to haul all the lashings up taut, when they have slackened, takes a considerable time.

Fig. 105.—Method of making butt joints with bamboos.

Fig. 106.—The Voisin method of making eyes by passing the end of the wire twice through a piece of copper tube, leaving an eye, and bending the end of the wire over.

An alternative method is to adopt the Voisin style of rigging. Take the copper tube, and cut it into short pieces about ½in. or ¾in. long. Through each of these a piece of the piano wire must be threaded and bent back, so that the tube may be pushed over a double thickness of the wire (see Fig. 106). Twist the end over and snip the wire off short. This will give a good eye fastening which cannot slip, and which is small enough to be clamped by the nut of the joint clip whilst being amply strong. A similar eye must be lashed at the other end of the length of wire necessary for the diagonal. It is not of the greatest importance to have a strong tension on the wire, but it is very advisable to have the tension of all the wires uniform. Straining screws can be regarded as refinements for gliders. There may be a little difficulty at first, but after a few attempts one can become quite an adept at getting the proper length of wire. The extent of the bracing can be gathered from Figs. 100, 101 and 104, each cell being braced along all diagonals, and the frames of the main planes stiffened, as shown in the plan view. If supported at its outer ends, this skeleton structure is capable of supporting a load of about 3cwt. in the centre.

In the construction of the tail, exactly the same procedure is to be followed. The spread being 6ft. 6in., four pieces of this length must be sawn off, and there will also be required six lengths of 2ft. 8in. for the vertical members and six lengths of 3ft. 4in. to serve as fore-and-aft members. The same pattern of joint-holder being available as in the building of the main planes, the completion of the tail will offer no difficulties. For its attachment to the supporting planes, four rods, 18ft. in length, must be used. These are laced between the bamboo struts of the main planes and tail, as depicted in Fig. 101, and are then lashed with wire drawn tightly round the struts and main poles. By rigging diagonal wires across top and bottom and across both sides, the entire frame of the glider will be rendered quite rigid.

Both the main planes have to be covered completely with calico, except for the space between the points 9 and 10 (see Fig. 100) on the lower plane. This space, which corresponds to the joints in the main poles, is required for the aviator, who supports himself on two bearers set at the most convenient distance apart and lashed at both ends to the main poles. The calico must be turned over the bamboo members and stitched in place after it has been drawn up as tightly as possible. The tail also needs to be covered with the same material, but in this case there are also three vertical panels to be added, as shown in the rear elevation of the glider. If necessary, the calico can be shrunk by one or two coats of starch paste.

Trials can be made in a steady wind, that is strong enough to lift the glider when it is held by one of the front cross-poles.

In the initial glides it is essential to have the assistance of two men. For this purpose two cords, about 6ft. in length, should be attached to the forward extremities of the lower main plane, and these should be held by the assistants, one at each end. Having determined the direction of the wind, face it, place yourself in the glider, with the supports under your arms, and give the order to start down the slope at a moderate pace. At the end of a few steps the glider will lift the passenger from the ground, but the assistants should continue to run right down the slope, keeping the cords in their hands. Caution is most advisable and it should not be until at least a dozen captive glides have been made that an aviator should attempt a free glide, and even then only if he feels perfect confidence in his ability to control the machine.

To steer to the right, throw the legs to the right; to steer to the left, throw them to the left; to alight, bring the weight of the body further forward. At first there will be a tendency to keep the body too far back. This must be strongly combated, for it is the only position that is dangerous. During the captive glides, the effect of various movements of the body must be closely watched, for upon them depends the control of the machine. When these details have been mastered, a short free glide can be attempted, the order to cast off being given to the assistants almost as soon as one's feet have left the ground. The cords should be released by the assistants simultaneously, otherwise the machine will not glide straight and evenly. The great thing to master is to bring the machine smoothly to the ground by stretching the legs forward. With these hints, it must be left to each one's practice to obtain the skill which renders long glides in even fairly strong winds quite safe. A few minutes in the air is worth more than the same number of weeks of theoretical study.

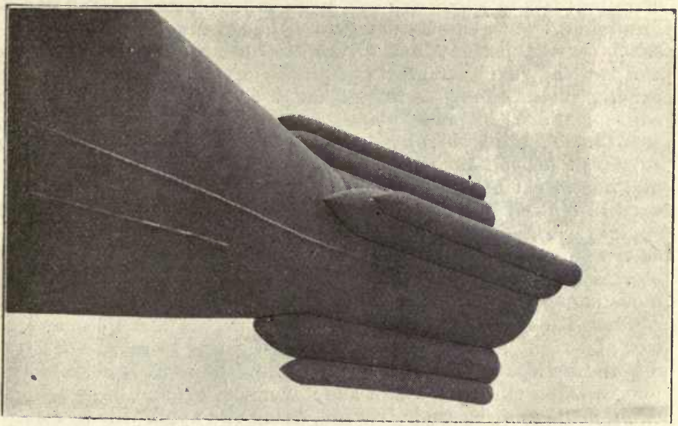


Fig. 107.—Stern view of "La Ville de Paris."

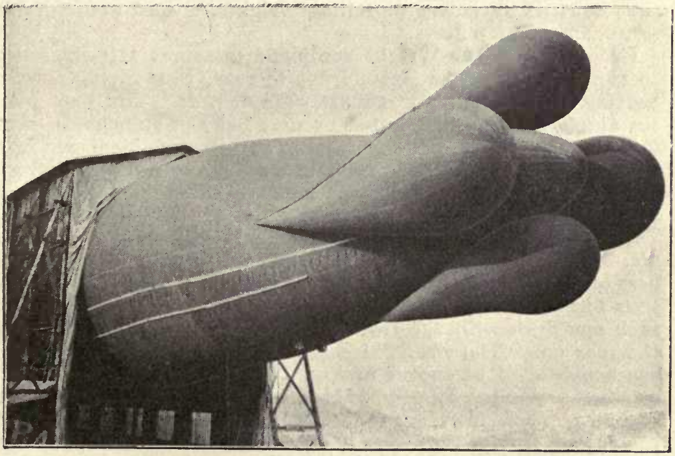


Fig. 108.—Stern view of "Clement-Bayard."

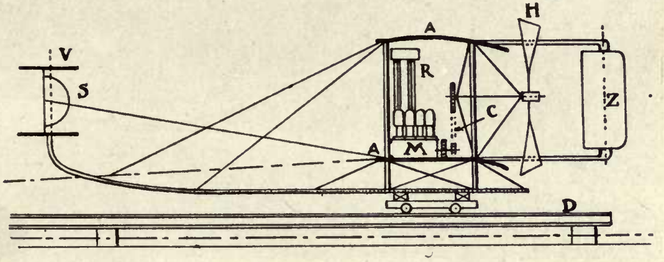
AEROPLANES OF 1908 AND 1909.

The Wright Aeroplane.

The Wright aeroplane is an exceedingly simple apparatus, the main features of which are two large superimposed planes or sustaining surfaces; two similar planes, but of much smaller dimensions, carried in front, and pivoted to form an elevation rudder; and, at the rear, two vertical planes or rudders, operating in exactly the same way as the rudder of a ship. Near the forward edge of the main lower plane, slightly out of the centre line, is a four-cylinder petrol motor, driving, by means of chains, a couple of propellers in the rear, both chains running in tubes, and one of them being crossed in order that the propellers shall turn in opposite directions. The operator sits to the left of the engine, counterbalancing its weight, and has a wooden lever in each hand, the left-hand lever raising or lowering the forward elevation planes, and the right-hand lever having a double movement, forward and rearward, to turn the rear vertical rudder, thus giving lateral movement to the machine, and to left and right in order to bend the wing tips to facilitate turning and maintain lateral balance. The apparatus is mounted on long wooden runners, which slide over the ground on a descent being made and, by their friction, bring the apparatus to a stop. Starting is generally accomplished by a catapult system, the aeroplane being mounted on a bogey running on a long rail and shot down it by means of falling weights, a cord and suitable arrangement of pulleys.

Each wing of the Wright aeroplane measures 41ft. from tip to tip, and is 6ft. 6in. from front to rear, thus giving a total bearing surface of approximately 538 sq. ft. The two main sustaining surfaces are united by nine pairs of stanchions, each 5ft. 10in. in height. The sustaining surfaces are composed of a wooden frame built up of two main members of American spruce each 41ft. in length, the front member having a thickness of about 2in., with its fore edge rounded off to offer less resistance. The main frame members are distant one from the other 4ft. 3in., and are united at their extremities by two cross members of the same thickness, and also rounded. Across the frame thus formed are placed 32 curved ribs (with a curve of 1 in 20), each one flush with the front frame member, but overhanging the rear one. The ribs, which have a total length of 6ft. 6in., are constructed as shown in Fig. 115, namely, of two curved members separated by wooden blocks gradually tapering towards the rear, where they are all united by a steel cable. Each of the curved frames thus formed is covered on both its upper and lower surface by rubbered-cloth nailed at the front edge and sewn at the rear.

The 19 wooden uprights uniting the two bearing surfaces are not all rigidly fixed. All the front ones and the middle rear ones are secured in aluminium sockets to the main frame members, but six of the rear ones—three at each end—are attached by a system of hook and eye illustrated in Fig. 119. The eye bolt is secured to the extremity of the stanchion, fits on the hook of the frame, and is prevented from slipping off by means of a split pin. These hooks at the same time serve to receive the ends of the wire stays with which the structure is strengthened. A feature of the staying of the Wright aeroplane is that there is no provision for regulating the tension of the wires. The end of the wire is doubled back to pass into a copper tube, the whole being soldered, and the loop thus formed fitting on to the hook of the frame member. The reason for this pivoting structure is to allow of bending the rear extremities of the wing tips in a manner and for a purpose that will be explained later.



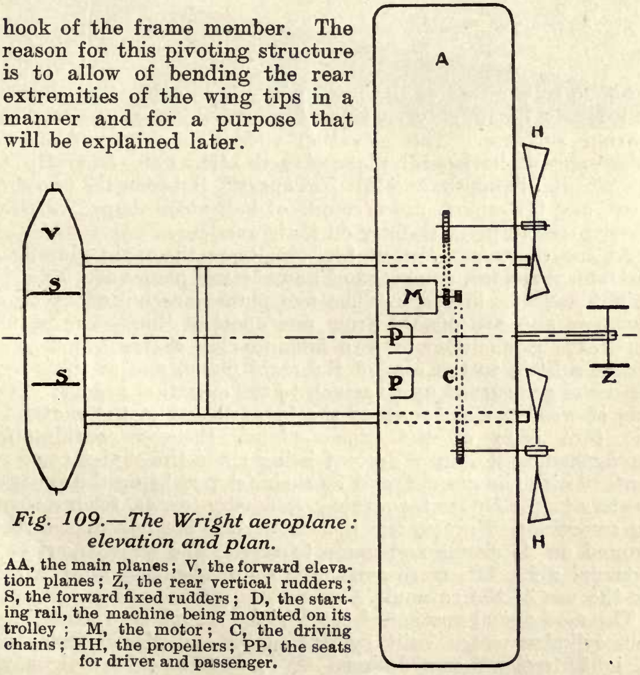


Fig. 109.—The Wright aeroplane: elevation and plan.

AA, the main planes; V, the forward elevation planes; Z, the rear vertical rudders; S, the forward fixed rudders; D, the starting rail, the machine being mounted on its trolley; M, the motor; C, the driving chains; HH, the propellers; PP, the seats for driver and passenger.

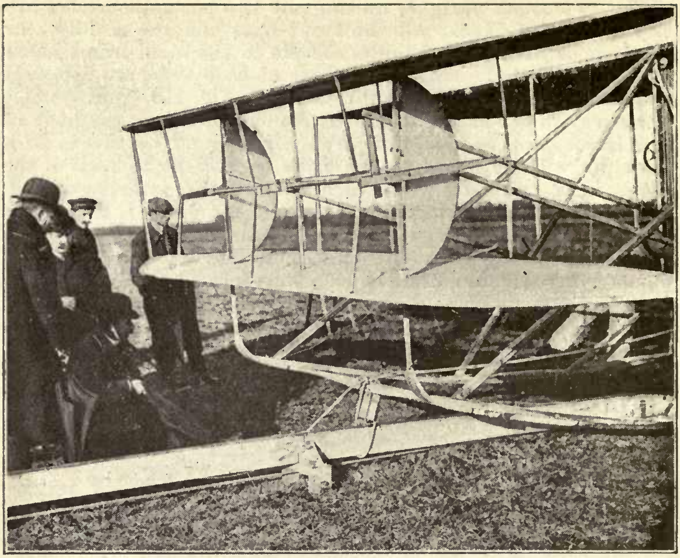


Fig. 110.—The forward elevation planes and the fixed vertical rudders. The machine on its starting rail.

About 10ft. ahead of the main wings is the elevation rudder, which may be roughly considered as a reduction of the main bearing surfaces. The elevation rudder is composed of two superimposed horizontal planes, each 14ft. 10in. from tip to tip, 2ft. 5in. in depth, and 2ft. 7in. apart. Between the two surfaces, and 6ft. apart, are a couple of half-moon-shaped vertical planes, free to pivot slightly on their axes.

At the rear, and distant 8ft. 6in. from the main planes, is the lateral rudder, composed of two vertical planes 5ft. 10in. in height and 2ft. in width. The two planes are united by cross members and are distant from one another 19in. The entire apparatus is mounted on two long wooden skates which commence a little to the rear of the main plane, and at their forward end are curved up to attach to the elevation rudder. Two sets of wooden stays connect the forward end of the skates to the fore edge of the upper plane, thereby considerably strengthening it. On a descent being made the skates come in contact with the ground, and by their friction bring the apparatus to a stop. Under favourable circumstances, as, for instance, on smooth, wet grass, the apparatus can be driven over the ground on its skates and made to rise in the air without any external aid. The more common way of starting, however, is by the use of the catapult.

The mechanical portion of the Wright aeroplane consists of a four-cylinder motor built by Bariquand and Marre from the Wright Brothers' own designs. It is what may be designated a medium-weight motor: not so light as the special aeroplane engines recently developed in France, but considerably lighter than the standard car engine, which it resembles in all main features of design. The engine is carried near the forward edge of the lower plane, but about 2ft. to the right of the longitudinal centre. The pilot occupies a seat to the left of the engine, thus counterbalancing its weight; the passenger's seat is between the pilot and the engine and almost in the centre line of the plane. Thus, whether a passenger is carried or not, the lateral balance of the aeroplane is not disturbed. The engine drives a couple of wooden propellers in the rear; those generally employed have a diameter of 8ft. 3in., and are geared 33 to 9, giving 450 propeller revolutions a minute. In this respect the Wright machine differs from most of the French machines, where the propeller is mounted direct on the engine shaft, and turns at from 1,100 to 1,500 revolutions a minute. During the 1908 trials in France, the propellers and the gearing were frequently changed, the longest flights being made with propellers of 9ft. 2in. diameter.

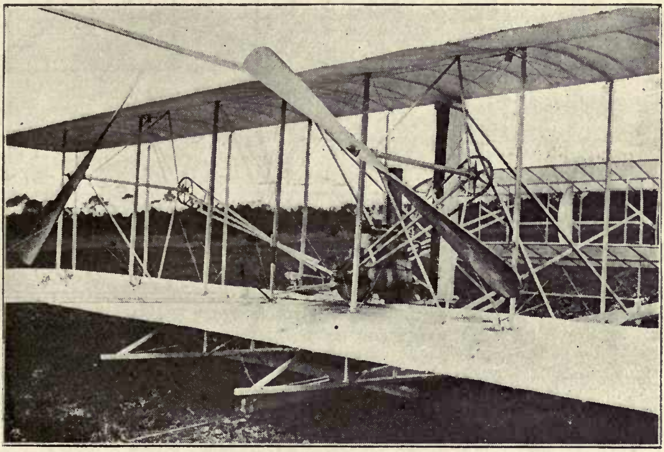


Fig. 111.—Rear view showing engine, propellers, and transmission. The skates are also clearly seen.

The supply of cooling water for the engine is contained in a radiator composed of plain, flat copper tubes attached to one of the forward stanchions of the aeroplanes. The quantity of water carried is a little over two gallons. The petrol supply is contained in a cylindrical reservoir, at first placed horizontally, but now hung vertically between the two main planes. The flow is by gravity to the petrol pump within the crankcase, from which the petrol is directly injected into the cylinders.

It has already been stated that, under favourable circumstances, the aeroplane can be started from the ground on its runners. The general method of getting into the air, however, is by the use of a rail and falling weights. It is a method that has been much criticised, the critics maintaining that, so long as this apparatus was necessary, the Wright aeroplane could never be employed for cross-country flights. The catapult system, however, is only a means for getting into the air, and, so long as operations are confined to flights over a specially-prepared ground, it is a most convenient method, and one that is successful in 99 starts out of a hundred. It will be soon enough to burden the apparatus with wheels when cross-country flights are attempted.

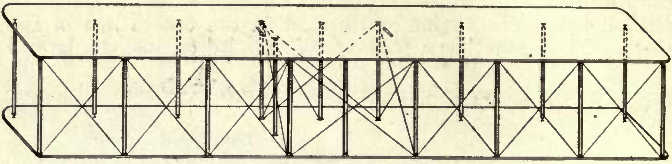


Fig. 112.—The struts and stays of the latest form.

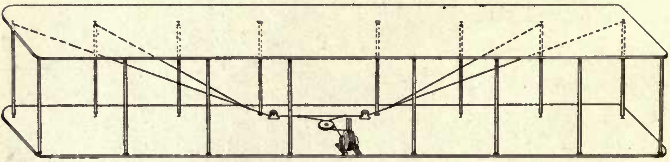


Fig. 113.—The primary warping mechanism with its lever to warp the upper plane.

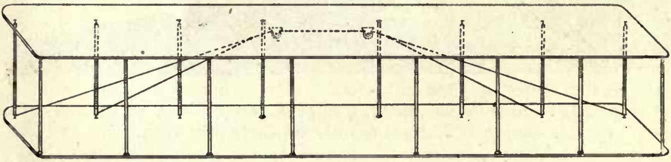


Fig. 114.—The secondary warping mechanism to warp the lower plane.

The wooden starting rail, the upper face of which is bound with metal, is 68ft. in length. A two-wheel wooden bogey, formed of two lengths of wood placed at right angles, is laid on it and receives the aeroplane, which, immediately before the start, is supported at the right-hand tip by a trestle; this side, of course, being heavier by reason of the motor being out of centre. To the rear of the aeroplane, as it rests on the starting rail, is a pylone, to the summit of which are hoisted a number of metal discs weighing about 14cwt. The rope securing the discs passes over a pulley at the summit of the pylone, under another pulley at the base, then travels forward underneath the

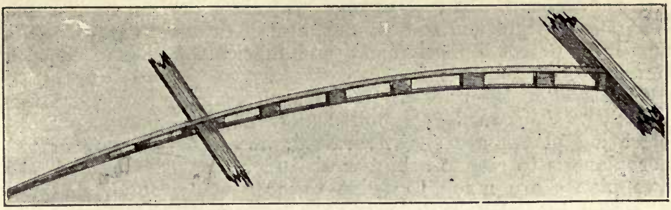


Fig. 115.—Showing construction of one of the curved ribs forming framework of the main wings to be covered with rubbered cloth on both surfaces.

aeroplane to a pulley at the extremity of the rail, returning along the rail to the aeroplane, to which it is attached by means of a hook.

When the aeroplane has been placed in position on its rail, and the weights mounted, it is temporarily attached in the manner shown in Fig. 116. Here the pilot's seat is shown at S; beneath him is a bar (A), hinged at B, and secured in a notch of the plate (P). Around the bar (A) is a short wire cable secured to the starting rail.

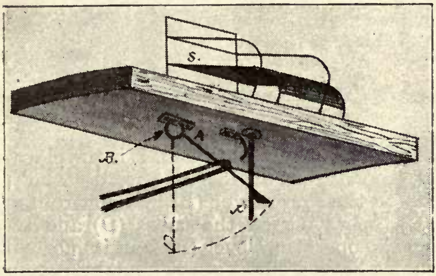


Fig. 116.—The method of attaching the aeroplane to the starting rail, and of releasing it.

The engine having been started and the trestle under the extremity of the wing replaced by an attendant, the pilot leans forward and pulls the bar (P) out of engagement with A, with the result that this latter falls, the cable (C) slips over its end, and the aeroplane is free to shoot down the rail. Under the combined influence of the falling weights and the revolving propellers, the 68ft. of the rail are covered in $3\frac{3}{5}$sec., which gives a speed at the end of the rail which may be estimated at 35 miles an hour. While running down the rail, the front elevation rudder has been kept in a position to hold the aeroplane down, and it is only as the end of the rail is reached that it is raised and the apparatus rises somewhat rapidly into the air to perform its wonderful evolutions.

The pilot has to operate two different steering levers in order to preserve the machine at the right altitude, to maintain longitudinal and lateral balance and to make his turns. He has, in no way, to occupy himself with the engine, which is indeed unprovided with any other control than an appliance for relieving the compression, and so stopping, when it is desired to descend. The point of ignition is fixed, the throttle does not exist, for the supply of petrol is mechanical, and lubrication is assured by a pump.

The lever in the pilot's left hand has a simple movement forward and backward. If pulled towards the pilot, the front elevation planes are slightly raised, and the tendency of the aeroplane is to rise to a higher altitude. If pushed ahead, the two planes are made to point towards the ground, and the direction of the aeroplane is then downwards. Reference to Fig. 117 shows how these movements are obtained. F is the elevation lever pivoting at G, and having attached to it, by a bolt, the bar (A,) connected up to the short lever (B) and controlling three connecting rods (C), operating on the tubes (D) and inclining the planes. When the operating lever (F) is in its normal position the elevation planes have a slight curve, but by reason of the difference of length between the front and the rear portions of the connecting rod (C), as well as the front and the rear portions of the planes, when the lever is carried full ahead the rear of the planes are carried upwards, as shown in the dotted line. When the lever is brought to the rear the forward edge of the planes is raised but slightly and the rear is fully lowered. The control of this elevation rudder is first given to pupils learning to handle the machine. Whenever the aeroplane has a tendency to dive the lever is pulled back; if the machine is going too high the rudder is pushed forward. The movement is only slight, and is very difficult to follow by an observer on land.

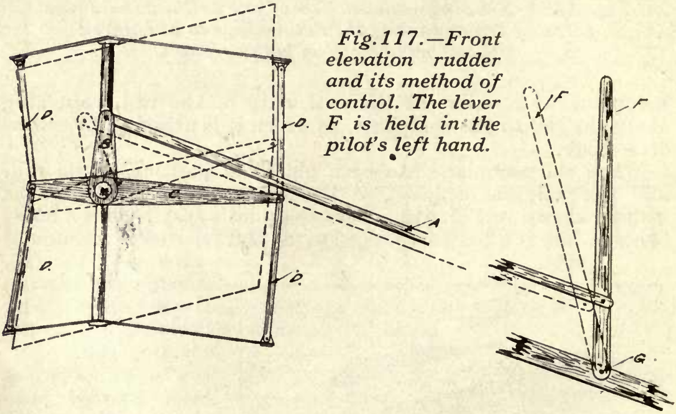


Fig. 117.—Front elevation rudder and its method of control. The lever F is held in the pilot's left hand.

The right-hand lever is more complicated in its operation, and more difficult to manœuvre than the one just described. It has two distinct movements—forward and backward and to left and right. If the lever is merely carried ahead it will direct the vertical rudder over to the left, and cause the aeroplane to turn to the left. How this is accomplished will be immediately understood by reference to Fig. 118, in which A is the right-hand lever, B the forked end connecting rod, C the pivoting crossbar, and

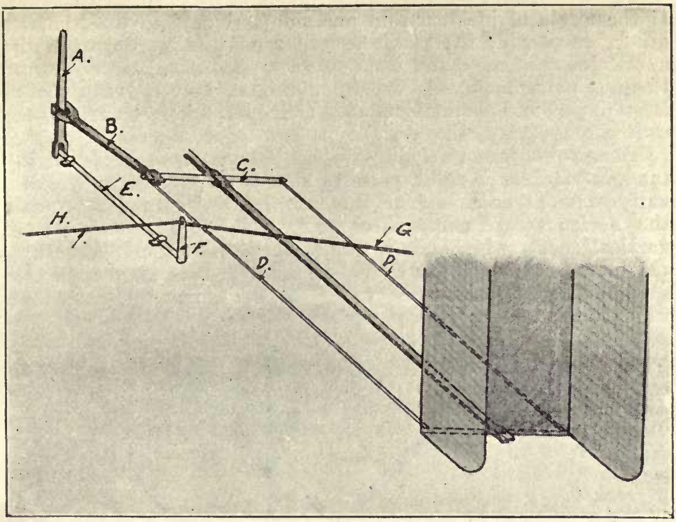


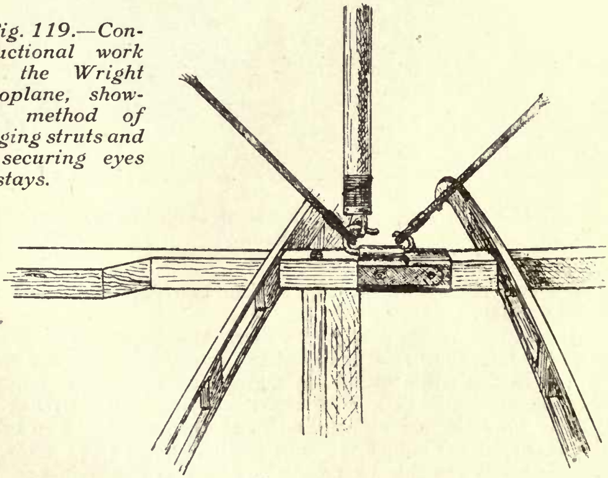
Fig. 118.—The combined rudder control and wing-warping mechanism.

DD the two cables connecting to the two extremities of the vertical rudder.

If, instead of being carried forward, the lever (A) is moved over to the left, it will naturally at the same time shift the short lever (F) in the same direction, tightening the cable (G), and slackening the cable (H), with the result, as shown in Fig. 13 (p. 21), of lowering the right-hand wing tips, and the two being inter-connected, as shown, raising the left-hand tips. This, of course, is made possible by reason of the pivoting joints of the rear stanchions already described, and gives the helicoidal torsion necessary for modifying the angles of incidence at which the ends of the wings are presented to the atmosphere.

The outcome of the movements of the rudders and of the warping of the planes requires to be carefully studied, because of the conflicting forces at work. When the wings are so warped at their rear corners (for the front edges remain always undeformed) that the left-hand end—assuming that the spectator is standing behind the machine and looking in the direction of travel—is depressed and the right-hand end is raised, the left-hand end presents the greater angle of incidence to the atmosphere and will rise because the pressure of the atmospheric action on this part is increased. The right-hand side offering a lesser angle of incidence will tend to fall. This permits the lateral balance to be maintained, but it also has the effect of causing the machine to turn on a vertical axis towards the left hand. Thus, as the angle of incidence increases the tendency to rise is gained at the expense of forward speed. Consequently, if the angle of incidence on one side is increased and, on the other, decreased, the machine will tend to slow down on the outside of the curve and thus produce opposition to the desired turning movement. To overcome this action the rear rudder is employed in combination with a fixed rudder forward of the centre of gravity, the Wright patents covering also a pair of rudders, one forward and one at the rear, operated simultaneously. The Wright patents also cover a pair of vertical vanes, one at each end of the machine and situated between the horizontal planes. These vanes are each mounted on a vertical shaft, which has a pulley at its lower end, and these shafts are connected up by cables with the steering apparatus so that they can be turned to oppose the secondary movements which tend to become produced.

Fig. 119.—Constructional work on the Wright aeroplane, showing method of hinging struts and of securing eyes of stays.



The quick-turning movement of the Wright machine is one of its distinctive features, and is in strong contrast to the slow-turning ability of almost all French machines. Naturally, a very wide turn can be made on the Wright machine by the vertical rudder only, but in practice the wings are always flexed a slight degree at the same time.

In reality, turning is only a secondary object of the flexing of the wing tips, the most important being to maintain lateral balance. In such an unstable element as the air the aeroplane has a constant tendency to oscillate in all directions. The tendency to plunge or rear is corrected by the manipulation of the elevation rudder through the left-hand lever; the tendency to roll is overcome by the flexing of the wing tips. Should the aeroplane take a list towards the left, the vertical rudder would at the same time be inclined; if it is brought back to a vertical position this tendency would be corrected. The contrary, of course, applies if the heeling movement of the aeroplane is towards the right.

It will be noticed that, with the exception of the operation of the vertical rudder, which requires the lever to be pushed ahead for a left turn and rearwards for a right turn, all the controlling movements are natural. Thus, to descend, the operator leans forward and carries his left-hand lever with him; to ascend, he pulls on the same lever. To make a sharp turn to the left, he carries his right-hand lever in that direction (at the same time, of course, moving it forward). If the machine is inclined towards the left, he leans over with his right-hand lever in the opposite direction, thus causing the aeroplane to right itself. There is a certain analogy between the operation of a Wright aeroplane and the controlling movements of a cyclist. In both cases the movements are slight and are performed, after the apprenticeship period, almost unconsciously. The cyclist, for instance, who feels his machine skidding under him, cannot say exactly when he began the correcting movement with his body, nor when he left off. The aeroplanist who corrects the aerial skidding of his machine would have equal difficulty in saying just when he begins and ceases his correcting movements.

The Voisin Aeroplane.

The Voisin type of aeroplane, often spoken of as the Farman type by reason of the success of this aeronaut with a machine built for him by the Voisin Brothers, may be roughly considered as a Hargrave box-kite with a horizontal plane in front and a vertical rudder in the rear cell. Originally, it consisted of a couple of superimposed planes, with a vertical rudder in the rear and a horizontal elevation rudder in front. In 1905 the cellular tail was added and the main planes were fitted with vertical divisions; since then the machine has undergone many minor changes, but its main features have remained unchanged.

The aeroplane may be divided into five distinct parts: the chassis, an entirely metal structure carrying the wheels by means of which the aeroplane runs over the ground prior to taking the air; the fuselage, or forward framework, carrying the engine, pilot's seat, and all controlling organs; the main forward planes, divided vertically into three distinct cells; the tail or rear cell, containing a vertical rudder; and the framework connecting the two.

On the earliest models the wings were plane surfaces, united, as already described, by four vertical planes, and was, in fact, nothing more than a huge box-kite. Experience soon showed, however, that this form, though possessing remarkable stability when used as a kite, was altogether lacking in this quality when built to travel through the air under its own power. The surfaces were, therefore, given a slight curvature, both in length and in width, the exact degree of curve being determined after numerous experiments. The two main surfaces measure 32ft. 9in. from tip to tip, 6ft. 6in. from front to rear, and are distant from one another 6ft. 6in. The framework of each wing is composed of two long hickory members, 32ft. 9in. in length, united by a series of slightly curved cross members, flush with the wooden frame member at the front, but exceeding the one at the rear, thus giving a rigidity to the edge which meets the air, and a certain amount of flexibility at the rear. The skeleton thus formed is covered with rubber-proofed cloth. The upper plane is a replica of the lower one, and is joined to this latter by eight pairs of bamboo stanchions suitably secured by metal joints and strengthened by wire stays. The ends are enclosed by a canvas covering stretching from frame to frame and stanchion to stanchion, and two other vertical divisions are fitted, dividing the structure into three distinct cells, the central one being the largest. The depth of the vertical planes is less than that of the horizontal planes, the former being attached to the stanchions.

Fig. 120. — The Voisin straining screw with wire loops to prevent turning.

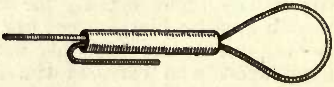


Fig. 121.—The Voisin eye at the end of wire stays.

The rear cell or tail, designed to fulfil the same functions as the tail of a kite, namely, to give stability to the main member, is much smaller than this latter, the measurement from side to side being 8ft. 9in. It is constructed, like the forward cells, of a wooden framework, covered with canvas and strengthened by wire stays, but its two ends are completely closed in. Between the two horizontal planes is a vertical rudder operated at will by the pilot and pivotable in a manner that will be described later.

The distance between the rear of the forward planes and the front edge of the rear planes is 13ft., the connection being made by four frame members united by stanchions and suitably strengthened by stays.

All the mechanical organs of the aeroplane are mounted on a special framework known as the fuselage, and represented by Fig. 122. It has, roughly, the form of a flat-bottomed hydroplane boat, and is formed of four longitudinal members united by vertical members suitably trussed. In order to offer less

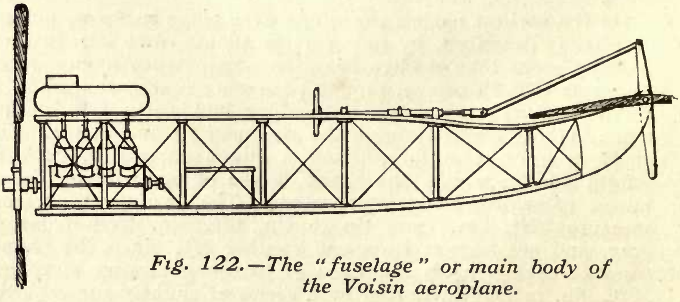


Fig. 122.—The "fuselage" or main body of the Voisin aeroplane.

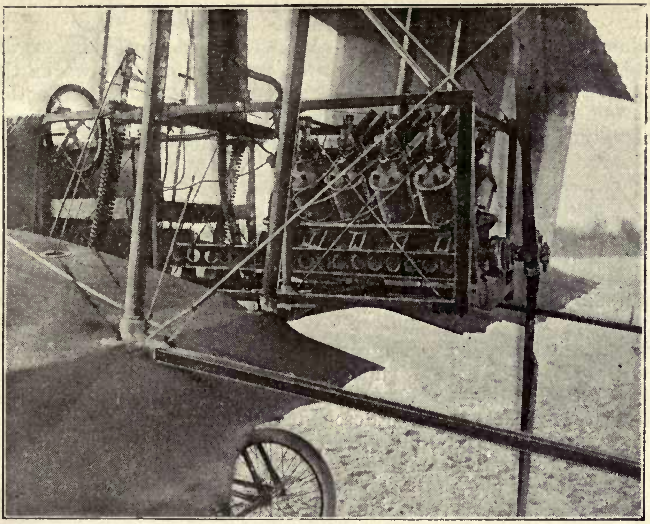


Fig. 123.—The rear of the "fuselage" of the Voisin aeroplane.

resistance to advancement, the framework is covered with rubbered cloth. The fuselage may be regarded as the main framework of the aeroplane, for to it are attached the fixed wings and the chassis carrying the wheels, while, mounted at its rear, is the engine and propeller and, immediately in front of this, the pilot's seat. At the front of the fuselage is the elevation rudder, consisting of two horizontal planes, each 6ft. 6in. in width and 3ft. from front to rear, pivoted as shown in Fig. 122, so as to vary the angle of inclination and determine the rise and fall of the aeroplane.

The chassis is an entirely metal structure mounted on pneumatic-tyred wire wheels and secured to the fuselage. It is fitted with powerful shock absorbers, and the wheels are mounted in the same way as castors, being free to turn in any direction. This is necessary to prevent breakage when landing, a fixed wheel always buckling up, whereas these "orientable" wheels, as the French term them, allow of settling down without any damage. Henry Farman has made over 300 descents with this type of wheel without a single breakage. The tail of the apparatus is also fitted with a pair of wheels, free to turn in any direction, of much lighter construction than those in front, their only work being to keep the rear cell from touching the ground.

A single steering wheel, mounted at the extremity of an almost horizontal steering column, controls all the movements of the Voisin biplane. It carries a drum A (Fig. 124) round which is wound a flexible wire cable carried along the frame members to the rear vertical rudder. Thus, a turn of the steering wheel to the right will ship the vertical rudder in the same direction and cause the apparatus to turn to the right. A turn of the wheel to the left will have the contrary effect. In addition, the steering wheel can be pushed away from or pulled towards the pilot, the shaft on which it is mounted having a squared section to allow of this movement. On being pushed ahead, the front elevation rudder is lowered, as can readily be understood from an examination of the diagram. A pull towards the pilot raises the front edge of the rudder and lowers the rear edge, the effect of this displacement of the plane being in the one case to cause the aeroplane to descend, and in the other to raise it. A universal joint (N) allows the plane to be operated whatever the position of the steering wheel.

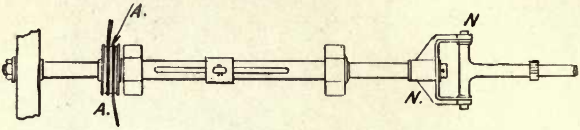


Fig. 124.—The steering shaft of the Voisin aeroplane.

Although the most important flights of Farman and Delagrange were made with an eight-cylinder Antoinette motor, there is no standard type of engine for Voisin biplanes. Recently a number of comparatively heavy-weight four-cylinder engines have been employed, while the Voisin Brothers themselves have a special four-cylinder motor of their own design now under construction. In every case, however, the motor is mounted on the rear of the fuselage, on a level with and near the rear of the lower plane. The Antoinette engine used by Farman and Delagrange drove a two-bladed steel and aluminium propeller having a diameter of 7ft. 6in. and a pitch of 4ft. 7in. The propeller was keyed directly to the main shaft of the engine, revolving at 1,050 revolutions a minute.

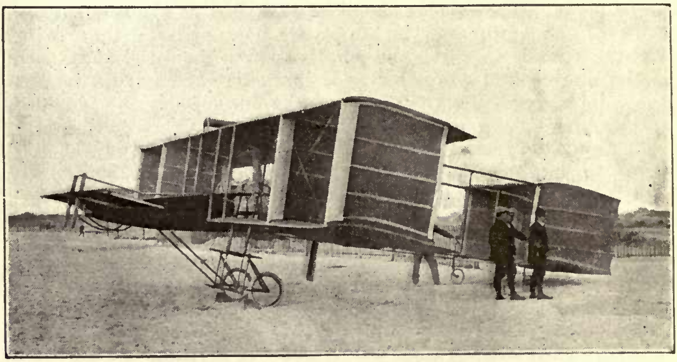


Fig. 125.—A Voisin aeroplane.

R.E.P. Monoplane.

Robert Esnault-Pelterie's flying machine, commonly known as the R.E.P., is one of the few that have been entirely designed and constructed by one man. The machine is a monoplane with a pair of flexible wings capable of being warped by means of four cables. The rear horizontal surface, or tail, fulfils the conditions of elevation rudder, and between it and the main wings is a vertical fin to assure lateral stability. The flying machine is mounted on two wheels placed tandem fashion, and on a light wheel at the extremity of each wing, the latter being brought into use only when a start is made. The main wheels are shod with pneumatic tyres and fitted with powerful pneumatic shock absorbers, the chassis to which they are attached being of steel tubes united by oxy-acetylene welding. The motor is at the front of the apparatus, and drives a four-bladed propeller mounted direct on its main shaft.

A feature of the R.E.P. aeroplane is its compactness, the length from wing tip to wing tip being 31ft., and its length from front to rear 26ft. Frictional resistance had been reduced to a minimum, and excellent construction has allowed the weight to be reduced to 925lb. for a total bearing surface of 163 sq. ft. The wings are constructed of a wooden framework with steel and aluminium joints, covered on their upper and lower faces with rubbered cloth. By reason of their flexibility and four flat steel stays, two under each wing, they can be raised and lowered in opposite directions—the right one being raised and the left one lowered, or vice versâ—in order to assure lateral stability or assist in making curves. The pilot's position is in a small cockpit between the two wings, and behind the motor.

The rear members consist of the tail, a plane surface capable of being raised or lowered at the will of the operator in order to determine the rise or fall of the aeroplane. The balanced vertical rudder is placed under the horizontal elevation rudder, and at the rear of the chassis. In its neutral position it constitutes, together with the vertical fin above and slightly ahead of the horizontal plane, a powerful equaliser imparting lateral stability to the aeroplane. The entire framework of the machine is covered in with rubbered cloth.

The engine employed is a seven-cylinder air-cooled R.E.P., the features of which are set forth in the chapter devoted to aeronautical engines. It develops 35h.p., and being right in the bow of the apparatus it receives a sufficient current of air to keep it cool so long as a speed of 28 miles an hour is maintained.

Control of the aeroplane is combined in two vertical levers to the left and right of the pilot. The left-hand lever, mounted on a universal joint, is capable of being moved in any direction, a lateral movement operating the wings, raising one and lowering the other, while a movement ahead or astern lowers or raises the rear elevation rudder. Lateral direction is assured by the right-hand lever, the turns being made in the direction in which it is desired the aeroplane should go. An illustration of the R.E.P. machine appears on p. 72.

Henry Farman.

Henry Farman's aeroplane No. 3, designed and built by himself, is similar in general features to the Voisin biplane he formerly piloted. The two main planes measure 34ft 6in. from tip to tip, and the length of the apparatus from front to rear is 42ft. 6in. The two planes are united by eight pairs of stanchions strengthened by wire stays, and, as on the first biplane used by Farman, are without vertical planes. Ailerons are fitted to the rear of each wing, a suitable arrangement allowing of their manipulation at the will of the pilot. The peculiarity of the rear cell is that it does not contain a lateral rudder, movement to left and right being obtained by warping the extremities of the two vertical planes. In front is a single elevation rudder in place of the two separate rudders on the Voisin machine. The framework known as the " fuselage " on the Voisin machine has been abolished on the new Farman, the motor, a four-cylinder Vivinus of comparatively heavy weight, being carried on a suitable base and attached direct to the centre of the lower plane. A one-piece two-bladed propeller, having a diameter of 7ft. 6in., is mounted directly on the end of the propeller shaft, revolving in the space between the main frame members uniting the front and rear planes. The pilot's position is immediately in front of the engine, seated on the fore edge of the lower plane.

A combination of skates and wheels has been employed for starting the machine and settling down to earth. Under the forward planes are two pairs of pneumatic-shod wire wheels, the inner one of each pair being slightly smaller than the outer one. Between the two is a long wooden skate stoutly attached to the planes, just clearing the ground at the front, but in contact with it at the rear. The tail is prevented from touching the ground by a couple of small wheels free to turn in any direction.

The Avroplane.

A triplane is A. V. Roe's latest type of avroplane (A. V. Roe plane). It is equipped with a two-cylinder 10h.p. J.A.P. air-cooled engine, which drives a four-bladed propeller of 7ft. diameter. The machine weighs no more than 250lb., which, with 150lb. for the aviator, makes a total weight of 400lb. This works out at 40lb. per h.p., which is in excess of the 25lb.

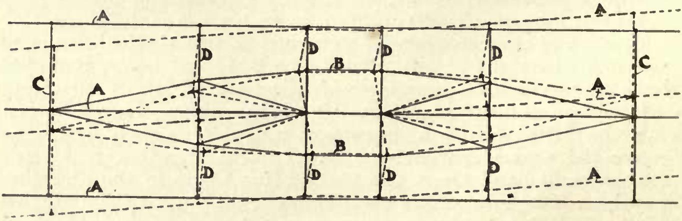


Fig. 126.—The system of warping the wings of the Roe aeroplane.

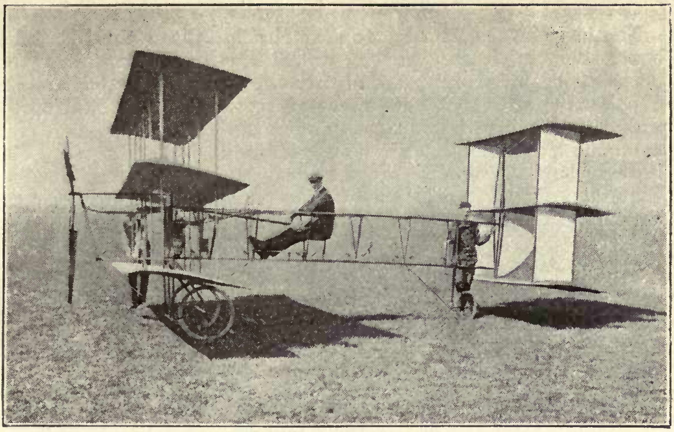


Fig. 127.—The A. V. Roe aeroplane or "Avroplane."

per h.p. usually carried by the successful French aviators. From tip to tip the main planes measure 20ft., and they are 3ft. 7in. deep. The tail is 10ft. wide and of the same depth as the main planes. The planes are set 3ft. 2in. apart. The overall length of the machine is 23ft. The total surface is 320 sq. ft., which works out at just 1¼lb. per sq. ft.

The machine has several novelties, of which the chief are the steering gear and the method of bracing and twisting the main planes to control the vertical and lateral course of the machine. The rear vertical rudder is turned by a rotary movement of the wheel, the rear planes or tail being fixed firmly to the body of machine.

The tilting and twisting of the main planes is carried out entirely through levers and rods, without the use of any cords or pulleys whatsoever, thus removing one source of danger in an aeroplane.

The central main plane (A) (Fig. 126) is braced from end to end by the wire braces (B), so that a girder unalterable in shape is secured. Vertical struts (C and D) carry the upper and lower planes and cause them to be warped similarly to the main central plane. To permit this movement (which would not be possible with stiff struts forming part of the girder), the struts marked D are all thinned in the middle so that they may bend as indicated by the dotted lines. The struts C, of course, do not require to be otherwise than stiff. Connections are made between the middle plane at its rear edge, through rods and levers, to the column of the steering wheel. The rocking up and down of this column moves the main planes and alters the angle of incidence; turning the steering wheel twists the main planes and moves the rudder at the same time.

Mr. Roe has not yet succeeded in making flights of any length: we fear that his aeroplane is underpowered.

Antoinette Monoplane.

The body of the Antoinette very closely follows the lines of a boat, the transverse section of which is triangular, and the planking replaced by a light canvas covering. The boat has a fine bow, and even at its greatest section is only sufficiently wide to allow of a narrow cockpit for the pilot, about one-third from the bow; the rear gradually narrows to a fine taper. The bearing surface consists of two wings to left and right of the boat-shaped body, and slightly raised so as to form a very open V, 42ft. from tip to tip. The surface of the wing is slightly curved, the exact form having been decided upon after numerous experiments with a view to determining the greatest sustaining power with the least resistance. Both surfaces of the wings are covered with fine varnished silk.

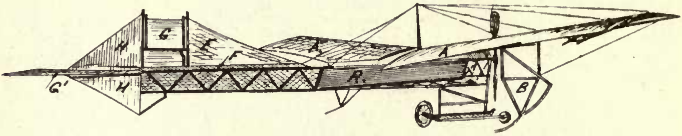


Fig. 128.—The Antoinette monoplane used by Mr. Herbert Latham.

At the rear extremity of each wing are carried what are known as ailerons, or supplementary bearing surfaces, pivoted to the rear of the main wing with the object of assuring transverse stability when making turns or when flying in a wind. In their normal position the ailerons are a prolongation of the main wing surface. They are connected together, and by means of a suitable lever can be made to occupy a position perpendicular to the wings, one of the ailerons being raised while the other is lowered. The same effects are procured with this system as with the flexing of the wing tips on the Wright type of aeroplane.

On the Antoinette monoplane all the rudders are at the rear. For the purpose of turning, the fin E, Fig. 129, is prolonged by another vertical plane pivoting round this latter, and in the illustration shown slightly to the right, this being the position it would occupy when about to make a turn to the right. This vertical rudder (H) is duplicated by one in the same plane, but separated from it by the elevation rudder (G), being a prolongation of the fin (F), when in a horizontal position.

The driver's position has been selected to give the maximum security. It is a small cockpit within the frame, and level with the rear of the wing tips; in case of accident it would be necessary for the whole forepart of the apparatus to be demolished before the pilot could be reached. To his right and left, and mounted on a horizontal axis, the pilot has an ordinary type of motorcar steering wheel. The one on the right controls the rear horizontal plane forming the elevation rudder; thus if the wheel is turned ahead the plane is lowered and the aeroplane descends. A similar wheel on the left controls the ailerons,

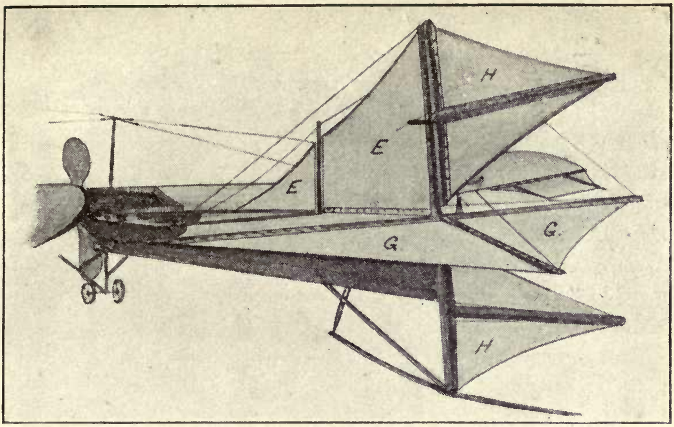


Fig. 129.—Vertical and horizontal rudders of Antoinette machines.

raising one and lowering the other, thus giving lateral stability in winds and assisting in making turns. The vertical rudder at the rear is operated by a horizontal foot lever and connecting cables. The pilot has a smaller wheel mounted on the end of a horizontal shaft running forward, immediately in front of him, this controlling both the petrol pump regulating the supply of fuel to the engine, and the position of the spark when running on accumulators. The engine, naturally an Antoinette, is carried in the bow of the apparatus, with its two-bladed steel and aluminium propeller mounted direct on the forward end of the main shaft. The radiator for the 50h.p. engine only weighs 26lb., and has a cooling surface of 130 square feet. It is composed of a number of long, fine section aluminium tubes placed on the side of the boat-shaped hull, as shown at R in Fig. 128, in which position the tubes receive a strong current of air while offering practically no resistance to advancement.

The Antoinette monoplane is mounted on a skate, with a couple of struts under the centre of each wing, and a strut under the tail. The skate extends about 3ft. ahead of the apparatus in order to protect the engine from shock in case of a violent descent. It is connected to the body of the aeroplane by two shock absorbers, one of them being placed exactly under the centre of gravity and the other further forward.

The Cody Aeroplane.

The Cody aeroplane is the result of the designer's experience in kite work embodied in a design on accepted lines. The Cody is a biplane, each plane being 52ft. long and about 6ft. 9in. wide, and presenting a sustaining surface of approximately 1,000ft. super. The framework is largely tubular. The two planes, attached to each other by 12 uprights and covered with

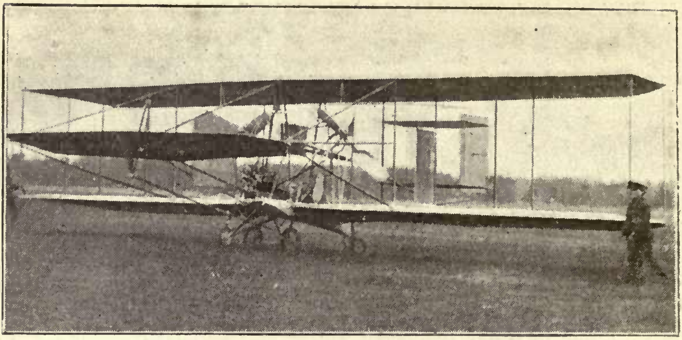


Fig. 130.—The Cody aeroplane on Laffan's Plain, 1909.

rubber-proofed canvas, are quite flat. Since it was first brought out, the Cody machine has undergone many changes. At the time of writing it has just undergone some further alterations, and now has the righting planes (horizontal) at the rear instead of in front as formerly, while it also has righting planes (vertical) at each end of the plane. Rudders are placed both fore and aft. The power is provided by an eight-cylinder water-cooled Antoinette engine of 50h.p. The radiator is composed of copper tubes. A new engine of 80h.p. is to be installed as soon as possible.

Howard Wright Aeroplane.

Both monoplanes and biplanes have come from Mr. Howard Wright, but it is with the two-decker that experience has been gained by this designer. On his restricted flying ground at Fambridge the machine has frequently left the ground in the small area available. Two unique features distinguish the design: the tubular steel framing and the twin propellers revolving in opposite directions on the same shaft. The main surfaces of the machine present a lifting area of 520 sq. ft., the tail offering another 100 sq. ft. With a 50h.p. four-cylinder Metallurgique motor, running at 1,500r.p.m., the soaring speed is 25m.p.h. and the flying speed 36m.p.h. A peculiar gearing, which baffles description and at first deceives even the eye of the trained engineer, provides the three-to-one speed reduction to the propellers and the reverse motion to one of them. Only three gearwheels are necessary, although a fourth is added for balance, and by a seemingly paradoxical movement two-thirds of the torque is transmitted to one screw and one-third of the torque to the other screw. With the same diameter for both propellers, the double thrust on one is obtained by the use of four blades, each of the same area as either of the two blades of the second propeller. Elevation is obtained by means of a horizontal rudder in front. Lateral stability is governed by the "ailerons" attached to the four after corners of the main planes, the four "ailerons" being simultaneously

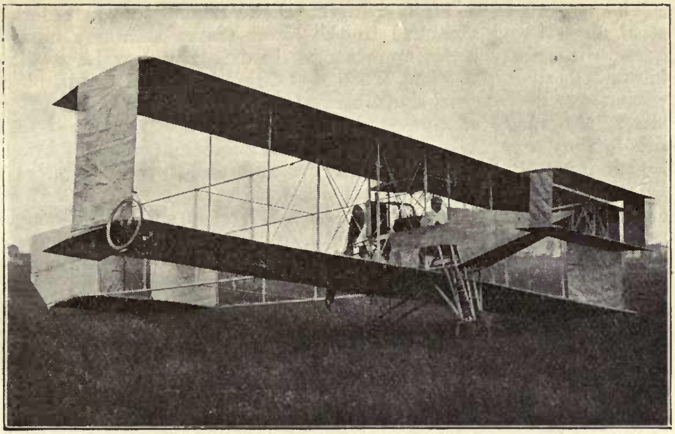


Fig. 131.—Mr. Howard T. Wright's aeroplane : Mr. Malcolm Ker-Seymer, pilot.

controlled by a single movement on the part of the aviator. They have this distinction from other " ailerons " that they have as much upward as downward movement. The machine runs over the ground on two wheels only, one under the aviator, the other under the tail. Two grounding wheels are fitted under the extremities of the lower main plane to preserve the wings from damage. An advantage of this bicycle mounting is that the budding aviator learns to obtain lateral balance before leaving the ground, and is thus at an advantage when he first rises in the air.

The Bleriot Monoplane.

" Bleriot XII.," the most recent of Louis Bleriot's series of monoplane flying machines, appears to be the most successful of them all, for it has proved capable of carrying two passengers with ease. The wings, which appear to measure 42ft. from tip to tip and to be about 6½ft. from front to rear—the builder wishes to withhold the exact dimensions at present—have a considerable curve from front to rear, have their angles widely rounded off, and are covered on both upper and lower faces with fine canvas. Below the main wings are two small horizontal planes attached to the lower frame members. At the rear are two horizontal planes, an upper one, fixed, but mounted on hinges so that the angle of inclination can be varied as found necessary, and a lower one a little further to rear, pivotable at the will of the pilot to form elevation rudder. Above the framework, and about one-quarter from the rear, is a large lateral rudder, being a square with the angles rounded off. An addition made to the machine takes the form of a jib-shaped fin placed ahead of the lateral rudder, this having been found necessary to increase the lateral stability of the aeroplane.

The engine is an eight-cylinder E.N.V. mounted on a light steel chassis and attached to the lower frame members immediately in front of the apparatus. It drives a very large diameter all-wood propeller, built by Chauviere, by means of a pinion on the engine shaft and single chain to the propeller shaft, the speed of the propeller being reduced to about 600 revolutions a minute. The pilot's seat is set across the lower frame members, behind the engine and under the wings. In this position M. Bleriot declares that he is better protected than in any other, for in case of a fall it is the motor which receives the shock, and not the pilot; while being placed near the ground, he is able to make his descents with greater certainty than when mounted higher. The seat is of sufficient width to accommodate two persons, but it has been found that a passenger by the side of the pilot alters the centre of gravity, better results being obtainable with the passenger sitting on the frame a little ahead of the pilot and facing him.

"Silver Dart."

"Silver Dart" was the fourth flying machine made by the Aerial Experimental Association. She was built at a quiet little watering place called Baddeck, on Bras d'Or Lakes, N.S. She is a biplane, the planes being bowed so that the ends converge towards one another. They are also arched, and are placed with the concave sides facing each other. Each plane is 6ft. wide and covered with vulcanised silk. The planes are rigid, with the exception of small triangular wings at the extreme tips. At the rear is the rudder. The elevation is controlled by a horizontal rudder (two planes) fixed in front. The power is obtained from an eight-cylinder air-cooled Curtis engine (V type) developing 50h.p. This drives a ten-bladed wooden propeller by means of four V leather belts.

With "Silver Dart" J. A. D. McCurdy has equalled the feats of Farman and Bleriot in flying across country. His best record in this respect is 20 miles. On that occasion the course lay over ice, across the town of Baddeck, over woods, etc. McCurdy, after this flight, stated that he saw no reason why ten times the distance should not be accomplished soon. It was only a matter of getting every detail perfect. He also stated that the question of lifting weight was a problem they had solved. What they wanted now was a propeller that would give greater forward thrust.

Short Brothers.

Besides the dozen machines which they are building in this country under the Wright Bros.' patents, Messrs. Short Bros., of Battersea, London, and of Sheppey, Kent, are devoting attention to aeroplanes of their own design. At the Aero Show of 1909 the main framing of one of these machines was exhibited, but during the intervening period many alterations have been made in the details. Messrs. Short Bros. are pursuing a policy of reticence, and up to the time when this book has gone to press have asked us not to make public any information about their aeroplanes.

AEROPLANE SPARS, RIGGING, AND FITTINGS.

The structure of an aeroplane consists of three principal portions, in addition to the propelling machinery, and these three may be termed (1) the struts or members of the framework which are under compression, torsion, or cross strain; (2) the tension rods or wires; and (3) the material of which plane surfaces are made. In the case of the first two portions of the structure, aeroplane constructors might do worse than turn to the builders and designers of light racing sailing boats and canoes, as, in these little craft, piano-wire stays and hollow spars have been brought to a high state of perfection for some years. Probably, every possible variety of spar has been tried in these vessels at some time or other, from the original solid stick to the modern hollow spar, which has superseded everything else, next in value being the bamboo. Of all these kinds, the one now in use consists of a piece of perfectly clean-grained Californian or Nova Scotian spruce, cut in half lengthways, and, after the centre has been scooped out, glued together again. These spars are only about 30 per cent. of the weight of a solid spar of the same size and material, yet they have about 75 per cent. of the strength of the solid wood, thus showing a great advantage, which more than counterbalances their high price. After the two halves are glued together they are screwed up between two planks by means of a series of cramps, as, unless the glue is under great pressure, a good joint cannot be obtained. The two principal makers of hollow spars in this country are Messrs. G. Hollwey and Sons, of Dublin (who were the first firm in Great Britain to take up the manufacture of hollow spars), and Messrs. A. Burgoine, of Kingston-on-Thames, who have made several hollow frames for the Clarke aeroplane. Many people think that a bamboo is as light and strong as a hollow spar of the same size, but this is by no means the case, as a series of tests carried out by us some years ago proved the hollow spar to be 15 per cent. lighter and nearly 20 per cent. stiffer than a bamboo of the same length and diameter. In the larger spars the difference in favour of the hollow spar is even more marked, as the shell can be kept thinner in proportion to the outer diameter. Steel tubes have often been tried in place of wooden spars, but they are not so good, being heavier for a given strength, and, moreover, they are prone to buckle and dent.

Wire Stays.

Quite as important as the wood frame is the wire used for the stays and the method of attaching it to the frame, as lightness and neatness are essential on the aeroplane. It is of no use to fasten off the ends of the wire in such a manner that they will slip, or in any other way be weaker than the rest of the wire. Before going further into the details of the end fastenings it will be well to consider the nature of the wire employed. This should be the best silver-plated piano wire, which may be bought in 50ft. coils of various gauges; No. 26 is about .06 diameter or, say, .002 sq. in. in sectional area, and as the breaking strain is over 800lb., the tensile strength is about 125 tons per sq. in.! The next size smaller has a breaking strain of about 520lb., and is quite strong enough for many of the lighter parts of the machine. The weight of the No. 26 wire is approximately 2¼lb. per hundred yards and the smaller size about 1¾lb. for the same length. This piano wire is not easy to obtain of the best quality, and unless it is absolutely reliable it is of no use to the maker of aeroplanes. Although the wire is very stiff, it is not tempered, but is merely drawn hard and not annealed; this makes the wire very strong without being brittle, and so soft is it that it can be cut with any ordinary wire cutters without damage to the cutting edges. It can also be filed to a point with a fine saw file, but there is one thing to be carefully avoided, and that is heating it in any way. For this reason it must never be soldered, as that will greatly reduce its strength at the point where it has been heated. In addition to being easy to cut, this wire can be bent flat upon itself and then straightened out again without breaking, and it can be twisted up as tightly as possible round itself without difficulty or damage; but so flexible is it that, when under great strain, the twisted portion will pull out straight; therefore, it is not a safe way to fasten the ends unless several turns are first taken round some fixed object. Fig. 132 shows an ordinary twisted eye in the end of a piece of piano wire, which, although it is the simplest and lightest way of making an eye, is, as I have just said, not to be trusted. Fig. 133 shows a somewhat similar eye, but in this case the wire is taken round a light heart-shaped thimble, and, when twisted at the end, solder is run into the twisted portion

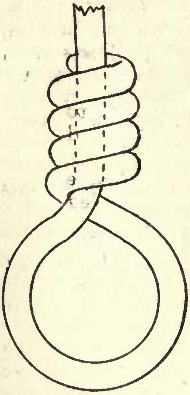


Fig. 132.—An ordinary twisted eye of wire.

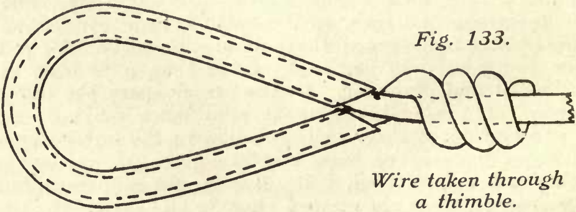


Fig. 133.

Wire taken through a thimble.

and round the thimble with a blow pipe. This will prevent any possibility of the wire slipping, but it will also reduce the strength at that point, so neither of these two methods is to be considered satisfactory. Figs. 134-138 show a simple form of shoe which we have devised for this wire, and which we have found quite satisfactory after two years hard testing. The drawings show a front and back view, a section through the centre of its length and plans of the top and bottom. It will

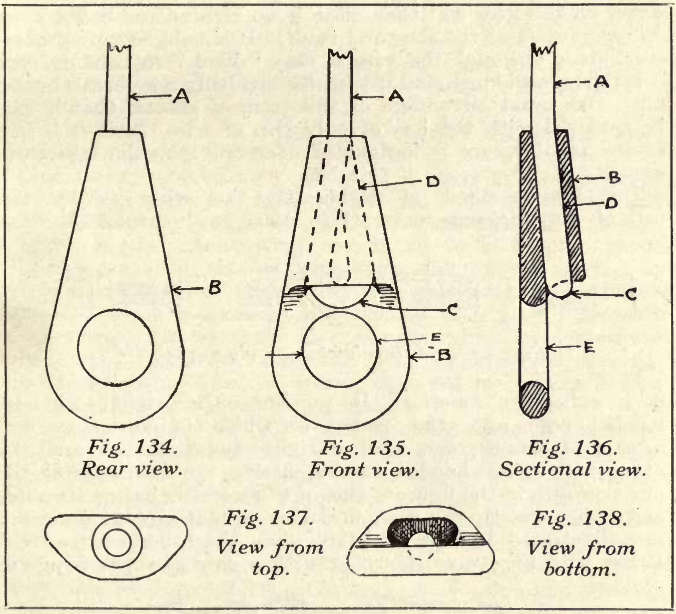


Fig. 134.
Rear view.

Fig. 135.
Front view.

Fig. 136.
Sectional view.

Fig. 137.
View from top.

Fig. 138.
View from bottom.

The Hope Rigging Eye.

be seen that the shoe consists of a small stamping of steel or gunmetal with a flattened conical end through which the wire passes. This end has two holes of the same size as the wire, drilled at a small angle, so that, while they start side by side underneath (Fig. 138), they both come out of one hole at the top (Fig. 137). Another method in the smallest shoes when they are made of gunmetal is to drill a central hole and drift it out at the bottom to twice its width or a little more. The lower part of the shoe may have an eye as shown in the foregoing figures or it may be one of the ends of a rigging screw as in Fig. 139. In all cases the method of attaching it to the wire is the same, and can easily be understood from the illustrations. In these figures A is the wire, B the shoe with an eye (E) at the lower end, D is the tapered hole in the upper part of the shoe, and C is the end of the wire (A) bent round upon itself and driven up into the tapered hole in the shoe. The method of fitting the shoe on the end of the wire is as follows:—The wire is passed down through the shoe from the small end or top. It is then bent slowly over until the end is turned back upon the main piece at a sharp angle, but, before it is bent far enough to touch it, the point is filed off on the inside to a long bevel, so that, when the two parts are closed together with the pliers, they form a reverse taper, which fits closely into the tapered hole in the shoe as in D (Fig. 135). If the wire is carefully filed and bent, it should jam tightly in the shoe, and the strain on the wire will then close it up tighter and cause it to grip the inside of the shoe and itself. It should be noted, however, that, although the wire is very " kind " in bending, yet it is fairly hard steel, and if bent too suddenly may break in the nip. One great advantage of this form of shoe is that it can be removed with the loss of only ½in. of wire, as if it is cut at the point where it is doubled over only the short piece is wasted.

The best method of tightening the wires is by the use of the rigging screw (Fig. 139) or " turnbuckle," as it is called in America. It consists of a right and left-handed bow nut, the centre of which is cut away and a pair of screws, one with a right-handed thread and the other with a left-handed thread, fitting the two ends of the nut as shown in the figure. One of these screws has on its outer end a shoe exactly the same in design as that already described and illustrated in Figs. 134-138, while the other end is fitted either with an eye as shown or with a pair of shackle lugs as may be most convenient. With a screw of this description any degree of strain can be put on the wire, but great care must be taken in selecting the screws, as unless they are of the very best quality, they are very apt to break at the end of the thread. For this reason it is always safest to have the screws nearly twice the diameter of the piano wire, and the threads should be carefully examined, while the nuts should be as long as possible. Screws of a size suitable for the fine wire required can now be bought ready made, and, no doubt, as the demand for aeroplanes increases, both shoes and rigging screws will soon be obtainable as a stock article.

Fig. 139.—A turnbuckle or rigging screw.

Fig. 140.—A simple rigging screw made out of a short cycle spoke and nipple, and two strips of metal.

COVERING MATERIALS FOR AEROPLANES.

Of the various kinds of materials used for covering the aeroplanes of flying machines, fine quality canvas, treated or untreated, is generally used. Several firms supply it covered on one or both sides with a very fine coat of indiarubber. The material thus treated will weigh anything between four to nine ounces per square yard. The joints are solutioned and sewn, making a waterproof joint. It is rather expensive, costing from 4s. to 7s. a square yard.

M. Santos Dumont is using oiled Japanese silk on his latest aeroplanes. This is naturally costly, but it is very light.

Fine canvas covered with pegamoid is likely to become popular with some aeroplane builders. It has a smooth surface and is about the same weight as rubber-treated material, but considerably less in price, costing from 1s. 6d. to 3s. a square yard.

Unless canvas is treated with some damp-proof solution it will be found to alter considerably with the weather. Ordinary untreated aeroplane canvas will slacken to a very noticeable extent during wet weather. A cheap damp-proofing for canvas is boiled oil, which can be applied by an amateur with a large-size paint brush. This, of course, does not make such a nice smooth surface as rubber or pegamoid.

The most difficult part to which covering material has to be attached is the underside or concave part of ribs. The material is usually sewn on, but a simple way is to use special big-headed nails and grips, which are being made specially for this purpose.

Some experimenters use paper backed with muslin, and then varnish the planes after they are made up. This method lends itself to easy repairing. M. Bleriot has used a strong paper parchment for some of his machines. A. V. Roe has recently been using a cotton oil paper covered with muslin, weighing only two ounces per square yard. This can be bought prepared, and is applied damp and glued on. When dry it has a smooth, drum-like surface. If experiments are likely to be carried out in rainy weather, the joints or, indeed, the whole surface should be covered with a thin coat of oak varnish or boiled oil. It is naturally not so strong as canvas, but can be easily repaired with the aid of the glue pot, and is a suitable and very cheap covering material for beginners.

Aluminium cloth woven with very fine threads of aluminium wire has recently been discussed, but very thin aluminium sheets would be no heavier, and would have a very smooth surface.

Another material of rather different construction is manufactured by Hutchinson, the French tyre maker. It is made of finest-grade Egyptian cotton, the outer diagonal being dyed yellow with chromate of lead to protect the rubber proofing from the sun's rays.

The material used by Farman, Voisin, Wright (in one instance), and others is made by the Continental Tyre Co.

PROPELLERS.

Of propellers and propelling devices there is a great variety, each the object of the supreme belief of its inventor. Some have reached the experimental stage, others have not got thus far, but up to the present time it has generally been found that some type of screw propeller is most suitable for practical work.

The aerial screw propeller differs little in its action from its marine prototype, each depending for its action on the imparting of a sternward velocity to a column, in the one case, of air and, in the other, of water. When the propeller screws itself forward the air slips past the blades, so that the propeller does not move forward so quickly as if there were no " slip." The distance moved forward at every revolution of the propeller, if there were to be no slip, is called the "pitch." Thus in Fig. 141, neglecting slip, a point on the propeller blade tip, instead of merely revolving in the circle B C D E F also advances the " pitch " distance A B. The resultant path which the tip actually takes is therefore B G H K L. The pitch multiplied by the number of revolutions per minute is the distance moved forward per minute. This will be the speed of the machine if there were to be no " slip." If " slip " be taken into account,

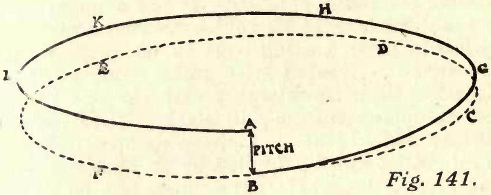


Fig. 141.

Speed of machine (in ft. per min.) = Pitch (ft.) × revs. per min.—slip (ft. per min.).

The slip velocity is that which is imparted to the column of air upon which the propeller acts. The thrust that is obtained from the action of this column of air is equal to

Weight of mass of air acted upon per second × slip velocity (ft. per sec.).

In the case of a stationary propeller there is no forward movement, so that there is only the slip velocity to consider, which is then much greater. At first it would appear that the thrust at starting would be much greater than when the propeller is travelling through the air, owing to the slip velocity being so much greater. It is found experimentally that this is not the case. In Sir Hiram Maxim's experiments, the thrust, with the propeller travelling at 40 miles per hour, was the same as that when the propeller was stationary, the revolutions per minute of the propeller remaining constant throughout. The reason for this is that, although the slip velocity is decreased, the propeller acts upon undisturbed " virgin " air, the equivalent of acting upon a greater quantity of air.

Great claims are often advanced, as to the thrust per h.p. that can be obtained with a given propeller. This quantity—the thrust per h.p.—cannot exceed a certain figure for a given pitch and number of revs. per min., as the following will show: The thrust multiplied by the number of revs. per min. and by the pitch gives the work done per minute. This figure divided by 33,000 gives the h.p. required to do the work, or

$$\text{H.P.} = \frac{\text{Thrust} \times \text{R.P.M.} \times \text{Pitch}}{33{,}000.}$$

The maximum value of the thrust per h.p. for any given number of revs. per minute and pitch (in feet) is therefore equal to

$$\frac{\text{Thrust}}{\text{H.P.}} = \frac{33{,}000}{\text{Pitch} \times \text{R.P.M.}}$$

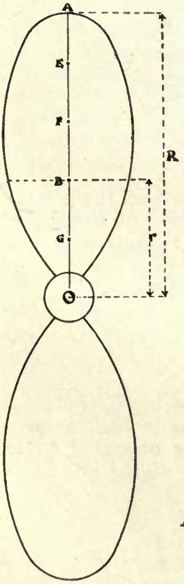
If the propeller is a good one, the thrust per h.p. will almost coincide with the amount calculated from the right-hand side of the equation above.

This holds good for a stationary propeller, but if the propeller travels through the air the thrust that will be obtained is

$$\frac{\text{H.P.} \times 33{,}000 \times \text{efficiency of propeller}}{\text{Speed of machine (ft. per sec.).}}$$

The whole blade of the propeller has to move forward the same amount. The parts near the boss will thus have to be set at a steeper angle, since the distance they move through circumferentially is less. Fig. 142 shows this more clearly. The outside tip (A) of the propeller moves round a circumference equal to 2 π × R every revolution. At any point B on the blade where the radius is r the distance moved through per revolution is $2\pi r$.

In both cases the point (A or B) must advance a distance equal to the pitch. Thus in Fig. 3, A O and B O are the distances $2\pi R$ and $2\pi r$ respectively through which the parts revolve, and both move forward the same distance O C. The outside point A moves along A C, but the point B moves along a steeper path B C. By setting off points E, F, G (Fig. 143), corresponding to the circumferences through which the points at E, F, and G (Fig. 142) move, the angles at which the parts of the blade at E, F, and G must be set are obtained.



Fig, 142.

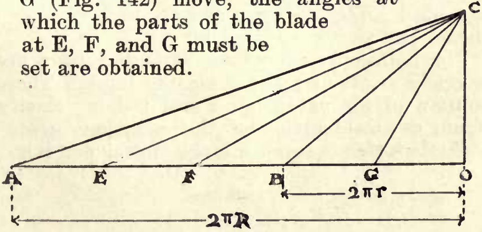


Fig. 143.

To determine with accuracy the thrust that a propeller will give and the h.p. that it will absorb requires a great amount of experimental work. Maxim tested his screws when stationary by mounting them on a shaft driven by belt from a steam engine. The shaft was free to move in its bearings and to one end of the shaft was fixed a spring balance, measuring the thrust due to the propeller when revolved. To test them when moving through the air, the screws were mounted at the end of a long arm, and the latter was rotated. By various ingenious means he measured the thrust when moving at a given speed through the air and at a given number of revolutions.

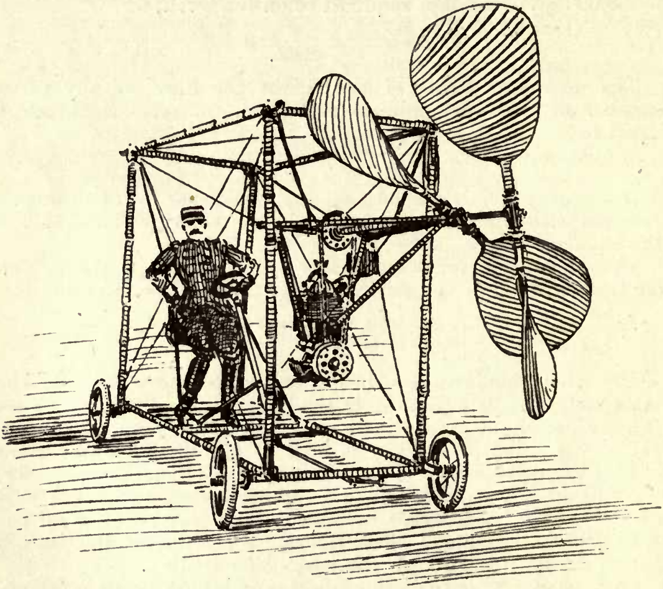


Fig. 144.—Capt. Ferber's road carriage for testing the values of propellers.

Captain Ferber carried out a series of tests on propellers by making them drive a small chassis. This arrangement ran along the road under its own power, and various measurements of thrust and power were made.

For heliocopteres, where vertical screws are used, the pitch is made small and the diameter large. There is then a large column of air acted upon and a low velocity imparted to it. From a consideration of the equations given above it will be seen that this ensures a large thrust per h.p.

AERIAL MOTORS.

From the earliest stages of the flying movement it has been recognised that a power-producing plant of lower weight per horse-power than anything employed for land or marine travel must be procured for successful navigation of the air. Long before the petrol engine was sufficiently developed to be of service, special light-weight steam engines were constructed for early flying machines, two important examples of their use being on the Langley model aeroplane, probably the first power-driven, heavier-than-air machine to leave the ground, and on the Ader and the Maxim, the first man-carrying aeroplanes to accomplish flight.

But the petrol engine offered distinct advantages over the steam engine for use on aeroplanes, and, during the active period from 1904 to the present day, has been used almost exclusively. French engineers, in particular, recognised that, for flying to be successfully developed, the petrol engine, as used on motorcars, must be made lighter and, generally, more reliable. Thus, in France, experimental work in light-weight petrol engines has been carried on concurrently with researches in the best form of sustaining surfaces and methods of securing equilibrium, until, at present, there are at least a dozen successful aeroplane engines, all of the internal-combustion four-cycle type, but differing considerably from their predecessors built for use on motorcars. Now, certain aeronauts maintain that the search for feather-weight engines is labour lost, and that flights can be made with any well-constructed car engine. Facts, however, are against this theory, for all flights, up to the present, have been accomplished by special engines, even the Wright motor, the one which most closely approximates to the car type of engine, being specially lightened and distinctive in design.

Low weight per horse-power is undoubtedly not only desirable, but essential for driving an aeroplane. Smoothness of running, reliability and regularity are equally important, and it remains to be seen whether the newer light-weight engines, with six, seven, eight or fourteen cylinders, can be made as satisfactory in this respect as the standard but heavier type of engine with only four cylinders.

The Wolseley Engine.

The Wolseley Co. has taken up the construction of light engines for aerial work. The firm has reduced the weight of its new type to 8lb. per horse-power, this figure being inclusive of flywheel, ignition, water-pipes, gas-pipes, etc., everything necessary to the running of the motor being weighed. Although there are many lighter engines, the Wolseley Co. has

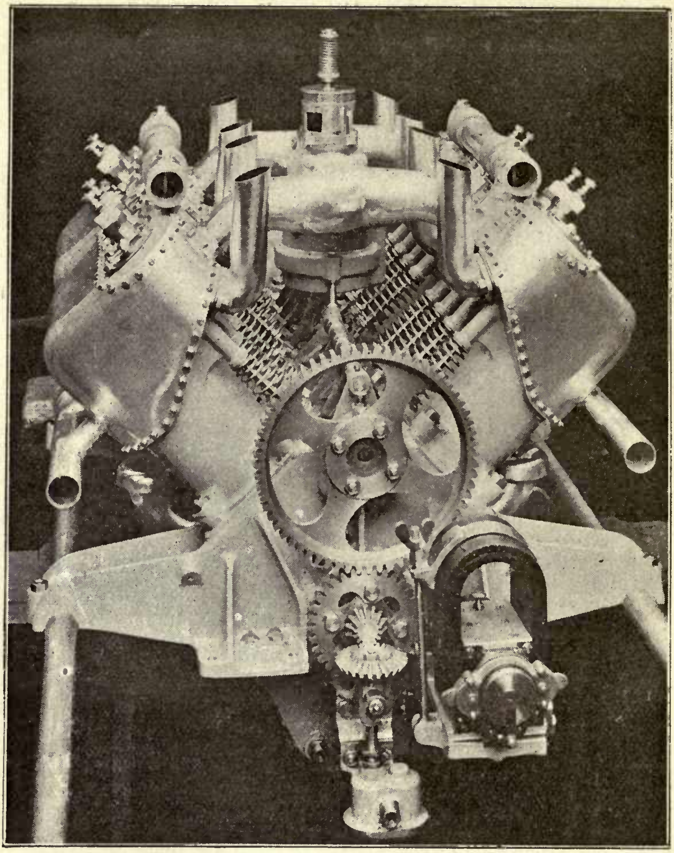


Fig. 145.—The Wolseley aerial engine.

not been led to reduce wholly the several working limits, its principal consideration being to produce a motor that can be relied upon to work for long periods at full load, without breaking down. The cylinders are set "V" fashion, four on either side of the crankcase, at 90 degrees to each other. The cylinders are cast in pairs, with jackets and liners in one piece, the metal being close-grained cast-iron, ground to gauge, the bore being 3¾in. and the stroke 5in. Sheet aluminium is employed for the water jackets, which are screwed to the cylinder castings. This method of construction allows the thickness of the metal to be uniform throughout, and offers advantages in the matter of cooling. The pairs of cylinders are staggered in relation to each other, the two connecting rods throwing on the same crankpin, and the big ends being of

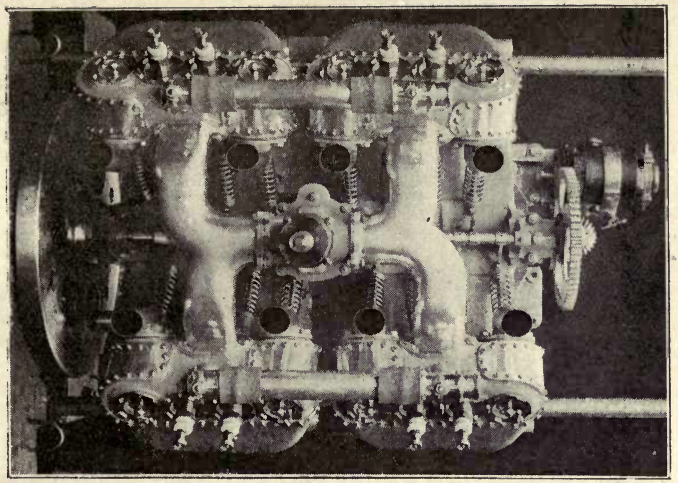


Fig. 146.—The Wolseley aerial engine seen from above.

phosphor-bronze, white metal lined. Three large bearings are provided for the crankshaft, and the lubrication is effected under pressure to all the main bearings and connecting rods. All the valves are side by side facing the centre, and are operated by a central camshaft, lifting shoes being interposed between the cams and tappets. The exhaust and induction piping is therefore situated between the cylinders over the top of the crankcase, the carburetter being mounted in the centre. Thermo-syphon cooling has been adopted. For the ignition, there is one eight-cylinder high-tension magneto running at crankshaft speed, a separate distributor being fitted and driven off the camshaft. One of the many good features of this engine is that the position of the carburetter enables a symmetrical induction system to be obtained, the distribution of gas to the cylinders being uniform.

The Gobron Engine.

Within each cylinder of the Gobron engine are two pistons, the upper one having its head turned downwards and connected up to an overhead beam, which in turn is connected to the mainshaft of the engine. Instead of the explosion taking place between the piston and the cylinder head, it occurs between the heads of the two pistons, which come together on the compression and exhaust strokes and leave one another, one ascending and the other descending, on the intake and power strokes. The principle will be understood by a reference to Fig. 147.

On the aeronautical engine there are eight cylinders, and consequently 16 pistons. Instead of being mounted vertically on the crankcase, as in the car engine, the cylinders form an X.

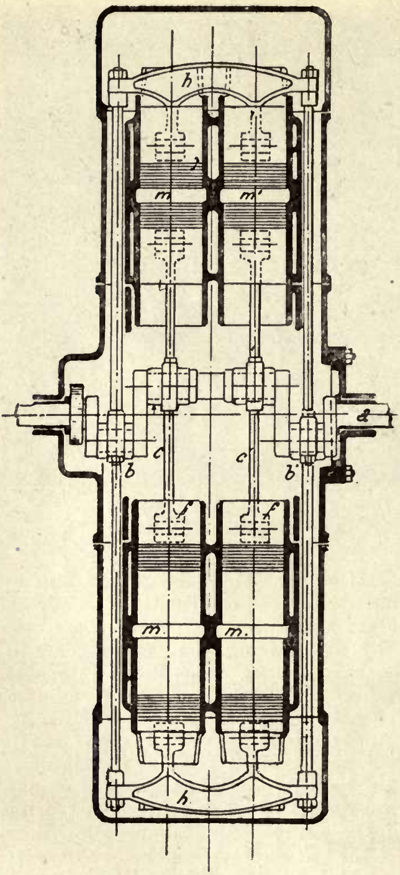


Fig. 147.—The Gobron aerial engine.

a, crankshaft; *b*, connecting rods for outer pistons; *c*, connecting rods for inner pistons; *f*, inner pistons; *h*, overhead beam attached to outer pistons; *m*, combustion space.

The engine may be regarded as a twin double-opposed motor, the pair of cylinders on the upper left-hand side being opposed to the pair on the lower right-hand side, while the pair on the upper right-hand side are opposed to the pair on the lower left-hand side. There is obviously a great saving of weight with this design, for the even torque of the eight cylinders allows the flywheel to be dispensed with, the crankcase is a remarkably light organ, and the crankshaft for the eight cylinders is of practically the same design as for the Gobron two-cylinder engine. As all the reciprocating parts are opposed, there is an absence of shock and an evenness of running specially desirable for flying-machine work.

The cylinders are cast separately, are turned inside and out, and are fitted with copper jackets for the circulation of cooling water. The bore is 3½in. and the total stroke 6½in.; this comparatively long stroke in relation to bore is only made possible by reason of the double-piston principle.

The valve mechanism is remarkably free from complications: the inlet valves are all automatic, while the exhaust valves are operated without the use of any gearing. The only gearing employed on the engine is that for driving the two high-tension magnetos carried to left and right of the rear extension of the crank. The same gearing is also employed for driving the lubricating pump. Naturally, the tendency of the oil is to descend to the lowest point of the four cylinders with their heads downwards. The pump, therefore, is employed to carry the oil from this point to the heads of the cylinders that are upwards, and to the bearings of the main shaft, thus establishing a complete circulation.

Complete weight of the Gobron engine is about 440lb. At 1,200 revolutions a minute the engine develops 80h.p., but on being accelerated to 1,800 revolutions will furnish 90h.p.

The need for lightness of details led to the development of multiple-cylinder engines, the cylinders of which radiated from a central circular crankcase, and the pistons of which were all connected up to one point. This type of engine has almost invariably seven cylinders, for it is only with an odd number of cylinders that the explosions can be obtained at equal distances. This can be best explained by means of a diagram of a six and seven-cylinder " star " engine. In Fig. 148 (A) the explosions take place in their natural sequence from cylinder 1 to 6. This, of course, would give six explosions per revolution of the engine shaft, and, further, all at equal distances, but for a whole revolution no power would be developed.

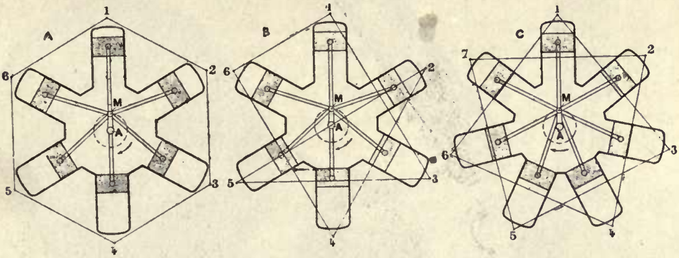


Fig. 148.

Why seven cylinders make a smooth-running engine.

The next method appears to be to fire alternate cylinders; but this would be no better, for, as followed out in Fig. 148 (B), the distance between 1, 3, and 5 would be shorter than the interval between cylinder 5 and 2, while there would be a very short interval between cylinder 6 and 1. With a seven-cylinder engine these difficulties disappear, for it is only necessary to fire on alternate cylinders, 1, 3, 5, 7, 2, 4, 6, to have the explosions at equal distances. This is shown clearly in Fig. 148 (C), an engine of this type having 3½ power strokes per revolution, or seven for every two revolutions of the mainshaft.

The R.E.P. Engine.

The first successful engine produced on this principle was the R.E.P., named after its inventor, Robert Esnault-Pelterie. Although, for special reasons, the inventor of the R.E.P. has preferred to mount the cylinders on the upper portion of the crankcase only, the method of operation does not differ from those engines having the cylinders placed at equal intervals around the periphery of the crankcase. It being impossible to get such a large number of cylinders on the upper half of a circular base of moderate dimensions, the designer has slightly staggered them, four being in one plane and the three others slightly in the rear and in another plane. For such an engine, the crankshaft must have two arms, or throws, to one of which the connecting rods of four pistons will be attached, and to the other will be linked up the three remaining pistons. As is shown in Fig. 149, there is one main connecting rod receiving three separate rods, two being on one side and one on another.

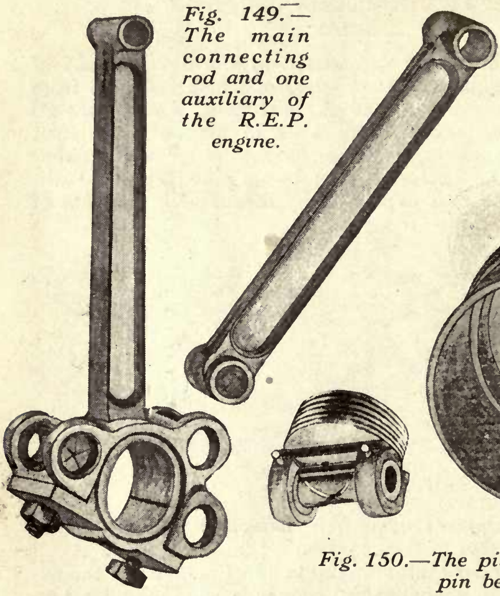


Fig. 149.—The main connecting rod and one auxiliary of the R.E.P. engine.

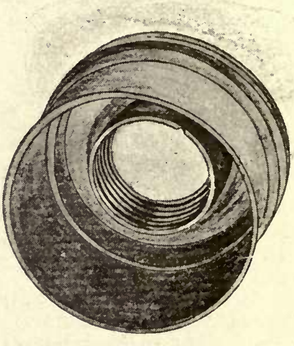


Fig. 150.—The piston and gudgeon pin bearing.

The circular crankcase is an aluminium casting to which the cast-iron cylinders are each secured by three bolts, nuts, and lock-nuts. Very light steel pistons are employed, the walls being so thin that it would be impossible to attach the gudgeon pin in the usual manner by bearings in the wall of the piston. The central portion of the head of the piston is, therefore, threaded to receive a special bearing. This piece, shown in Fig. 150, is screwed into the head of the piston, being prevented from turning by means of a countersunk screw, and carries, integral with it, the two bearings for the gudgeon pin.

On the R.E.P. engine there is but one valve for both the intake of the fresh charge and for the exhaust of the gases. It is carried in the head, and is operated in a special manner by an overhead rocker arm. The manner in which the two functions are fulfilled by one organ is both simple and effective. The rocker arm, operated by the camshaft, can maintain the valve in three distinct positions. On the full opening, the valve is lifted off its seat in the usual manner, allowing the aspiration of explosive mixture. In another position, a steel collar surrounding the valve stem uncovers a number of holes within a cylindrical cage, thus giving communication between the exhaust pipes and the combustion chamber and allowing the spent gases to be driven out. In its third position, these holes are closed and the valve face is resting on its seating, thus shutting all connection with both inlet and exhaust pipes.

The valves are operated by a single cam, or, more correctly, by a single disc, the face of which has three pairs of bosses, the three larger ones corresponding to the lift of the valve for intake and the three smaller ones to the lift for the exhaust.

The seven-cylinder R.E.P. engine has a bore of 3.3in. and a stroke of 3.5in. It is rated at 30h.p. at 1,500 revolutions a minute, and weighs complete, ready for running, 115lb.

The Gnome Engine.

The seven cylinders of the Gnome aeronautical engine radiate from a circular crankcase. Unlike the standard type of engine, on which the cylinders are stationary and the crankshaft is driven round by reason of the power strokes on the piston, the Gnome engine has a fixed crankshaft, with cylinders and crankcase revolving round it. With such a type of engine, air-cooling

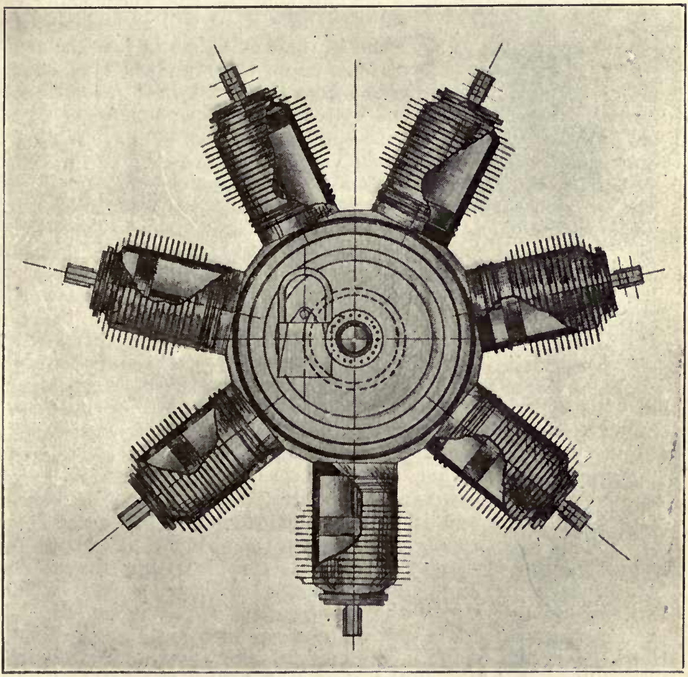


Fig. 151.—The seven-cylindered Gnome engine.

is naturally employed, for the speed of the cylinders through the air is ample for dissipating the excess of heat.

Practically every portion of the Gnome engine is machined out of nickel steel. The cylinders, for instance, are produced from a solid bar of steel, machined to the required shape, with their radiating fins, then bored out until the walls are very much thinner than would be possible with a cast-iron cylinder, and yet possess even greater strength. They are mounted around the circumference of the circular crankcase.

The axis of the wheel thus formed is the crankshaft, having a single crank, or throw, secured in bearings in the centre of the two end plates, or hub caps, bolted to the face of the hub. If each of the pistons is connected up to the single crank pin of the crankshaft it is obvious that, on the wheel being revolved, the pistons will ascend and descend in their cylinders in just the same manner as on the standard type of engine where the crankshaft revolves and the cylinders remain stationary.

In the head of each cylinder is an exhaust valve, operated by a rocker arm. Instead of being in the head of the cylinder, the intake valve is in the head of the piston, the charge passing from the crankcase to the combustion chamber above the piston. The carburetter, which may be of any ordinary type, is carried on the outside of the engine, the mixture obtained from it passing through the hollow crankshaft into the crankcase, and from there, as explained, into the cylinders. Lubrication is suitably provided for.

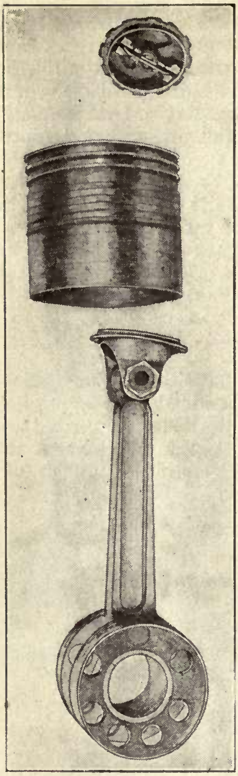


Fig. 152.—The piston, main connecting rod, and inlet valve of the Gnome engine.

One of the most interesting features of the Gnome engine is the method of attachment of the seven connecting rods to the single crank pin. There is one main connecting rod, its lower end terminating in two steel discs, through the centre of which the crank pin is passed, and around it being six holes in each of the two discs to receive the ends of what are known as the secondary connecting rods. Within the hollow face of each disc is mounted a large ball bearing carrying all the connecting rods on the crankshaft. The gudgeon pin for each connecting rod is carried in a separate piece screwed into the head of the piston. The engine, which is rated at 50h.p., has a bore of 4.3in. and a stroke of 4.7in., the total weight being 165lb.

Bayard-Clement.

In principle there is a similarity between the Gnome air-cooled rotary engine and the seven-cylinder water-cooled engine produced at the Bayard-Clément factory. This latter has seven cylinders radiating from a circular crankcase, the axes of the cylinders being placed horizontally, with the axis of the crankshaft vertical. Here the cylinders are fixed, the explosions driving round the crankshaft, as on the standard type of engine. Water cooling is employed, the water circulating through a copper jacket surrounding the cylinder walls. The cylinders, which are of steel, are bolted to their seating in the usual way, and have a bore of 3.9in. and a stroke of 4.4in., the power developed being 50h.p. Each cylinder has a separate dome-shaped head screwed into position and then brazed; the combustion chamber is hemispherical, this form giving the greatest efficiency, there being no pockets into which the gas can become lodged, and but small loss from radiation. There are separate intake and exhaust valves in the head of the cylinder, the two being operated by a single rocker arm with blade springs, with, of course, but one horizontal tappet rod. One position of the beam opens the inlet valve, while the opposite position operates the exhaust.

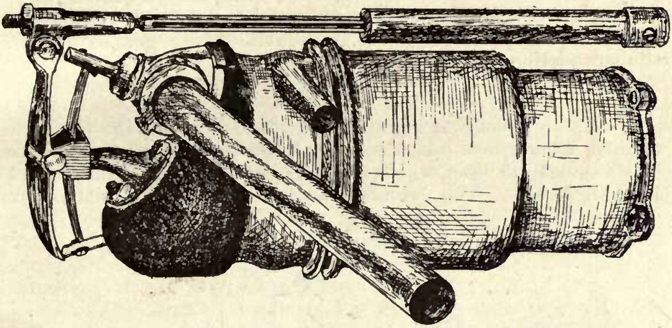


Fig. 153.—One of the cylinders and the valve gear of a Bayard-Clement engine.

In the upper portion of the crankcase are housed the valve-operating mechanism and all the timing gear. It is within this casing that is lodged the central cam, receiving its movement from an intermediate gear and turning eight times slower than the main shaft. The single cam carries four bosses and four hollows, corresponding to the position of the rocker arm for the exhaust and the inlet. Explosions take place in alternate cylinders at each revolution, there being consequently 3½ explosions per revolution of the engine, or seven explosions for two revolutions. The commutator is mounted on a vertical spindle and driven off the main shaft at half the speed of this latter. The carburetter is carried at the base of the engine, outside the crank chamber, but feeding its mixture into a receiver within the case, from which the intake pipes lead to the different cylinders. The carburetter weighs 1lb.

The vertical crankshaft, in two parts bolted together and carried on ball bearings, has a single crank pin to which all the seven connecting rods are attached. There are no flywheels, either internally or externally.

The axis of the main shaft being vertical, it is necessary, for aeroplane work, to drive through bevel gearing to the horizontal propeller shaft. This movement is obtained by a pinion on the extremity of the mainshaft meshing with a vertical crown gearwheel on the propeller shaft, the latter being geared down in the proportion 1 to 5.

Pipe.

A very light engine has been produced by the Pipe Co. This engine, which develops 50h.p. at 1,200r.p.m., and a maximum of 70h.p. at 1,950r.p.m., has eight cylinders of 100mm. bore by 100mm. stroke. The cylinders are mounted " V " fashion and staggered in the usual manner of the aero engines; but from this point the design is quite a departure. Over the trunks of each pair of cylinders there is a light metal hood, a single long hood extending over the combustion head and valve chambers on each side of the crankcase. These hoods form jackets through which not water but air is circulated by a blower mounted on one end of the crankshaft. The exhaust and inlet valves are united in one detachable piece set concentrically in the hemispherical combustion dome. They are set in the cylinders at an angle of 45 degrees to the cylinder axis, and are therefore vertical. They are operated by overhead rockers worked off a single centrally-enclosed camshaft, which runs on ball bearings. The carburetter is placed between the two rows of cylinders, and is entirely automatic in action. It delivers

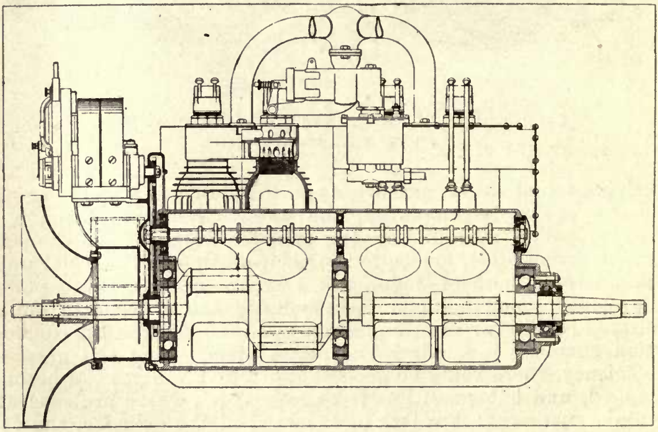


Fig. 154.—The eight-cylinder Pipe engine elevation.

the gas into the four pipes arranged star fashion, each branch leading to a pair of inlet valve chambers; high-tension magneto is employed for ignition.

The Farcot.

The only other engine with multiple cylinders radiating from a circular crankcase is the Farcot eight-cylinder air-cooled motor (Fig. 156). The feature of this is that the cylinders are alternately staggered on the crankcase, four of them being in one plane and four in another. The vertical crankshaft has two pins placed at 180 degrees in relation one to the other, one throw receiving all the connecting rods of the cylinders in the upper plane, and the other those of the cylinders in the lower plane. The method of firing the cylinders is: first all four cylinders in one plane, alternate cylinders being fired until the circle is completed, then the four cylinders on the opposite plane in the same order. The cooling of the engine is assured by a powerful fan mounted on the extremity of the vertical shaft, and throwing a strong current of air on to the cylinders. The power is transmitted from the vertical shaft to the horizontal propeller shaft, through bevel gearing contained within an extension of the crankcase housing.

One of the distinctive features of the Farcot engine is a valve performing the functions of both intake and exhaust. The valve is carried in an outstanding pocket, as in the standard type of car engine, with this difference, however, that here the valve stem is horizontal. A cam of special profile raises the valve to

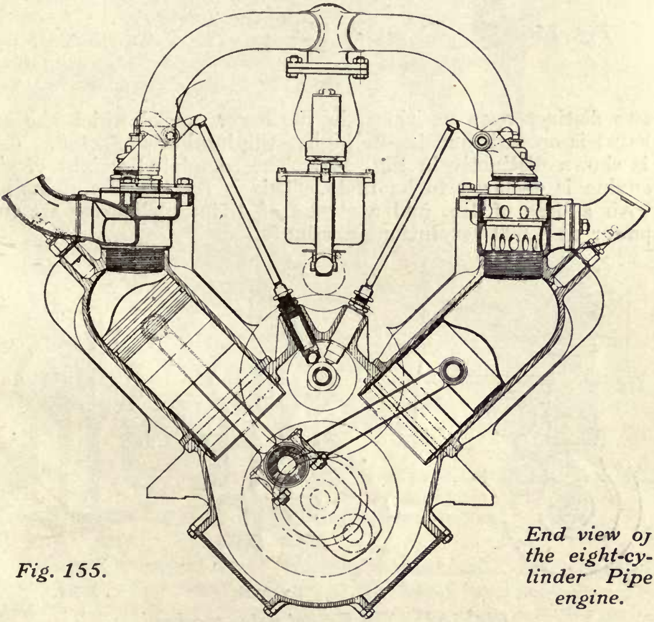


Fig. 155.

End view of the eight-cylinder Pipe engine.

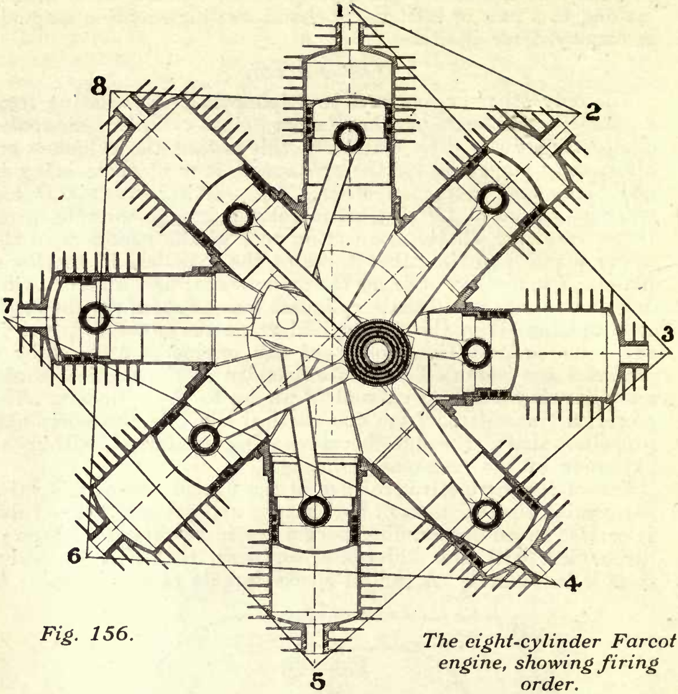


Fig. 156. *The eight-cylinder Farcot engine, showing firing order.*

two distinct open positions, in the lower one of which the exhaust is opened, and in the higher the intake is effected. This is shown distinctly in Fig. 157. The completed weight of the engine is declared to be 125lb. This is for the 50h.p. engine with a bore of 4in. and a stroke of 4.7in., delivering its full power at 1,600 revolutions a minute.

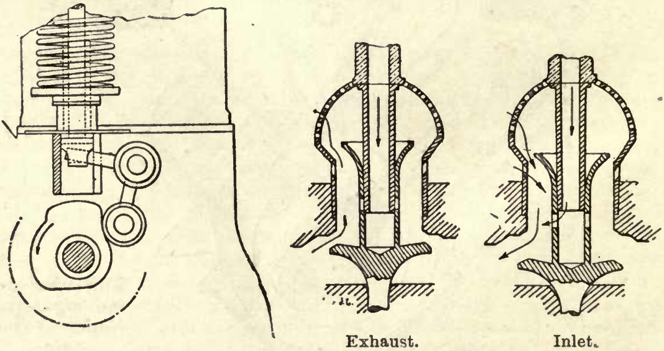


Fig. 157.—The Farcot valve mechanism.

Vivinus.

In the Vivinus engine a great feature has been made of accessibility. In the main, the design follows that which has been used for many years in the firm's productions, but a lot of metal has been saved, and the weight has been reduced to about 3½lb. per horse-power. All the exhaust and induction piping, which is on one side of the engine only, is held by four boxes. The camshaft is in a small box outside the crank chamber, and can be removed bodily by removing six screws. In an equally easy manner the camshaft can be drawn through one end without touching any part of the engine. The base chamber is one barrel, the front cover being in one piece with the box covering the gears. Thermo-syphon cooling is employed and high-tension magneto ignition. The tappet guides are held down by four dogs, and can be very quickly removed.

The Wright Bros.

There is very little departure from standard practice in the Wright aeronautical motor. It has four separately-cast cylinders of 4.4in. bore and 3.9in. stroke, fitted with separate water jackets and mounted on an aluminium crankcase. All valves are in the head, the exhausts (B) (Fig. 158) being mechanically operated by a simple vertical spindle and rocker arm, and the inlets (A) being automatic. The only really distinctive feature about

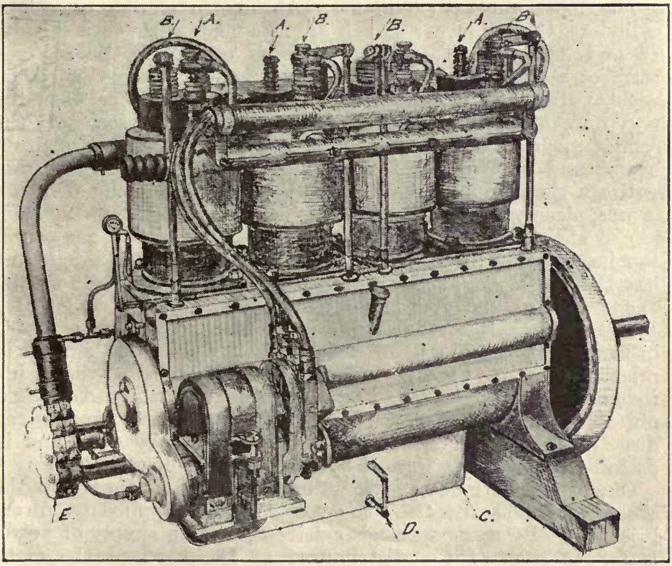


Fig. 158.—The Wright Bros. engine.

the engine is that there is no carburetter, the petrol being supplied by direct injection by means of a pump on the right-hand side of the engine, worked through worm gear off the camshaft and by a short shaft across the interior of the crankcase. On the same side of the engine is the lubricating oil pump, also worked off the camshaft through worm gear and by a short shaft across the crankcase. The base (C) of the crankcase forms an oil reservoir, from which the lubricant is pumped up to the main bearings, then drips down again to the reservoir through pipe D, being filtered on the way.

Ignition of the engine is by means of a high-tension Eisemann magneto, carried on a platform near the base of the crankcase, and worked off the forward end of the camshaft. The water for cooling the engine is circulated by a rotary pump (E), mounted on the forward end of the mainshaft. The radiator consists of a series of plain, flat copper tubes attached to one of the stanchions of the aeroplane. The petrol tank is a cylindrical vessel carried in a vertical position and also secured to the stanchions. The engine has free exhaust, and has also auxiliary exhaust ports at the end of the stroke.

The Antoinette Engine.

The most generally employed Antoinette engine has eight cylinders, though larger models are also made with, respectively, 16 and 32 cylinders. The aluminium crankcase, having the form of a rectangular prism, receives two rows of cylinders on each of its faces inclined at 45 degrees, the angle between the two rows of cylinders thus being one of 90 degrees. On the earlier models the cylinders were cast separately, had separate heads, and were copper jacketed. The 1909 models have been entirely changed in this respect, the cylinders being of steel, in one piece with their heads and valve pockets. The machining of such a piece is really a work of fine metallic sculpture, the justification for which is found in the decreased weight, no less than 1½lb. having been gained on each cylinder, or a total of more than 12lb. over the entire engine.

The main shaft of the engine has four throws, and is carried in five bearings. The two rows of cylinders are slightly offset in relation one to the other, thus allowing the two connecting rods of opposed cylinders to be connected up to the same crankpin. The camshaft is carried above the main shaft, and driven directly off this latter, the valves being side by side, and in pockets, in the angle formed by the two rows of cylinders.

One of the distinctive features of the Antoinette engine is the absence of a carburetter, the petrol being supplied by direct injection. By means of a gear-driven pump, a supply of petrol is fed to each of the distributors at the head of the eight cylinders, where it is stored until the intake stroke. The intake valve is automatic, and, on its opening, the petrol is drawn out of its lodging place, finely sprayed and mixed with air as it is carried into the cylinder. The petrol pump has a variable stroke, thus allowing more or less fuel being fed to the distributors according to the speed required. There is little if any saving in weight by direct injection, for in place of a carburetter, a pump, special piping, and distributors have to be employed; but the advantage claimed for the system is more reliable carburation under all conditions. Lubrication of the motor is assured by a gear-driven pump. The propeller, which is built up with forged steel blades, is generally mounted on the forward extension of the main shaft.

The Greene Engine.

The Greene Motor Patents Syndicate, of 55, Berners Street, W., have produced a special engine for aeroplane work. The design is not new, an engine of this pattern having been constructed seven years ago, and the fact that it is now being constructed by the Aster Engineering Co. vouches for its quality. The reduction in weight has been effected by the employment of pressed copper water jackets, overhead valve gear, and sheet metal bottom to the crank chamber. One advantage of using detachable water jackets is, of course, that the cylinders can be machined inside and out to be of uniform thickness. The water jacket joint is made with a rubber ring, which, after a few runs on the bench, subject to the heat of the water, becomes partly vulcanised, remaining soft only at its contact with the copper. The inlet and exhaust valves are set in cages in the head of the combustion chamber, and provision is made to prevent a valve dropping into the cylinder should it break. The overhead camshaft is made in one piece, but the camboxes are arranged to swing back in sets of four, to give access to the valves. The rockers actuating the valves have rollers at their near ends running on the face of the cams, and each is contained in its own oil-tight case. Forced-feed lubrication is employed, and ignition is high-tension magneto. A feature of the mounting of the cylinders is that the holding-down bolts pass through pillars in the upper crankcase casting, and some of these bolts are used for the main bearings, which are five in number. This enables the crank chamber to be closed underneath by a metal tray. The engine shown is a four-cylinder 60h.p., developing its power at 1,000r.p.m., and weighing 235lb. only, including piping, carburetter, etc., but excluding flywheel. A bigger engine, of the same general design, with eight cylinders set "V" fashion, is used on "Baby," the War Office dirigible of 1909.

New Engine Motor Co.

The engine made by the New Engine Co., Ltd., is a two-stroke motor that differs from others of its kind in that special scavenging arrangements are provided. At each stroke an enormous volume of air is swept through the cylinders, so that, besides driving out all products of combustion, enough cooling effect is produced in the pistons and cylinder walls to render any external water or air-cooling superfluous. To attain this end, some departures from ordinary practice are, of course, necessary. The exhaust port is very high up, in fact it opens half-way down the stroke, and the inlet is just below it. Both ports are exceptionally large, and a fan, driven off the engine, forces a large volume of air through from inlet to exhaust, thoroughly scavenging and at the same time cooling. This action continues during the rest of the down stroke and for part of the up stroke, but before the inlet valve is closed a very rich mixture is introduced, which, mixing with the air already in the cylinder, forms a gas of the right strength, which is compressed and fired in the ordinary way. The compression used equals 80lb. per square inch. To introduce the rich mixture, a pump is required, working at slightly higher pressure than the scavenging fan, and there is a distributing arrangement in the induction piping. The bore of the engine exhibited last week is 4½in., stroke 4in., and 40h.p. is developed at 1,500r.p.m. A feature of this very interesting motor is the high speed at which it can run. These features combined naturally make it possible to obtain a high power for a given cylinder capacity, and it is stated that, for a given size, one-third more power can be developed than is obtained from any ordinary four-stroke engine.

The E.N.V. Engine.

The E.N.V. engine is a French production from English designs, having eight cylinders of 3.9in. bore by 5.1in. stroke set at an angle of 90 degrees to one another. The cylinders are cast separately without water jackets, are machined inside and out, and provided with copper water jackets, which are neither riveted nor held with a junk ring, as is the usual method, but are the result of electro-deposition. This method of construction allows of cylinders of accurately the same weight and

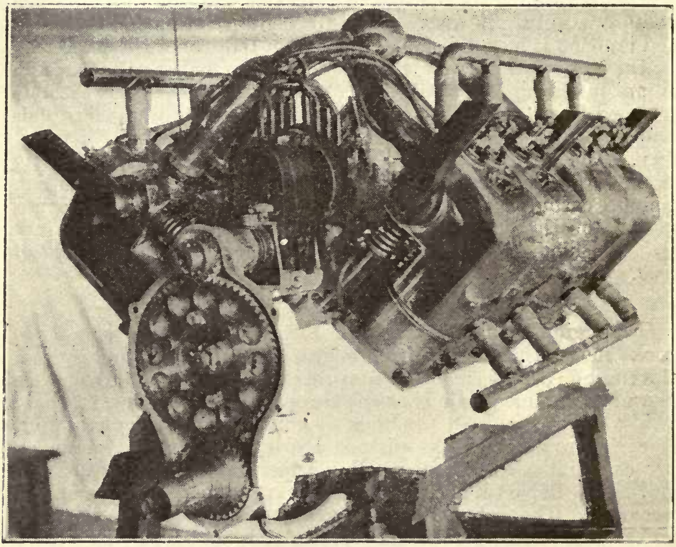


Fig. 159.—The E.N.V. Engine.

thickness of wall, while the system of deposit allows the copper to be so closely joined to the cast iron of the cylinder that it is impossible to say where the copper leaves off and the cast iron begins. The only disadvantage that can be brought against it is that of increased cost.

All valves are carried in the angle formed by the two lines of cylinders, and are operated by a single camshaft, machined out of the solid and hollowed for lubrication purposes. A distinctive feature of the camshaft is that it is slidable in a longitudinal direction at the will of the operator, thus varying the lift of the valves. The crankshaft is a fine piece of workmanship, with four throws and circular webs, which have the effect of aiding the flywheel action. The shaft is mounted in plain bearings of exceptional length, while the crank pins are of the same diameter as the bearings, each one receiving two connecting rods side by side.

The Dutheil-Chalmers.

Dutheil-Chalmers aeronautical engines are all horizontal, and constructed with two, four, six or more pairs of cylinders, the most commonly-employed types, however, having respectively two and four cylinders. Where specially light weight is desired, the engines are air cooled, but for all the larger four-cylinder engines water cooling is employed.

The cylinders are opposed and slightly offset in relation one to the other to allow the connecting rods to be attached to different pins of the crankshaft.

There is a very complete circulation of water around the cylinder head—the part that most needs cooling.

The inlet valve on this model is automatic, though we understand that a special model is now being constructed with mechanically-operated inlet in conjunction with the exhaust. The exhaust valve is operated by overhead rocker arm, and is placed immediately in the head of the cylinder. The valve is guided for a considerable length, and allows the gases to exhaust free into the air; a baffle plate is, however, fitted to prevent the hot gases coming in contact with the valve spring. The camshaft is carried above the crankshaft and parallel to it, there being but one cam for two valves.

The high-tension magneto is generally carried on the upper portion of the crankcase, and is geared off the camshaft. Double ignition is provided by accumulators and coil, and a very ingenious system is adopted on these motors by which spark plugs can be changed while the engine is running. The device consists of a movable plate carrying four plugs, two receiving their current from the magneto and two from the accumulators. By turning the plate round, any one of the plugs can be brought into communication with the combustion chamber.

All the engines have a bore of 125 millimetres and a stroke of 120 millimetres, the normal engine speed being 1,200 revolutions per minute. The two-cylinder engine weighs 165lb. and gives 20h.p.; the four-cylinder engine weighs 264lb. and develops 40h.p.; while the six-cylinder model develops 60h.p. for a total weight of 375lb.

Aero Motors, Ltd.

The Aero Motors, Ltd., which is under the guiding power of Mr. F. R. Simms, who brought the original Daimler engine to this country, has produced a six-cylinder engine which develops 50h.p. at 1,000r.p.m., weighing only 220lb., this weight being exclusive of the flywheel and exhaust piping, but including water and induction piping, magneto, etc. The cylinders are set at 120 degrees to each other, on opposite sides of the crankcase, and slightly staggered, in order to bring two big ends on each crank throw. They are 110mm. bore by 110mm. stroke, and are cast separately, with super-imposed valves in a pocket facing the centre. All the valves are operated from a single central camshaft on the top of the crankcase, the exhaust valves being operated by a direct push, lifting shoes being fitted between the cams and tappets. The inlet valves open automatically, but are closed mechanically by a spring-rotated rocker arm on top of the engine. To permit the valve to open, this rocker arm is drawn down by a tension rod operated by a bell-crank pivoted on a spindle above the camshaft. One end of the rocking lever carries a shoe which runs over the face of the cam. Gas is supplied from a carburetter situated centrally above the engine, and delivering the mixture through two branches to a pipe along the top of each set of cylinders. Forced feed lubrication is employed for the main bearings and big ends. For the gearwheels, grey fibre is used, with magnolia cheeks. The magneto is mounted on a bracket above the cranks at the forward end. A rather neat fitting is used to secure the two side plates of the mixture chamber on which the air and mixture throttles are mounted. The fastening is a simple blade spring attached to the main pipe pressing on the centre of the plates, which can, of course, then be quickly detached.

The Renault.

Air cooling is employed on the Renault eight-cylinder aeronautical engine. The cylinders, which have a bore of 90 and a stroke of 120 millimetres, are mounted in the form of a " V " on an aluminium crankcase. The two lines of cylinders are slightly offset, thus allowing two connecting rods to be attached side by side on a single throw of the crankshaft. The main shaft is mounted on five bearings.

All the valves are worked off a single camshaft, the inlets being in outstanding pockets within the angle formed by the two lines of cylinders, and exhausts immediately above them are operated by rocker arms. The arrangement of the carburetter and inlet piping is somewhat original. The float chamber and nozzle are carried quite on the outside of the engine and very low down, the top of the carburetter being on a level with the base of the cylinders. This has been done in order to make it possible to place the tank in a convenient position to feed by gravity, instead of by pressure, as is done on most aeroplanes.

Probably the most distinctive feature of the engine is that the propeller is mounted on the extremity of the camshaft, and not on the main shaft. It is now generally recognised that greater efficiency is obtained from a propeller turning at 600 to 900 revolutions a minute than from one running at 1,200 to 1,800 revolutions a minute. A suitable reducing gear has been difficult to find, and it needed the daring of a Wright to adopt the somewhat clumsy transmission by chain. On the Renault engine no reducing gear is required, the crankshaft turning at half the speed of the main shaft, giving 900 revolutions per minute of the propeller with the engine running at full speed. The camshaft is specially constructed for the work it has to perform, and is mounted on ball bearings.

The engine is enclosed by a light aluminium housing at both ends and on the top, and even the small amount of space between the cylinders has been closed up by aluminium plates.

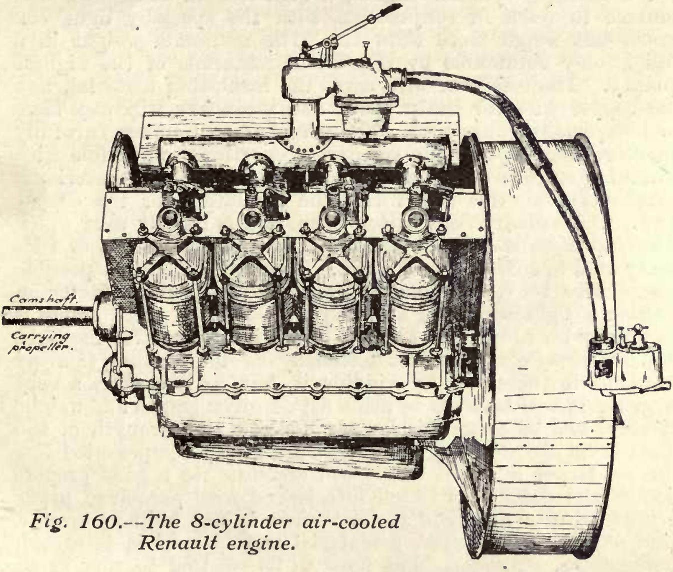


Fig. 160.--The 8-cylinder air-cooled Renault engine.

At the rear of the engine, and mounted on the end of the main shaft, is a powerful centrifugal ventilator, also partially housed, which draws a strong current of air into the V-shaped space formed by the cylinders. Everything being closed up, the only possible escape for the air is between the fins of the cylinders, with the result that these latter are kept at a normal temperature. Ignition is by high-tension magneto, which is carried within the angle formed by the cylinders. Lubrication is assured by pump circulation, the supply of oil being carried in a reservoir forming the extreme base of the crank chamber and delivered under pressure to the main bearings of the engine. Under brake test the engine gives 55h.p. at 1,800 revolutions, and in full running order, but with tanks empty weighs 375lb.

LIGHT IGNITION APPARATUS.

For special requirements, it is possible to produce ignition system components much below the weight standard employed for car use. Although it is improbable that the coil and accumulator system of ignition will become a standard part of the aerial engine's equipment, as the high-tension magneto is, in every way, better suited, it may be stated that an efficient trembler coil can be made 1¼lb. in weight only, whereas the ordinary patterns weigh from 4lb. up to, in extreme cases, 8lb. For a multiple cylinder engine, a high-tension distributor and contact to work in conjunction with the specially light coil would not weigh more than 1lb. The minimum weight in a coil is only obtainable by the use of materials of the highest quality. The soft iron wire core, the insulating material, and the copper wire for the primary and secondary windings have to be specially considered. The core has to be most carefully annealed and kept to the smallest proportions compatible with obtaining sufficient magnetic effect. The insulating material is paraffined silk; this also forms the insulation for the copper wire. On ordinary coils cotton insulation is largely used which takes up more space and necessitates a greater weight of wire being used to obtain a good spark. The use of the finest possible gauge wire for the secondary coil is an important factor in making a light coil. On ordinary coils Nos. 36 or 38 gauge is commonly used, whereas 42 or 44 gauge is required for the light coil. Such wire necessitates extremely careful handling to avoid breakage in the course of winding it, but, as it enables a very large number of turns to be made with a given length and weight of wire, and as upon this largely depends the strength of the spark from the coil, any difficulties are amply compensated for. The condenser in the ordinary coil accounts for a good proportion of the weight, as tinfoil interleaved with paraffined paper is used. For a light coil the condenser is best built up from a kind of metallised paper, a material mainly used in telegraph instruments. The terminals have to be reduced to very small proportions, and the case is best made of moulded vulcanite. Wood may be used, but, being necessarily very thin, it is fragile as compared with vulcanite.

Accumulators of the ordinary pattern do not permit of a very appreciable reduction in weight from the standard ignition patterns, except at the risk of proving unreliable. The weight can, if need be, be cut down to one-half the usual weight by using very thin plates, but, as there is no strength to resist the stress of charging and discharging, such plates easily buckle and go to pieces. This defect can be minimised by giving extra support to the plates by means of special bridge pieces. The thin plate is also at a disadvantage, in that it lacks the depth of active material necessary to give it a good working capacity. Extra light cells have been made by dispensing with the usual lead grid, into which the active material, the lead oxide, is pressed. A skeleton lead frame with a series of pockets or ledges is formed which supports loose granules of active material. This is mounted in a perforated celluloid envelope. This cell is about one-half the weight of the usual plate pattern. The Schmitt, a French-made cell, is constructed on this principle. Another cell of specially light construction is the Lithanode, in which the active material is formed in blocks and the amount of inactive lead in the plates is considerably reduced. In the Fors cell, one of the electrodes consists of a porous pot containing lead peroxide instead of the usual positive plate. This makes a light cell of high capacity.

High-tension magneto machines, suitable for firing a single-cylinder engine, can be obtained at a weight of 4lb., exclusive of the driving sprocket or pinion, and for a six or eight-cylinder engine a special type with distributor can be had at 7lb. In the Ruthardt machine special lightness is obtained by eliminating the usual iron pole pieces and a number of the minor fittings, besides using aluminium for the base and frame of the machine. The magnets consist of flat steel rings with the polar space bored out. The absence of pole pieces gives a good magnetic circuit and a strong " field of force " at minimum weight. It is not possible to save much weight in the armature, as there must be a definite amount of wire and soft iron to produce a spark of sufficient firing intensity, and there is also the condenser, which must have a given capacity, to consider. Modification in the mechanical parts and design alone give much scope for weight saving. In the Simms aero magneto, a light machine of high power is obtained by the use of aluminium where practicable and the employment of the highest workmanship throughout. The Nieuport machine is of the specially light, simple, and compact type, and is distinctive, in that it has no high-tension distributor, as ordinarily fitted. The current is drawn direct off collecting rings on the armature shaft, and a peculiarity is that two sparks occur simultaneously in the engine, one in a cylinder concluding its exhaust stroke and the other in a cylinder completing its compression stroke. These machines range from 4¼lb. for a single-cylinder upwards, and the absence of the distributor makes the machine considerably simpler in construction than the ordinary type. The Bosch and Nilmelior (Bassee-Michel) machines are made in small and light models, the former being 4¾lb. and the latter 6lb. There is considerable difference in the magnet system of the various machines. In one type a single magnet is used, whilst in others there are two pairs of double magnets, one placed over the other, and in a few other machines there are three pairs. A powerful magnet system is an advantage for starting by insuring a strong spark at low speeds, but, necessarily, this entails extra weight in the machine.

THE CYCLOPLANE.

The Cycloplane is the invention of John Gaunt, of Cycloplane Works, Gargrave, near Leeds. It is a device for fitting to cycles or boats, and is claimed to give a certain lifting power when driven through the air, though not sufficient to lift the bicycle off the road, or the boat out of the water. By thus reducing the frictional contact of the cycle with the road, or the skin-friction of the water in the case of a boat, it is claimed to reduce the effort or power required for propulsion. It is regarded by the inventor as a stepping-stone to aviation, and to afford would-be aviators experience by half-riding and half-flying.

In design, the Cycloplane, which is constructed of three-ply birch wood about 1-16in. in thickness, resembles a tent, with the ground sheet cut away in the centre, the section being like an inverted V with a V-shaped plane inside. It is about 5ft. in length. It is attached to a bicycle by a steel mast above the rider's head; it can be set at any angle, within certain limits; it will tilt sideways and veer round in either direction, also within certain limits.

On the cycle being driven forward, with the Cycloplane set at an angle giving the best results, determined by individual experiment, a lifting effect occurs. When the speed of the cycle, plus the velocity of a head wind, amounts to 25 miles per hour, the lift off the tyres is calculated to be 54lb., with a drift of 5.4lb. This gives 54lb. (12lb. its own weight and 42lb.) gliding on the air and 42lb. reduction of the weight on the tyres.

Fig. 161.—The Cycloplane.

In a rear wind it has its obvious advantages, and can be tilted at an angle that will take the greatest advantage of the head wind, but not increase the lift.

The chief point of its practicability is whether the lift is of more assistance to the cyclist than the extra resistance in head wind, and this the inventor claims to have proved to be the case.

Canvas has been tried for the planes and abandoned in favour of wood.

The invention was shown at the Aero Exhibition, 1909.

TABLE OF WIND PRESSURES.

Miles per hr.	Ft. per min.	Ft. per sec.	Lbs. per square foot.		
			Max.	Min.	Mean.
1	88	1·47	·006	·0025	·004
5	440	7·33	·147	·062	·0997
10	880	14·7	·591	·249	·401
15	1320	22·0	1·32	·559	·898
20	1760	29·3	2·35	·991	1·59
25	2200	36·6	3·67	1·55	2·49
30	2640	44·0	5·3	2·4	3·59
35	3080	51·3	7·2	3·04	4·88
40	3520	58·6	9·43	3·98	6·39
45	3960	66·0	11·92	5·03	8·08
50	4400	73·3	14·7	6.2	9·97
55	4840	80·6	17·8	7·5	12·05
60	5280	88	21·2	8·9	14·4
70	6160	102·7	29	12·2	19·7
80	7040	117·3	37·5	15·8	25·4
90	7920	132	47·7	20·1	32·3
100	8800	146·6	59·1	24·9	40·1

For the calculation of this Table from the formula

$$p = kv^2$$

(where p = pounds per square feet
v = speed in ft. per sec.
and k = coëfficient)

the values adopted for k have been :—

Minimum value, k = ·001154 (Carus Wilson)
Maximum value, k = ·002737 (Clark)
Mean value, k = ·001855.

The mean value has been taken from :—

k= ·001154 — C. Carus Wilson.
·001378 — J. Aspinall.
·002330 — Smeaton & Rouse.
·002502 — Hawksley.
·002737 — D. Kinnear Clark.
·001700 — du Buat.
·001670 — Langley.
·001370 — National Physical Laboratory.

To convert feet per second into miles per hour, a very good approximation is obtained by multiplying the number of feet per second by $\frac{2}{3}$.

Ex. :—30ft. per sec. = 20 miles per hour (approx.).

CONVERSION TABLE.

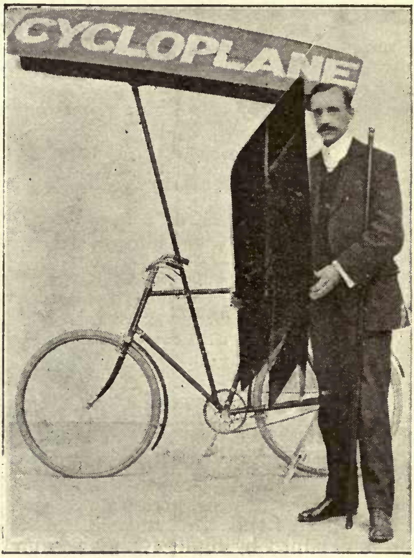
Metres per sec. to Miles per hour.

Metre per second.	Feet per second.	Miles per hour.	Metre per second.	Feet per second.	Miles per hour.
1	3·28	2·24	11	36·09	24·61
2	6·56	4·47	12	39·37	26·84
3	9·84	6·71	13	42·65	29·08
4	13·12	8·95	14	45·93	31·32
5	16·40	11·80	15	49·21	33·55
6	19·68	13·42	16	52·49	35·97
7	22·97	15·66	17	55·77	38·03
8	26·25	17·90	18	59·06	40·27
9	29·53	20·14	19	62·34	42·51
10	32·81	22·37	20	65·62	44·74

Telegrams—"GAUNT, GARGRAVE."

John Gaunt

AEROPLANE ENGINEER,
GARGRAVE, via Leeds.



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