# Flying Machines:

## PRACTICE AND DESIGN.

THEIR PRINCIPLES, CONSTRUCTION AND WORKING.



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*"Modern Engines and Power Generators," "Electrical Installations," "Electrical Distribution by Alternating Currents and Transformers," "Marine Propellers and Internal Combustion Engines," "Photographic and Optical Electric Lamps," and numerous scientific articles and papers.*

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WITH OVER SIXTY ILLUSTRATIONS AND DRAWINGS.

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*Popularly treated, but upon a strictly scientific basis, and with new Formulæ, Rules, Measurements, and Principles.*

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# FLYING MACHINES.

# FOREWORDS.

THIS small work is offered as a general review of the flying machine problems, and an attempt has been made to lay down the numerical values of the elements of the aeroplane machine's design and construction, and its natural and fundamental principles. This has not hitherto been done in such a way as to enable a designer to proceed in a methodical manner.

Quite recently, a leading article in a leading journal devoted to flight, discussing aeroplane designs, and coming to the subject of setting about to design a machine, gives the following instructions, and no more :—

> "The only way to commence is to start by guessing, and then follow on by modifying the values chosen until a reasonable agreement is obtained"—

a quotation which displays the chaotic state of the art at this date.

All new departures in mechanical invention are in this stage at first. Men succeed in making a practicable machine before the principles and numerical values are known. Well, it was the same with electric dynamos and motors 30 years ago. Machines were made, sold, and worked by designers working pretty much as directed in the above quotation.

But no machine devised by man is incapable of reduction to orderly principles and values, and progress is delayed until this work is done.

In setting out to design any machine, say a steamship, locomotive, or aeroplane, some data is given—some values within the bounds of reason and possibility, such as total weight, speed, and purpose for which it is to be used, are given or assumed. The total weight of an aeroplane machine may be anything desired over four or five hundredweight, it all depends on power. A smaller machine takes more power per pound weight, requires a larger angle of plane, has less fuel-carrying capacity.

Speed should be fixed as high as possible ; it should be 80 or 90 miles per hour ; but high resistance begins to appear above 50 miles an hour, and rapidly increases.

With the weight and speed factors agreed upon, it is an easy matter to proceed by the principles herein given to make out the essential elements of any aeroplane.

The examples given of the calculations are only typical ; other weights, speeds, and triangles of planes may be substituted to meet different cases coming before a designer.

There are other machines which, although they may look unpromising in a rough drawing only suggestive of a design, yet may offer another solution of the problems of flight, hence some attention has been given to them. The helicoptere has been considered fully, more for the purpose of showing the impracticability of large lifting screws to be employed if it is to rise straight up.

The machine which is now wanted must rise straight up from land or sea anywhere, should come down in safety in any event of an accidental kind, and be capable of " hovering " " soaring," and straight flight. All of which the helicoptere claims, but fails to perform, due to the lifting propeller difficulty.

But other propellers than screws may get over the difficulty. There is ample scope for the real inventor, as distinguished from the copyists.

The structural construction of machines is rather beyond the scope of this work, it would require a volume itself, but it is routine work with which all draughtsmen and designers are familiar.

The author's theory of the aeroplane, as herein given, is based firstly upon the fact that an aeroplane moving through air at an incline to its line of flight deflects the air downwards with which it comes in contact with a velocity *Rate*—equal to its forward speed—divided by the ratio of the base to the perpendicular of the triangle of the plane, the base being the line of flight, and the plane the hypothenuse.

Secondly, the weight of air deflected at the velocity rate is proportional to the required lift multiplied by 32·2 and divided by the velocity rate.

Thirdly, the area swept is proportional to the weight of air deflected, divided by the velocity rate by the perpendicular of the triangle of the plane by the weight of a cubic foot of air; and finally the total span of all the planes, on any machine, is then found by dividing the area swept by the forward speed per second.

All the other dimensions naturally follow upon the determination of these fundamentals.

For the sake of simple explanation 6 to 1 has been taken in one example as ratio of base to perpendicular of triangle of the plane; it may be anything between 4 to 1 and 10 to 1 in different cases.

The base A C of the aeroplane triangle need not in any case exceed 6 ft. 6 in. Monoplanes are perhaps best for small one-man machines up to 700 lbs. to 800 lbs. total lift, with a 6 ft. triangle base. For heavier machines up to 1,600 lbs. lift, a biplane or triplane construction is necessary.

However, it seems from theoretical considerations that the base of the triangle of the planes should bear a proportion to the total lift and the number of superposed planes, as given in the theory herein.

The theory may be somewhat imperfectly set forth and illustrated, but the author believes it will be found a reliable and helpful working basis for those who may essay the design of aeroplanes.

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*Glasgow, December,* 1909.

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ERRATUM.

Page 64, bottom line, 18 ft. should read "88 ft."

# LIST OF ILLUSTRATIONS.

# FLYING MACHINES.

## CHAPTER I.

### INTRODUCTORY.

THE subject of mechanical flight has of late sprung into a position of considerable interest to mechanical engineers. Actual flight by a machine containing its own motive power has been accomplished with a considerable degree of success, and the problems connected with the design and construction of flying machines are better understood, receiving, as they are, the close attention of capable engineers.

In all new inventions their progress at first is impeded by many erroneous theories, and misinterpretation of results of experiments. Mechanical flight is no exception to this rule. Professor Langley, long years ago, clearly expounded the theory of the aeroplane, and practically demonstrated the correctness of his theories, despite the many difficulties he had to contend with, not the least the lack of a suitable motor in his early days.

Although it may seem a small step from Langley to Wright Brothers, Voisin, and others, yet, as a matter of fact, it required much inventive genius and practical skill to supply the necessary inventions to put his theories into successful operation in a practical flying machine. The problems of balancing, steering, and governing the vertical height of the machine, starting it up to a soaring velocity, turning round a corner, and landing, had all to be solved. While these problems could be foreseen and considered, their solution was almost impossible without experiments with an actual flying machine of sufficient power and size to carry the experimenter.

As time goes on, and further improvements are made, longer flights will be easier accomplished and more experience gained, so that many of the, at present, difficult problems will be reduced and further progress made.

In the present stage of the art and science of mechanical flight no one can pronounce adversely upon any proposition made upon a basis of scientific laws and facts ; the subject is only in its primitive stages, and the possibilities of discovery and invention are almost unlimited. The present type of machine is by no means the last and final design.

Elderly engineers can remember a time when great records were made on the old ordinary bicycle, with its direct-driven front wheel of six feet diameter, which was then considered a marvel. It took some years for the bicycle engineers to discover that a simple chain gear would give even greater speeds with a much smaller driving wheel, making three or four times the number of revolutions while the driver pedalled at the same speed as before. When the safety geared bicycle appeared, one wondered why such an apparently simple and well-known device as a multiplying gear had not been applied at first, or at least long before it was really introduced.

This is one instance of many which could be quoted to show that the thing that is, is by no means to be accepted as the correct thing to be. A keen intellect examining into it, with the conviction that it can be improved upon, very often is inspired by an invention of some simple nature which makes a vast change for the better, and the real new departure is often so ridiculously simple (after it has been demonstrated) that one wonders how it escaped notice so long. Mechanical flight is in that stage where anything is possible.

On the other hand, we have enough accumulated reliable knowledge on the general laws and data connected with the subject, to enable one to check the propositions and schemes brought forward by sanguine inventors who have no idea as to how to set out a design, or calculate its dimensions, weight, horse power, and so on.

If the inventor could master the elementary science of the subject, and carefully make plans and calculations, it would, in many cases, save himself and others trouble and loss. That the subject is not a difficult one to master may be found from the contents of succeeding chapters.

The questions of equilibrium and balancing are not treated in this book to any extent. These problems are of a higher order than an elementary book can include, although, practically, balance is not difficult to obtain.

It may be as well to refer to the nomenclature of aeronautics briefly. The abuse of the word "soaring" by foreign and some home writers would lead one to believe that they had no word equivalent to "gliding," for they mostly use "soaring" when they mean "gliding."

The words applied to various acts in connection with flying or flight are not always used in the same sense by different writers. The various kinds of flight observed in birds can be imitated, and the same distinguishing names given them.

Flight or flying means moving through the air in any direction from place to place, as seen in birds and insects.

We have all seen birds floating along with outstretched wings, without flapping them, for long periods. This kind of flight is properly called "gliding," although Continental writers always call it "soaring;" but floating along on motionless wings is not "soaring."

The word "soaring" essentially implies moving up and up on the wing, like a lark or an eagle, to great heights.

Then we have seen hawks "hovering"—that is, suddenly become still, as if fixed in the air above a spot on earth, with wings outstretched. Bees also hover over flowers. "Hovering" is a valuable phase of flight for military or naval purposes.

Finally, we have ordinary flying or flight, in which the bird settles down to a steady forward speed with regular wing beats. These words will be used throughout in the sense indicated above.

## CHAPTER II.

### The Principles of Flying Machines.

We are all aware of the force of the wind, proving that the air has weight and exerts pressure when in motion, and that air offers resistance to any body driven through it. The common fan blower shows that it takes power to set air in motion. The balloonist takes advantage of the weight of the air by filling the balloon with a gas of less weight per cubic foot than air, so that the balloon and its contents are, as a whole, of less weight than the mass of air it displaces.

A vessel of light oil or spirit sealed up may be forced under water, but if properly dimensioned it will rise up through the water, for the water displaced is heavier than the vessel and its contents.

Flying machines heavier than the volume of air they displace act upon a different principle, namely, *reaction is always equal and opposite to action* (the law which holds good whenever a mutual action occurs between two bodies). Thus if by means of a wing, a screw, a plane or a fan, air is acted upon and set in motion, say downwards, the force which is exerted by the implement, whatever it may be, driving the air down, is balanced by an equal force tending to drive the implement upwards.

The flapping wings of a bird drive the air down with a force equal to the bird's weight, and the reaction floats the bird in the air, while some of the air acted upon by the wings is driven astern with a force reacting on the bird in the opposite direction and driving it ahead.

The recoil of a gun when a charge is fired is a familiar example of this law. So also is the flight of a rocket, the force of burning gases ejected downwards reacts upon the rocket and carries it upwards.

A paddle wheel on a steamship throws the water astern with a force which reacts and drives the vessel ahead; so does an air or a screw propeller.

The thrust experienced by whatever implement we use to propel the water or air, or other body, is equal to the weight of the body moved by the implement, multiplied by the velocity given to the air or water. Taking the weight in pounds per second, and velocity in feet per second, the thrust or lift of the reaction is found by multiplying the weight W by the velocity V and dividing by 32·2.

This number, 32·2, is used to reduce the thrust to pounds, and need not be investigated in this place. Throughout this book, for simplicity, we shall use 32; but when accurate calculations are called for, the reader should use the whole number, 32·2. This number is represented by a small ($g$). Thus we may simply write

$$T = \frac{W\,V}{g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

T, the thrust, is equal to weight W, say 20 lbs. multiplied by velocity V, say 64 ft. per second, and divided by $g$, 32, hence

$$T = \frac{20 \times 64}{32} = 40 \text{ lbs.},$$

so that if a propeller or wing drives 20 lbs. of air per second at a velocity of 64 ft. per second, it gives a lift or thrust equal to 40 lbs.

Here, then, we have the fundamental principle of mechanical flight, and all flying bodies or machines act upon this principle.

Now air has a very small weight compared with water, which is 800 times heavier, and one consequence of this is that the implement must act upon an enormous quantity (cubic feet) of air to get any great weight of it into motion.

This results in the necessity for using very large propellers, or planes, or whatever else is to be employed to apply the force. Nature herself is limited by this fact, for no large flying birds exist. The largest birds known weigh only about 30 lbs., and have an enormous span of wing surface, 10 to 12 square feet in area. Probably the small birds are the survival of the fittest, for birds, like men, have to come to earth for means of existence, and larger birds would have great difficulty in moving near the earth.

Eagles, for instance, can be caught upon a level plane, as their wings cannot get a full stroke; their legs being short, they prefer to rise from a rock or eminence, or by jumping from a height into the air.

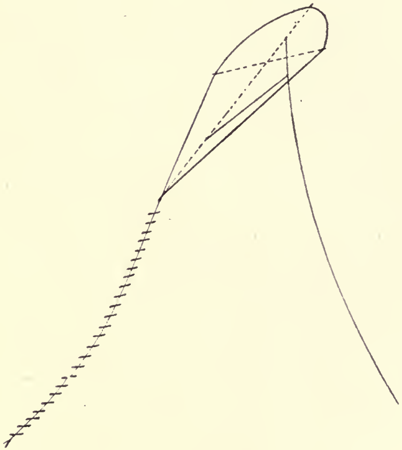

FIG. I.—Kite.

There is little hope that the flying machine will ever be small in size; we have nothing to work upon but this air of small weight, so that the great bulk to be acted upon must always be considered.

There is another reason why propellers or planes working in air must be large in area, as we shall see further on when we consider the question of the horse power required to do the work of flying, and lifting, a body in air.

Again, another principle of flight is this: if a stream, or current, or jet of air flowing with any velocity meets, and is deviated or turned aside by any plane or body, it exerts a pressure upon the plane or body in a definite direction. The common kite, fig. 1, and the aeroplane machine alike depend upon this principle. Fig 2 shows an inclined plane and a wind blowing in the direction of the arrow. The plane being fixed, the wind when it strikes it will be deflected downwards and the plane pressed upwards. And if the plane were movable, and driven forward against the air, it would deflect the air downwards and be itself pressed upwards.

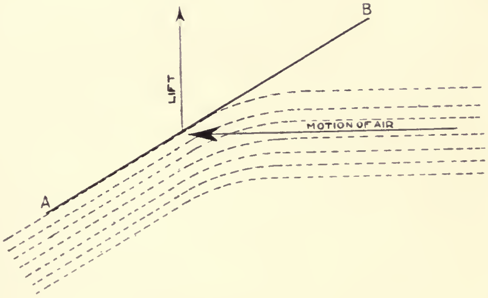


FIG. 2.—Deflected Air Stream.

A better effect is obtained from curved surfaces as in fig. 3, a curved plane driven against the air deflecting it downwards and being itself pressed upwards.

Now it must be evident that if a curved or flat plane, whether it is a kite or an aeroplane, is to be used for lifting itself and additional weights, we must be able to find out how to calculate this lift for any given plane, otherwise we could not be sure whether the plane is too small or unnecessarily large for its purpose.

It is necessary, in order to understand the designs of various flying machines, to study the few elementary principles upon which they are constructed. The fundamental principle of action and reaction we have already referred to, and shown we can calculate out the effect in pounds, lift or thrust.

A lift of equal value is experienced by an inclined plane whether the air moves against the plane or the plane against the air, provided the angle of inclination, the velocity, and the dimensions of the plane are the same.

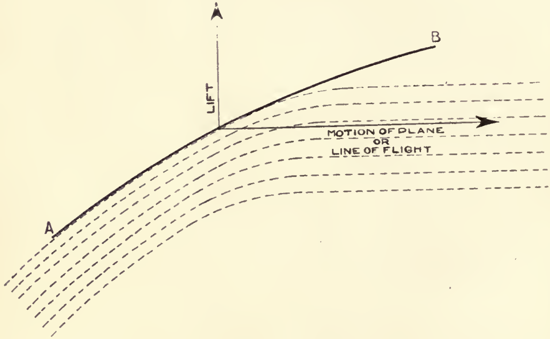


Fig. 3.—Aeroplane Deflecting Air.

Fig. 2 shows an inclined plane against which a current of air moves and is deflected downwards, resulting in a lift shown by the vertical arrow.

Fig. 3 shows a plane moving through air, and inclined to the line of motion; the air is deflected downwards and reacts upwards, as shown by the vertical arrow.

Referring to fig. 4, A C is the line of motion or line of flight of an inclined plane A B.

At P, say 6 ft. along A B, a line P Q dropped vertically is, say, 1 ft. in length. The inclination of the plane, in common language, is six to one or one in six, which means that travelling up the plane a body would be raised 1 ft. in 6 ft. travelled.

The angle $\alpha$, formed by the sides P A and A Q, is called the angle of the plane, *i.e.*, the angle which the plane makes with its line of flight. The third side, P Q, of the triangle is called the perpendicular, and if we divide this perpendicular by the side A P, which is called the hypothenuse, we get a number called the sine of the angle $\alpha$,

$$\frac{PQ}{AP} = \sin \alpha.$$

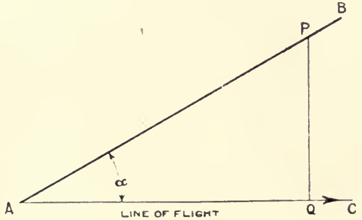


FIG. 4.—Triangle of Aeroplane.

In the example where

$$\frac{PQ}{AP} = \frac{1}{6}, \text{ then } 0{\cdot}1\dot{6}\dot{6} \text{ is } \sin \alpha.$$

Practical planes vary in inclination from 1 deg. to 14 deg. for angle $\alpha$. We have only to look up a table of sines, etc. to find the value of sin $\alpha$ or tan $\alpha$, which we may use to find the lifting power of the plane.

The common formulæ given in engineering works for the lift on an inclined plane driven through the air at an angle inclined to the line of flight is to take into account the weight of air per cubic foot, 0·08 lb., the surface area of the planes in feet represented by F. The speed forward of the plane in

## TABLE OF NATURAL SINES, ETC.

| Deg. | Sine. | Covers. | Cosec. | Tan. | Cotan. | Secant. | Versine. | Cosine. | Deg. |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1·00 000 | Infinite | 0 | Infinite | 1·00 000 | 0 | 1·00 000 | 90 |
| 1 | ·01 745 | ·98 255 | 57·2987 | ·01 746 | 57·2900 | 1·00 015 | ·00 015 | ·99 985 | 89 |
| 2 | ·03 490 | ·96 510 | 28·6537 | ·03 492 | 28·6363 | 1·00 061 | ·00 061 | ·99 939 | 88 |
| 3 | ·05 234 | ·94 766 | 19·1073 | ·05 241 | 19·0811 | 1·00 137 | ·00 137 | ·99 863 | 87 |
| 4 | ·06 976 | ·93 024 | 14·3356 | ·06 993 | 14·3007 | 1·00 244 | ·00 244 | ·99 756 | 86 |
| 5 | ·08 716 | ·91 284 | 11·4737 | ·08 749 | 11·4301 | 1·00 382 | ·00 381 | ·99 619 | 85 |
| 6 | ·10 453 | ·89 547 | 9·5668 | ·10 510 | 9·5144 | 1·00 551 | ·00 548 | ·99 452 | 84 |
| 7 | ·12 187 | ·87 813 | 8·2055 | ·12 278 | 8·1443 | 1·00 751 | ·00 745 | ·99 255 | 83 |
| 8 | ·13 917 | ·86 083 | 7·1853 | ·14 054 | 7·1154 | 1·00 983 | ·00 973 | ·99 027 | 82 |
| 9 | ·15 643 | ·84 357 | 6·3925 | ·15 838 | 6·3138 | 1·01 247 | ·01 231 | ·98 769 | 81 |
| 10 | ·17 365 | ·82 635 | 5·7588 | ·17 633 | 5·6713 | 1·01 543 | ·01 519 | ·98 481 | 80 |
| 11 | ·19 081 | ·80 919 | 5·2408 | ·19 438 | 5·1446 | 1·01 872 | ·01 837 | ·98 163 | 79 |
| 12 | ·20 791 | ·79 209 | 4·8097 | ·21 256 | 4·7046 | 1·02 234 | ·02 185 | ·97 815 | 78 |
| 13 | ·22 495 | ·77 505 | 4·4454 | ·23 087 | 4·3315 | 1·02 630 | ·02 563 | ·97 437 | 77 |
| 14 | ·24 192 | ·75 808 | 4·1336 | ·24 933 | 4·0108 | 1·03 061 | ·02 970 | ·97 030 | 76 |
| Deg. | Cosine. | Versine. | Secant. | Cotan. | Tan. | Cosec. | Covers. | Sine. | Deg. |

feet per second squared represented by $S^2$. Then the lift L is found by multiplying all these together—

$$L = \frac{0{\cdot}08 \times F \times S^2 \times \sin \alpha}{32}$$

We can cancel 32 out by dividing 0·08 by it, and get

$$L = 0{\cdot}0025 \times F \times S^2 \times \sin \alpha.$$

Suppose $\sin \alpha = 0{\cdot}15$,

and $F = 100$ square feet,

and $S = 60$ ft. per second.

Then we get the lift

$$L = 0{\cdot}0025 \times 100 \times 60 \times 60 \times 0{\cdot}15 = 135 \text{ lbs.}$$

Then to find the thrust, T, required to drive the plane forward at the 60 ft. per second, we are given that

$$T = \frac{0{\cdot}08 \times F \times S^2 \times \sin^2 \alpha}{32}$$

or

$$T = 0{\cdot}0025 \times F \times S^2 \sin^2 \alpha.$$

Then in the above case T would be found as

$$T = 0{\cdot}0025 \times 100 \times 60 \times 60 \times 0{\cdot}15 \times 0{\cdot}15 = 20{\cdot}25,$$

which shows that a thrust of 20·25 lbs. on a plane whose angle has a sine equal to 0·15, gives a lift of 135 lbs.

From this we can also deduce $\sin \alpha$ of the plane by dividing the

$$\frac{L}{T} = \frac{135}{20{\cdot}25} = 6{\cdot}6 \text{ to } 1\text{; or}$$

$$\frac{T}{L} = \frac{20{\cdot}25}{135} = 0{\cdot}15.$$

Using an inclined plane, the thrust is multiplied in the ratio of the inclination to obtain the lift; if the plane is six to one, the lift will be six times the thrust, theoretically.

These formulæ are not correct for aeroplanes, although they have been generally accepted as correct up till now.

The surface F of a plane may remain constant, while its dimensions may be altered; or it may, without alteration, be driven end on or broadside on. In the first case it might be a plane of 24 square feet area, say, $2 \times 12$, and then be altered to 4 ft. $\times$ 6 ft. F is the same in both, but we know from actual experience that the $2 \times 12$ will lift far more driven broadside on than the $6 \times 4$ similarly driven, and the $2 \times 12$ plane driven end on would scarcely lift any at all. For these reasons F is not used in the author's formulæ for lift and power.

The lift of the aeroplane is due primarily to the mass of air deflected downwards by it, at a velocity V, when the plane has a forward speed S. Hence, mass of air W, and V its velocity, should be used in calculations, especially for practical designs, in preference to surface F and $S^2$ (the forward

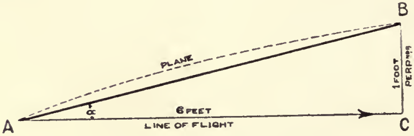


Fig. 5. Triangle of Plane.

speed squared). The author prefers to somewhat modify the formulæ, so that the doubtful factor of surface area of planes is eliminated. The important area A, with which we have to deal, is the area swept over by the aeroplane in its horizontal flight in square feet per second; the forward speed S is only one factor in that quantity. The span $l$ of the aeroplane, that is its length transversely to its line of flight, is the other factor, so that A, the area swept by the plane, $= S \times l$.

V, the velocity of the air deflected by the plane downwards, has S also as one of its factors.

It would be quite as rational—or, rather, irrational—to take the surface of the blades of a marine screw propeller as the factor in calculating the thrust as to take the surface of an aeroplane as the factor in a flying machine. In the marine case we take the area of the disc swept by the blades as the base of a column of water acted upon by the blades. There is a maximum pressure exerted by the blades per square foot of their area beyond which there is no increase of thrust. Similarly with aeroplanes, there is a limit to the lift per square foot of plane area.

If we consider the plane as the hypothenuse of a triangle, the base may be taken as the plane's width,

It is necessary in practice to build the aeroplanes to some angle of a definite value, and the line of flight is taken as the floor level, or some other datum line is taken, from which the angle of the plane can be measured. In actual flight the angle of the plane to the line of flight can be varied, by altering the angle of the keel of the machine to the line of flight, by means of vertical steering planes, or elevators.


Fig. 6.—Curved Planes.

But for engineering reasons it is obvious an angle must be selected for the builders to work to. An angle of about 9 deg. seems best for machines, working in air, at forward speeds of 40 miles per hour or thereabout; this gives an incline of about 6 to 1; that is a base A C of 6, and a perpendicular B C of 1. The sloping line, or hypothenuse, being the aeroplane joining the perpendicular and base, fig. 5.

If the planes are curved, as they generally are, as in fig. 6, then we take the dimensions from *a b*, *a c*, *b c*. The angles and planes may be geometrically drawn, and the lengths of the base and perpendiculars measured by scales, taking *a c*, *a b*, *b c* in feet.

Let the following symbols be employed for the values of the various dimensions, if drawn in straight lines, as shown in the diagrams.

$$\left.\begin{array}{l} B\,C = \text{Perpendicular} \\ A\,C = \text{Base} \\ A\,B = \text{Hypothenuse (plane)} \end{array}\right\} \text{in feet length.}$$

S = Forward speed per second in feet.

A = Area swept by machine per second, square feet.

W = Weight of air deflected by the aeroplane per second downwards in pounds.

R = Resistance to the machine flying through air.

$w$ = Weight of machine in pounds, fully loaded.

L = Lift of machine.

$l$ = Span = length of all the planes added together.

V = Velocity imparted to the air deflected downwards by planes.

$s$ = Superficial area of planes.

For curved planes $a\,c$, $b\,c$, $a\,b$ = the three sides of the triangle of the plane, $a\,c$ the base; $b\,c$ the perpendicular; $a\,b$ the hypothenuse, or plane. (See fig. 6.)

$$V = \frac{\text{The perpendicular of the triangle of the plane}}{\text{Base of the triangle of the plane.}} \times S.$$

$$\text{or } V = S \div \frac{\text{Base}}{\text{Perpendicular}}$$

$$L = \frac{W\,V}{g} = \text{the lift of machine.}$$

$$A = \frac{W}{V.\ B\,C.\ 0{\cdot}08} \text{ or } S \times l$$

$$l = \frac{A}{S}$$

$$W = \frac{w \times 32}{V} \text{ or } = V\,A.\ 0{\cdot}08.\ B\,C.$$

The angle of the plane, $c\,a\,b$, is taken about 9 deg., or a ratio of base to perpendicular of 6 to 1, for purposes of calculation, whether small or large planes are used.

A plane inclined at 6 to 1, as above defined, should multiply the thrust of the propeller into a lift six times greater, neglecting all losses; but in practice the lift of a 6 to 1 plane is only 4 to 1, giving an efficiency for planes of

$$\frac{4}{6} = \cdot 66, \text{ or } 66 \text{ per cent only.}$$

Upon these principles the author bases his working hypotheses for aeroplanes. It takes into account every factor, and is equally applicable to monoplanes, biplanes, and multiplanes. The "aspect" of the planes takes care of itself, and need not be considered at all; neither need we consider $s$, total surface of planes; that also follows naturally without any calculation

For simplicity, it is assumed that the student will draw out the planes accurately to a fairly large scale and measure the lengths of $a\,c$, $a\,b$, $b\,c$ in feet; suppose $a\,c = 4$ ft., $b\,c =$ 9 in., then

$$\frac{a\,c}{b\,c} = \frac{4 \text{ ft.}}{0 \cdot 75 \text{ ft.}} = 5 \cdot 3 \text{ to } 1$$

is the inclination of the plane; or, as a tangent, if $b\,c = 9$ in. or $\cdot 75$ ft., and $a\,c$ 4 ft., then tangent $\alpha$ equals

$$\text{Tan } \alpha = \frac{\cdot 75}{4} = \cdot 1875.$$

In all aeroplane calculations, V, the velocity of the air deflected downwards by the planes, is the important factor, and if S is the speed of the planes forward per second, then

$$V = \frac{S}{\frac{a\,c}{b\,c}}, \quad \ldots \ldots \quad (2)$$

or (the speed S multiplied by the tangent)

$$V = S \times \frac{b\,c}{a\,c} \quad \ldots \ldots \quad (2\text{A})$$

V, in the foregoing case, if the speed S was 60 ft. per second, would be by (2)

$$V = \frac{S}{\frac{a\,c}{b\,c}} = \frac{60}{5 \cdot 3} = 11 \cdot 3 \text{ ft. per second,}$$

and by (2A)

$$V = S \times \frac{b\,c}{a\,c} = 60 \times \cdot 1875 = 11{\cdot}3 \text{ ft. per second.}$$

In order to calculate the lift of a plane, besides V, we must find W, the weight of the air acted upon per second. This we do according to my system by first finding the area A swept over by the planes at the speed S, which we have given as 60 ft. per second. This weight is equal to

$$W = V \times A \times 0{\cdot}08 \times B\,C \quad . \quad . \quad . \quad . \quad (3)$$

wherein 0·08 is taken as the weight of 1 cubic foot of air. The area A swept by an aeroplane is equal to $l$, the span, multiplied by S, the speed in feet per second—

$$A = l \times S. \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Suppose four planes of 20 ft span and a speed of 60 ft. per second, then

$$A = 4 \times 20 \times 60 = 4800 \text{ square feet.}$$

B C is the height of the perpendicular in feet, which was assumed as 0·75 ft.

Now $\quad W = V \times A \times B\,C \times 0{\cdot}08.$

$\therefore \quad W = 11{\cdot}3 \times 4800 \times 0{\cdot}75 \times 0{\cdot}08 = 3242$ lbs. of air per second deflected by the plane.

We have found V and W ; $g = 32$, and the lift, from (1),

$$w = \frac{W\,V}{g},$$

$$\therefore w = \frac{3242 \times 11{\cdot}3}{32} = 1145 \text{ lbs.}$$

$$w = \frac{V \times A \times B\,C \times 0{\cdot}08 \times V}{32}, \text{ or}$$

$$V^2 \times A \times B\,C \times {\cdot}0025.$$

For the formula $W = V \times A \times B\,C \times 0{\cdot}08$ ; B C can be measured easily on a scale drawing of any plane.

In setting out to design an aeroplane, we must determine upon two factors—the speed forward S and weight $w$ to be sustained in the air.

The best inclination of the plane from experience, and also from theoretically examining the problem, we take to be six to one, the ratio of the base to the perpendicular of the triangle of which the plane is the hypothenuse. Therefore, A C, the base of the triangle, is $= 6$, and the perpendicular B C $= 1$, and the tangent $\frac{1}{6} = 0{\cdot}166$, as in fig. 6.

From these we may proceed to determine the velocity V of the air deflected downwards by the aeroplane at its assumed speed forward. We assume this speed to be 60 ft. per second for the present purposes, and calculate the velocity V from (2) or (2A).

For an incline of six to one, taking six as the base and one as the perpendicular, the value of V is

$$V = \frac{S}{\frac{AC}{BC}}$$

$$= \frac{60}{6} = 10 \text{ ft. per second,}$$

from the fact that in some practical man-carrying aeroplanes, at present, their weight $w$ is about 1,200 lbs. total. We can, in order to illustrate the methods of calculation, assume $w$ as 1,200 lbs. to be lifted, and leave it to the designer to keep the weight below that figure.

We have obtained the necessary values of the factors in the design for constructional purposes—

S = 60 ft. per second.
V = 10 ft. ,,
B C = 1 ft.

One cubic foot of air we take to weigh 0·08 lb.

The important area in square feet we require to find is not the area of the surface of the planes, but the area which the planes sweep over in one second ; for that area multiplied by V gives the total cubic feet of air acted upon by the planes per second, and the cubic feet multiplied by 0·08 gives the pounds weight of air moved at a velocity V per second.

A lift L of 1,200 lbs. is required to support $w$ 1,200 lbs. in air, hence L, the lift, is 1,200 lbs. Now, by fundamental formulæ W, the weight of air to be accelerated is

$$W = \frac{w \times g}{V}$$

Hence,

$$W = \frac{1200 \times 32}{10} = 3840 \text{ lbs.}$$

of air accelerated to 10 ft. per second.

We now proceed to find the first requisite dimension of the aeroplane; that is, the length of the planes $l$, or total span of the planes on a machine of this weight and speed.

$l \times S$ equals the area A swept in one second, and, from (3),

$$A = \frac{W}{V \times B\,C \times 0{\cdot}08} = \frac{3840}{10 \times 1 \times 0{\cdot}08} = 4800 \text{ sq. ft.}$$

We know $S = 60$, hence

$$l = \frac{4800}{60} = 80 \text{ ft. span,}$$

the amount of all the spans added together, say 2 planes each 40 ft. long.

If we take the base of the triangle of the plane as the width of the plane, then we have a sustaining area of $6 \times 80 = 480$ square feet.

Fig. 6 shows the triangle referred to above.

The aeroplane machine may be constructed as a monoplane, biplane, or multiplane. But whatever the number of planes may be, the ratio of base to perpendicular and the velocity V impressed upon the air at a normal forward speed must first be ascertained.

Suppose it is preferred to have a large number of small planes, say, of dimensions B C $1\frac{1}{2}$ in., A C 9 in., or 0·125 ft. and 0·75 ft. respectively, the ratio of B C to A C is still the same, six to one; and at 60 ft. per second speed, V is still 10 ft. per second. The only things reduced are B C and A C. W, the weight of air acted upon, must be still the same, 3,840 lbs. But the area swept, A, varies inversely as B C is increased or decreased, hence

$$A = \frac{3840}{10 \times 0{\cdot}125 \times 0{\cdot}08} = 38400 \text{ square ft.}$$

and S = 60 ft. per second,

$$\therefore l = \frac{38400}{60} = 640 \text{ ft. span,}$$

say 40 planes, each 16 ft. long.

Applying this formulæ to an actual machine, we may take Blériot's monoplane which flew across the English Channel.

The following are the particulars obtainable :—

Span (total of all planes) $l = 40$ ft.

Speed $S = 56$ ft. per second.

Lift (or total weight of machine) $L = 715$ lbs.

The ratio of base to perpendicular of the triangle of plane is not given, but it appears to be about 6 to 1·2.

1st. $A = l \times S$ . . . . . . . . . (4)

$= 40 \times 56 = 2240$ square feet area swept.

2nd. $V = \dfrac{S}{\dfrac{a\,c}{b\,c}}$ . . . . . . . . . . . . . . (2)

$= \dfrac{56}{\dfrac{6}{1{\cdot}2}} = \dfrac{56 \times 1{\cdot}2}{6} = 11$ ft. per second.

3rd. $W = V \times A \times B\,C \times 0{\cdot}08$ . . . . . . . . (3)

$= 11 \times 2240 \times 1{\cdot}2 \times 0{\cdot}08 = 2365$ lbs. of air.

4th. $L = \dfrac{W \times V}{g}$ . . . . . . . . . . . . . (1)

$= \dfrac{2365 \times 11}{32{\cdot}2} = 800$ lbs. lift.

As given above, the lifted weight was 715 lbs. The difference is no doubt due to the small planes at the after end of the machine, which act as vertical rudders and will have small lifting efficiency, and a good margin of lifting effect is allowed.

Whether it is better to use two or three or four large planes, or a multiplicity of small planes, has not been practically demonstrated, but we know that the biplane and monoplane machine have flown with some success, while no great success has followed the trials with multiplanes.

Hitherto, we have assumed the planes to be flat. In practice they are curved, and just what the curve should be is not practically settled; for a time it will be left to the experience or opinion of designers. What we are concerned about at present is the fundamental principles, which should be mastered by all interested in aeronautical subjects.

### Power required for Aeroplanes to Support them in the Air.

The power required is compounded of two portions—first, the power to sustain the weight in the air, and, secondly, the power to force the whole machine through the air. The first is much the same as that required to push a motor-car or bicycle up an incline. A flying machine is virtually climbing up a hill all the time. The horse power required by aeroplanes is variously calculated. A rule for finding horse power required is given by Mr. Herbert Chatley as follows: Divide the lift or weight by four, and multiply by the speed in miles per hour, and divide the result by 375. Suppose the speed is 40 miles per hour, and weight 1,200 lbs., we have—

$$\text{H.P.} = \frac{1200 \times 40}{4 \times 375} = 32, \text{ nearly.}$$

It is founded upon the assumption that the lift is four times the thrust.

If the speed is in feet per second, the rule is to divide the lift or weight by four, multiply by the speed in feet per second, and divide by 550—

$$\text{H.P.} = \frac{1200 \times 59}{4 \times 550} = 32,$$

59 ft. per second being equal to a speed of 40 miles per hour.

If a machine has a higher ratio of lift to thrust, it will be seen from above that the horse power required is less. These powers do not include losses by slip of propeller nor friction of driving gear, and are merely nominal.

But the correct way to calculate the power for maintaining the machine afloat is to take V, the downward velocity impressed upon the air by the planes as formerly found, and W and $g$, and the fact that in practice a machine with a plane inclined at one in six lifts only four times the thrust, showing an efficiency of only $\frac{4}{6} = \cdot 66$ for the planes, or 66 per cent efficiency.

In our former example, W = 3,840 lbs., V = 10 ft. per second; the horse power formulæ, then, to find the actual horse power continually expended in overcoming gravity

$$\text{H.P.} = \frac{W \times V^2}{2g \times 550} \quad . \; . \; . \; . \; . \; . \; . \; (5)$$

$$= \frac{3840 \times 10 \times 10}{2 \times 32 \times 550} = 11 \text{ H.P.}$$

But the efficiency, if the lift is only four times the thrust with planes inclined at six to one, is only 0·66, or, in other words, the actual power required will be in the ratio of as

$$\text{H.P.} = \frac{11}{0 \cdot 66} = 16 \text{ H.P. for lifting.}$$

Now, besides sustaining the weight of the aeroplane, we have to propel it through the air; hence, besides the

$$\text{H.P.} = \frac{W \times V^2}{2g \times 550},$$

the horse power expended in supporting the weight, we have R the resistance to overcome at S the forward speed; the horse power for this is

$$\text{H.P.} = \frac{R \times S}{550}, \quad . \; . \; . \; . \; . \; . \; . \; (6)$$

If R = 150, S = 40, then

$$\frac{150 \times 40}{550} = 11 \text{ H.P. for driving ahead.}$$

to be added to the 16 H.P. for lift = 27 H.P. in all, and this 27 H.P. does not include the power lost in the propeller slip, nor friction in transmission. These may amount to 20 per cent at least; hence the brake horse power at lowest estimate would be about 34. By putting (5) and (6) together we get, for the total horse power, the formula

$$\text{H.P.} = \frac{R \times S + \dfrac{W \times V^2}{2g}}{550} \quad . \quad . \quad . \quad . \quad (7)$$

An empirical formula for resistance is

$$R = S^2 \times l \times B\,C \times {\cdot}0024 \times \sin \alpha,$$

and horse power for

$$R = \frac{S^3 \times l \times B\,C \times {\cdot}0024 \times \sin \alpha}{550}.$$

Practically as good a test as any, and a very simple one for an actual estimate of engine horse power, is to measure the petrol consumed by the engine in full flight for, say, 30 minutes or 15 minutes, in pints. An engine on an average, in good condition and working over three-quarters of full load, takes one pint of petrol per horse power per hour.

Suppose on a run of 15 minutes the consumption was 11 pints, that is 44 pints per hour, the horse power of the engine would then be approximately 44 H.P. It is a rough estimate, but quite near enough for comparisons.

Higher efficiencies may, however, be confidently expected, but we cannot hope for aerial locomotion ever to be so economical as land or water locomotion.

In land locomotion we express the resistance as a percentage of the whole weight moved. In motor cars with pneumatic tyres it is 2 per cent, on steam railways it is about 1 per cent, a fast ocean liner 0·7 per cent, 10-knot tramp steamer 0·1 per cent. In flying machines $12\frac{1}{2}$ per cent has been found for the Wright machine, $13\frac{1}{2}$ per cent for the Voisin machine.

This high coefficient in flying machines is due to the fact that, besides the frictional resistances, we have virtually to travel up an incline all the time in supporting the weight in the air; in the other cases the weight is borne by the land or water, and nothing is required to be expended in power for sustaining the weight. The 11 H.P., as found above, is therefore a necessary loss, and cannot by any contrivance, except by a balloon, be reduced.

The horse power of the Blériot machine is given as 25.

From our previous calculations of this machine we have found

$$W = 2365 \text{ lbs. of air and } V = 11 \text{ ft. per second.}$$

Now from

$$\text{Lifting H.P.} = \frac{W \times V^2}{2g \times 550} \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

$$= \frac{2365 \times 11 \times 11}{2 \times 32 \times 550} = 8 \text{ H.P., nearly,}$$

and with 66 per cent efficiency, we get

$$\text{H.P.} = \frac{8}{0{\cdot}66} = 12 \text{ H.P. for lifting.}$$

The total horse power is said to be 25, from which we deduct 20 per cent losses by friction and transmission, giving 20 H.P., less 12 H.P. for lifting, leaving 8 H.P. for driving.

We can now ascertain the resistance R of this machine from

$$\text{H.P.} = \frac{\text{R.S.}}{550} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (6)$$

$$\therefore \text{R} = \frac{\text{H.P.} \times 550}{\text{S}}$$

$$= \frac{8 \times 550}{56} = 80 \text{ lbs. resistance, nearly.}$$

At the present moment the actual performance of flying machines is difficult to ascertain. Somewhat wild statements are made by inventors and builders, and no records of any independent tests have been published. Such as they are, the results claimed can only be given as approximations to the facts, so far as engine power and efficiencies are concerned.

## Winged or Fish-tail Flying Machines.

The only examples of this class of machine are small models. A flapping wing, like all other to-and-fro movements, introduces large unbalanced forces, due to the fact that the wing reverses its motion at the end of every stroke, and that it stops and starts again with great rapidity. Let anyone hold out a flat board, a yard long, and try to flap it up and down like a wing, it will be found very trying work, due to the continual stopping and starting.

However, if we employ a cylinder and piston to flap the wings, advantage can be taken of the momentum of the wings to compress the motive fluid in the cylinders, and thereby store up energy to be expended again in starting the return

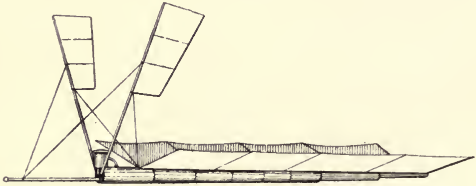

Fig. 7.—Hargreaves' Flapping Wing Machine.

stroke, as is the common practice in steam engine design, by providing what is called "cushioning" in the cylinders.

This simple mechanical device has been, in most flapping wing machines, neglected.

Cams or cranks employed to flap the wings must fail, for the enormous strains thrown upon them at reversal of stroke, and their great frequency, cannot be balanced without some cushioning device.

Mr. Lawrence Hargreaves, of Sydney, New South Wales, however, recognised these points in his early designs for flapping wing machines, operating them by steam or compressed air directly by a piston and cylinder.

The wings he employed were not exactly like bird wings, they were rather like aeroplanes, having an up-and-down motion. Fig. 7 shows one of his machines driven by compressed air, carried in the long tube which forms the backbone of the machine; it is 2 in. diameter, 4 ft. long, carrying 144 cubic inches of compressed air 230 lb. per square inch.

The wings, carried on rods which vibrate through an arc of a circle in a plane at right angles to the body of the machine, are flexible; in fact they were of paper on the model, hence they naturally feathered to right and left as the stroke was made up or down.

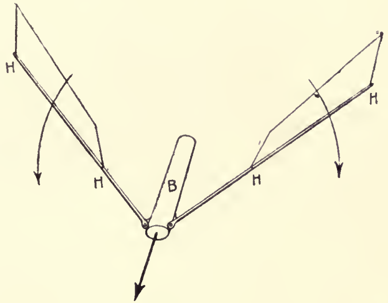


FIG. 8.—Hargreaves' Wings.

A diagrammatic plan of the machine and its wings is shown in fig. 8, showing the wings in the forward stroke, and in fig. 9 showing them in the back stroke. The wings are supposed to be hinged at H H, so that they swing round on the rods and present the incline face to the air; in the first figure the wings are travelling outwards, and hence are inclined inwards, and *vice versa* in the second figure. Now we may consider the wings, in which the thick arrow represents the line of flight.

And in this respect we could calculate out the thrust produced with any given stroke and frequency if we knew the angle of the planes.

Suppose a body B (fig. 9) with two radial rods capable of vibrating on hinges *h h*, through, say, one-third of the circle each, and wings W W attached also by hinges H H, and springs or stops fitted to the wings so that they swing over to a determined angle at each reversal of the rods' vibration, we will have in effect a Hargreaves' set of wings.

The motion of the rods must be in a plane at right angles to the body B, and the motion of the wings at the reversal of the stroke must be in a plane at right angles to the rods.

Whether it is possible to construct such wings mechanically light enough and strong enough for an actual flying machine is a problem to be solved by some inventor ; perhaps instead

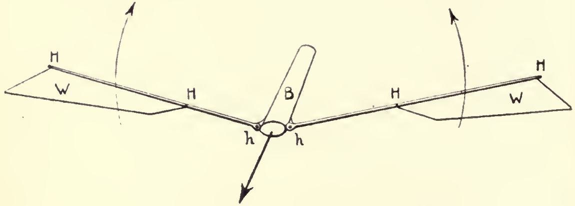


FIG. 9.—Hargreaves' Wings.

of hinged wings, flexible wings of thin springing material would be better, remains to be seen.

Such a machine would require supporting aeroplanes, the wings acting as propellers only.

In the Hargreaves' model the planes are end on. They would, we now know, be better broadside on ; the design becoming more like fig. 10, which shows the plan and elevation of a machine designed and built by the late Mr. F. H. Wenham, in which an aeroplane with six planes is fitted with these wings ; the wings are in front, and flap round on the reversal out beyond the outer ends of the planes.

In the Hargreaves' model the area of the wings was 216 square inches, and of the plane 2,128 square inches.

The action of these wings is more like that of the fish-tail propeller ; a fish tail is a flexible propeller vibrated in a horizontal plane. Marine propellers were tried on the same principle ; they were known as the Macintosh propellers. The blades were flexible and of coarse pitch when moving slowly, but as the speed increased, they were bent back and the pitch of the blades became finer, and approached the form of a disc pressing back against the water by its spring force.

There is no doubt a good deal of resemblance between the bird's wing, the fish tail, and the Hargraves' wings in their action.

The subject of winged machines, like most others relating to flight, at this date, is entirely eclipsed by the screw-propelled

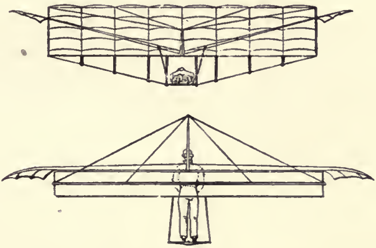

FIG. 10.—Wenham's Flying Machine.

aeroplane. The student and inventor, however, should be acquainted with all the types and their peculiarities. The tail moves in a horizontal plane in some fishes. As a propeller it may be imitated by a flexible wing *d* on a vertical pin R, fig. 11, which is a plan view of a lever for working the tail. When the lever L is moved in direction of arrow *a* around fulcrum E, the wing *d* assumes an angle *a*, and when it moves in direction of dotted arrow *b* the wing flaps over to position *c*. Thus by working the lever to and fro rapidly, with power applied at P, the wing or tail, acting as an inclined plane, sends the fluid astern at the race, and the reaction of this fluid sends the fish ahead.

More than likely if ever the winged machine is made of large size for practical use it will be operated on the principles indicated by these diagrams.

There is a considerable field of investigation open to the inventor who takes up the question of aerial propulsion by these wings vibrating on a swinging rod, the motions of the rod being at right angles to the motions of the wing. In the fish-tail propeller the motions of the lever and wing are in the same plane.

They have been called trochoidal propellers, from the curved shape they assume when made of flexible material.

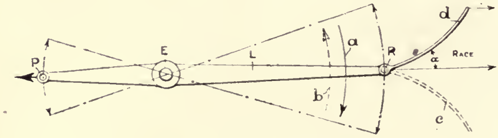


FIG. 11.—Fish-tail Propeller.

But the curve is not a trochoid curve at all, it is part of a parabolic curve ; no doubt if they come into use they will receive a more expressive cognomen.

### CALCULATIONS FOR FISH-TAIL OR WING PROPELLER.

The fish-tail propeller is not one to be driven at a high speed ; that is its drawback. And the speed is not constant during the swing. Its speed is that of a pendulum ; starting from zero it reaches a maximum when in the middle of the arc of swing, and then comes to zero again.

The mean speed M S is found by dividing the length $y$ of the arc in feet by the time $t$ of the swing in seconds, and by the square root of 2 ( $\sqrt{2} = 1{\cdot}44$).

$$MS = \frac{y}{t \times 1{\cdot}44} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Suppose $t = 1$ second per swing
and $y = 5$ ft. the length of the swing,
then

$$M S = \frac{5}{1 \times 1{\cdot}44} = 3{\cdot}47 \text{ feet per second.}$$

or if the time of one swing was 0·5 seconds, then

$$M S = \frac{5}{{\cdot}5 \times 1{\cdot}44} = 6{\cdot}8 \text{ feet per second,}$$

practically 7 ft. per second. We can thus calculate for different speeds or frequency of beats.

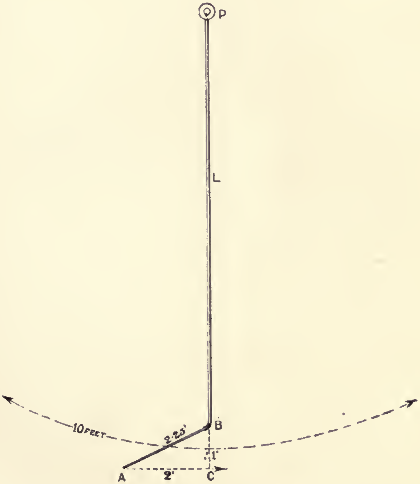


FIG. 12.—Fish-tail Propeller

We may take the case of a fish-tail propeller A B, 7 ft. span and 2 ft. 3 in. broad, hinged to a lever L on a pivot P (fig. 12), and swinging through an arc of 10 ft., making five swings per second, or $t = 0{\cdot}2$ second per swing.

Then
$$MS = \frac{10}{\cdot 2 \times 1\cdot 44}$$
$$= \frac{10}{\cdot 288} = 35 \text{ ft. per second.}$$

From fig. 12, if A B, the tail, is 2·25 ft. and B C 1 ft., then A C would be 2 ft.; that is,
$$\frac{BC}{AC} = \frac{1}{2} = \cdot 5.$$

Then the velocity V impressed on the air would be
$$V = MS \times \frac{BC}{AC} \quad \ldots \ldots \quad (9)$$
$$= 35 \times \cdot 5 = 17\cdot 5 \text{ ft. per second.}$$

The area A swept by the tail is equal to the span $l$ multiplied by the mean speed M S.
$$A = l \times MS.$$
$$= 7 \times 35 = 245 \text{ square feet.}$$

Then the weight W of air moved would be, from (3),
$$W = A \times V \times BC \times 0\cdot 08$$
$$= 245 \times 17\cdot 5 \times 1 \times 0\cdot 08 = 343 \text{ lbs.}$$

and the thrust would be
$$T = \frac{W \times V}{g} \quad \ldots \ldots \ldots \quad (10)$$
$$= \frac{343 \times 17\cdot 5}{32} = 190 \text{ lbs.}$$

The horse power would be
$$H.P. = \frac{R \times MS + \left(\frac{W \times V^2}{2g}\right)}{550} \quad \ldots \ldots \quad (11)$$

where R is the resistance of the tail to the swing in lbs., say 50 lbs. in this case, and M S we have as 35 ft. per second, then
$$H.P. = \frac{50 \times 35 + \left(\frac{343 \times 17\cdot 5 \times 17\cdot 5}{64}\right)}{550}$$
$$= \frac{1750 + 1640}{550}$$
$$= \frac{3390}{550} = 6\cdot 2 \text{ H.P.}$$

which with 190 lbs. thrust gives about 30 lbs. thrust per horse power. This does not allow for inefficiency of the tail or frictional or other losses.

This example is given in order to show how to make the calculations, and not as an actual example of planes at work, as wing or fish-tail propellers.

Made of very thin flexible steel or other metal on a large scale, they might prove of considerable value; hence the calculations given may guide the experimenter.

As with the screw propeller—the larger W the weight of air moved, and the smaller V its velocity, the more economical of power it is.

In the same way the flapping wing machine propeller can be calculated; these were used as shown in figs. 7 and 10 by Wenham and by Hargreaves.

This is a type of propeller not hitherto made much of nor well understood. In fact the principles of its action have not been before now brought into arithmetical calculations.

In the present stage of aeronautical progress, nothing practicable can be neglected without risking failure to find something of value. The fish and the bird do very well with flapping propellers.

The bird's wing at its outer end and outer posterior edge acts as the propeller; its stiffer part next the body forms part of the supporting surfaces. Some writers carefully consider its general formation as pointing the way to man in his investigations, but they forget that its peculiar shape and form is due to a large extent to the fact that it is designed to fold up snugly and fit close to the sides of the bird. In a mechanical wing, not designed to fold against a body, it would be folly to make it a copy of a bird's wing.

To sum up the power question.

All propellers working in a fluid give a higher efficiency the smaller the velocity of the slip V and the greater the cubic feet of fluid accelerated.

In the aeroplane we have two slips—first, the slip at the screw propeller, and, secondly, the slip at the aeroplane, which we found under the conditions stated at page — to be equal to 11 H.P. It has also two frictional losses—loss between engine and propeller, and in head resistance of aeroplane and its contents.

The helicoptere flying machine has one great slip, the sustaining propellers accelerating the downward column of air without the screw advancing upwards ; it has also to provide power for overcoming the head resistances.

The fish-tail propeller makes no difference in these respects, as it also has slip, to which is to be added the slip of the aeroplanes.

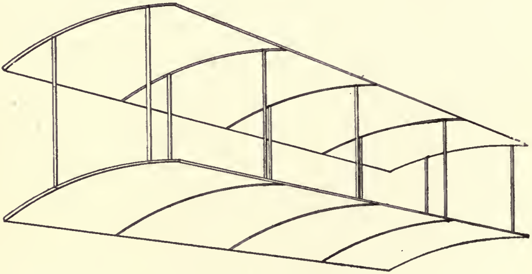

FIG. 13.—Aeroplanes.

The aeroplane has attracted the undivided attentions of aeronauts for a quarter of a century, and now that it has at last actually flown and carried two or more men, it seems not possible to carry it to much greater utility, and before long the field of operations will again be left to the investigator and scientific inventor to strike out fresh lines, and discover new inventions.

We may now consider the practical results of experience with actual aeroplanes to find what relation obtains between weight lifted and the total span of the planes and the total surface of the planes. The following tables gives some useful numbers for consideration :—

TABLE I.

| Name. | Span. Ft. | Surface. Sq. ft. | Weight. lbs. | Lbs. per sq. ft. of surface. | Lbs. per ft. of span. |
|---|---|---|---|---|---|
| | | Biplanes. | | | |
| Short | 40 | 520 | 360 | 0·7 | 4·5 |
| Howard Wright | 40 | 620 | 1,100 | 1·77 | 13·7 |
| Voisin | 33 | 537 | 1,100 | 2·04 | 17 |
| Voisin | 33 | 537 | 1,250 | 2·32 | 19 |
| Delagrange | 33 | 537 | 1,100 | 2·04 | 17 |
| Pischoff | 35 | 495 | 530 | 1·07 | 7·5 |
| Breguet | 40 | 518 | 1,120 | 2·16 | 14 |
| | | Monoplanes. | | | |
| Weiss | 34 | 150 | 360 | 2·4 | 10·6 |
| Rep | 32 | 155 | 792 | 5·1 | 24·7 |

TABLE II.

| Driver. | Maker. | Area square feet | Lbs. total weight. | Engine H.P. | Propeller diameter. | R.P.M. | |
|---|---|---|---|---|---|---|---|
| | | Biplanes | | | | | |
| Tissandier | Wright | 538 | 1034 | 25 | 8 ft. | 450 | 2 propellers |
| Lefebvre | Aerial | 430 | 1000 | 25 | 8 ft. | 450 | 2 ,, |
| Farman | Farman | 430 | 1200 | 50 | 6 ft. 4 in. | 1200 | 1 propeller |
| Legagneux | Voisin | 530 | 1200 | 55 | 6 ft. 6 in. | 1150 | 1 ,, |
| Gleine Curtis | Curtis | 255 | 704 | 30 | 6 ft. | 1300 | 1 ,, |
| | | Monoplanes | | | | | |
| Blériot | Blériot | 220 | 715 | 25 | 6 ft. | 1400 | 1 ,, |
| Latham | Antoinette | 530 | 1200 | 50 | 7 ft. | 1100 | 1 ,, |

The biplane is a machine with two superposed planes. The monoplane has only one plane. Some aeroplanes have three decks of planes, and are called triplanes, and some have multiplanes. But it depends, as can easily be seen from our calculations, that whether we use monoplanes, biplanes, triplanes, or multiplanes, or whether we adopt large or small planes, we must get in the necessary plane span.

It will be difficult to get a monoplane of sufficient span for heavy lifts, together with a strong construction. The biplane and triplane form a girder construction readily, which can be stiffened by ties and struts. Multiplanes become too high and heavy, and are, therefore, of less stability.

The biplane, hitherto, has given the best results.

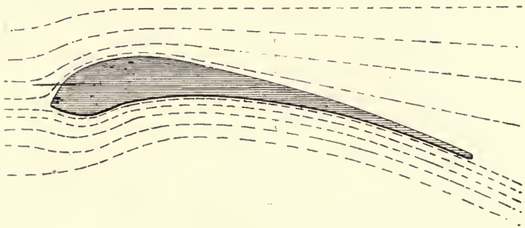

FIG. 14.—Form of Aeroplane.

The best form of aeroplanes are curved, see fig. 13, so that the fluid is gradually deflected downwards on the sustaining surfaces. In practice, the form shown in fig. 14 is said to prove superior. The blunt end is the forward end. The stream lines are shown. Considering the air which is

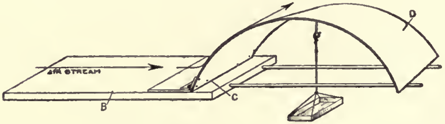


FIG. 15.—Lifting Effect of Air on Back of Plane.

deflected upwards, it would be imagined that this deflection would be a source of loss of power, but practice shows apparently that it is not so.

Mr. José Weiss has studied this point, and by experiments, given a demonstration which goes to prove that a current or stream deflected on a convex surface causes a lifting on the back. Referring to fig. 15, a curved sheet D is hinged at C to a board B, and has a hook on which it may be weighted. If a stream of air is blown along parallel to the board, the curved blade is sucked up. Mr. Weiss states that if the current of air has a velocity of 80 ft. per second, a convex surface of 20 square inches will support nearly half a pound in this way.

He states that anyone can try the experiment by bending a sheet of note paper, as shown in fig. 16, fasten it to table at *a*, and by blowing a stream of air by mouth parallel to the table the curved part will be sucked upwards.

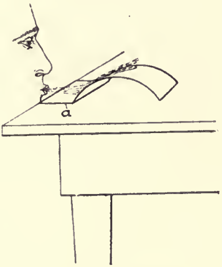


FIG. 16.—Experiment showing Lifting Effect of Air on Back of Plane.

My own idea of the action is that the upward and slanting motion of the deflected stream creates a partial vacuum on the convex back of the blade, much in the same way as by blowing a current of air across the mouth of a vertical pipe dipping into water creates a partial vacuum in the pipe, and the water flows up, see fig. 17. A somewhat similar action can be shown by an old experiment, fig. 18. Take a cotton reel and a card, hold the reel a short distance above a card, blow down the central hole and the card will be sucked up. The air, as it flows out radially at considerable velocity, expands and becomes less in lateral pressure than the atmospheric pressure.

It is doubtful if ever a more efficient lifting instrument than a well-designed curved aeroplane can be devised. The secret of its high efficiency lies in the fact that it can deflect such a huge mass of fluid at a low velocity, while travelling itself at a high forward velocity, so that quite a small thrust forward can sustain a large weight.

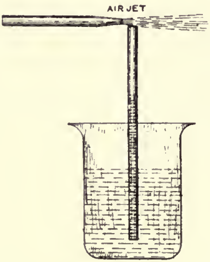


FIG. 17.—Air-jet Experiment.

But the necessity for continuous high forward velocity is a considerable drawback. It necessitates a preliminary starting up to speed, and considerable wide space, both for starting up and landing. Landing can be safely effected

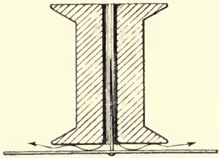

FIG. 18.—Air-jet Experiment.

only from such low heights, when the engine is stopped by design or accident, that the machine has still some forward velocity when it alights. If the height at which the engine stops is so great that all forward velocity is lost before landing, all control and stability is lost.

These are inherent defects in the system, and apparently nothing has yet been suggested as to any remedies.

For these reasons hopes were entertained that by rotating the planes instead of driving them straight along the line of flight, that a lift could be maintained economically. Screw propellers on a vertical shaft were early proposed in a type of machine called a helicoptere for this purpose, generally two, one right handed, the other left handed, so as to balance each other.

Fig. 19 is an outline of such a machine as usually proposed. A is one of the screws mounted on a hollow shaft C, and B is

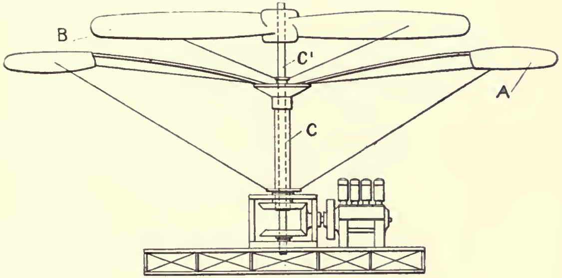


FIG. 19.—Helicoptere.

the other screw mounted upon a central shaft $C^1$. They are driven by bevel wheels or other device in opposite directions.

It may be said at once that no screw propeller can possibly support a weight in air with anything approaching economy of power like an aeroplane. A screw working in a fluid, without advancing through it, gives velocity to the fluid, which is all "slip," and it is working under the most disadvantageous conditions.

But rotating planes need not be helical at all. The makers of air blowers long ago found that out, and devised more suitable blades for seizing upon the air and impelling it forward.

A lifting rotating blade, or a blower of air, requires to suck in its feed. It is not like a screw propeller driving into the feed with a high velocity in an axial direction.

Fig. 20 may be taken as an illustration of a common type of air-blower, with rotating planes properly shaped. Thousands of this type are in practical use every day—proof of their efficiency. From a list before me, a 6 ft. blower runs at 340 revolutions per minute, or, say, six revolutions per second (not to go into fractions). At that speed it propels,

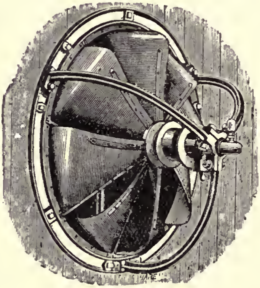

FIG. 20.—Fan Blower.

or accelerates, 1,000 cubic feet of air per second, with an expenditure of 5 B.H.P. at an acceleration of 35 ft. per second. Here we have 80 lbs. of air (W), accelerated to 35 ft. per second (V), and by the fundamental formula the thrust T is

$$T = \frac{W\,V}{g} = \frac{80 \times 35}{32} = 87,$$

a thrust or lift of 87 lbs. for 5 B.H.P. = 17·4 lbs. per horse power.

In all these efficient air-blowers the blades are curved axially aft to a much greater extent than is done in any blades working in water. At any rate, their efficient action upon the air explodes the idea of the air disturbance by many blades in a small diameter having any detrimental effect.

In another way this air-blower is instructive: At three revolutions per second it delivers 40 lbs. of air at about 16 ft. velocity per second with 2 B.H.P. expended.

The blades are more like sails or aeroplanes curved at the tips to take advantage of the centrifugal force due to the whirling of the air with the blades. If rotating planes or blades are to be used for lifting purposes, they must not be helical.

## The Principles of the Screw Propeller and Helicoptere.

These principles are the same as those of the aeroplane. The propelling or lifting thrust T is

$$T = \frac{W\,V}{g},$$

where W is the weight of air moved, V its velocity, and $g$ 32.

And by transposition we get

$$V = \frac{T\,g}{W} \text{ and } W = \frac{T\,g}{V}.$$

To sustain a pound weight in air, by a propeller, evidently requires a thrust T of a propeller = 1 lb. Hence we can find what value V should be when T = 1 and W = 1 we get

$$V = \frac{1 \times 32}{1} = 32 \text{ ft. per second}$$

as the speed V to be imparted to the fluid per second by the propeller, but we could make W less or more and still get the same thrust T.

Thus, if W = 4 lbs., then we would get in this case

$$V = \frac{1 \times 32}{4} = 8 \text{ ft. per second}$$

as the speed of air sent astern by a propeller to sustain 1 lb. in air.

The energy or work done in sustaining the 1 lb. weight is equal to, in foot-lbs. per second,

$$F\,P = \frac{W \times V^2}{2g} \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Hence a very important fact, which must never be overlooked or neglected, and that is, that we may increase T by either increasing W or V or both, but an increase of V demands more power in proportion to the square of V, while it is only directly proportional to W. For instance, in the first case

$$T = 1, \quad V = 32, \quad W = 1, \text{ hence}$$

$$F\,P = \frac{1 \times 32 \times 32}{64} = 16 \text{ foot-lbs. per second,}$$

and in the second case

$$T = 1, \quad V = 8, \quad W = 4, \text{ we get}$$

$$F\,P = \frac{4 \times 8 \times 8}{64} = 4 \text{ foot-lbs. per second} \quad . \quad . \quad (15)$$

For the same thrust the work required in the latter case is four times that required in the former case.

That is to say, the energy required to lift a pound weight in air by a propeller is not a fixed quantity, but depends on V and W, and hence if W = 16 lbs. and V = 2 ft. per second,

then $$F\,P = \frac{16 \times 2 \times 2}{64} = 1 \text{ foot-lb. per second.}$$

One foot-pound of energy per second would lift 1 lb. of weight against gravity.

In the first case the weight lifted would be 34 lbs. per horse power, in the second 137 lbs., and in the third 550 lbs. per horse power, from which it will be seen that there is in theory no fixed limit to the weight lifted per horse power expended on a propeller.

Now let us consider the size of a propeller required to support 1,000 lbs. in air with a value of V = 16 ft. per second. First find the weight W of air required. It is (13)

$$W = \frac{T \times g}{V}.$$

We have $T = 1000$, $g = 32$, $V = 16$, hence

$$W = \frac{1000 \times 32}{16} = 2000 \text{ lbs. of air per second.}$$

The cubic feet in this weight would be

$$\frac{2000}{\cdot 08} = 25000 \text{ cubic feet,}$$

and this, at 16 ft. per second, equals an area of

$$\frac{25000}{16} = 1560 \text{ square feet—}$$

giving a propeller of great size, nearly 44 ft. in diameter, for the lifting propeller.

If V were increased to 32 ft. per second, W would be equal to

$$\frac{1000 \times 32}{32} = 1000 \text{ lbs. of air per second,}$$

and the cubic feet, 12,500, which, divided by the velocity = 32, equals 390 square feet area of propeller, or 22 ft. diameter.

In the first case the horse power expended on the air would be from (3)

$$\frac{W \times V^2}{2g \times 550} = 14 \cdot 5 \text{ horse power}$$

and in the second case 29 H.P. would be required.

These worked-out examples of calculations show clearly the limits to sizes of propellers for lifting; they, in their work, are practically working against a fixed body, *i.e.*, the airship at a constant level above the earth. As propellers they are only sustaining weight, and their efficiency is simply dependent upon the value of V.

The horse powers calculated by these formulæ is the actual horse power at the propeller blades; the horse power at the engine would probably be double or more to make up for frictional losses.

To consider now the propulsion of the helicoptere airship. In the foregoing we have simply considered its support against gravity, and seen that propellers for that purpose must of necessity be large, owing to the small weight of air per cubic foot. A screw works to great advantages when it has a forward motion through the air, because it then acts upon a much larger volume of air. If the screw advances with a velocity S, and accelerates the air entering it by a further velocity V, and A is the sectional area of the current of air entering the screw, the volume acted upon is equal to A (S + V). The thrust T is, if the weight of air per second = W,

$$T = \frac{W\ (S + V)\ V.}{32} \quad . \ . \ . \ . \ . \ (16)$$

In propulsion we have to overcome the resistance R of the air only, and that is small if the airship is properly shaped. It, however, increases as the square of S the velocity of the ship.

The efficiency of the propeller is

$$\frac{S}{S + \frac{V}{2}}$$

Now $$T = \frac{\cdot 08 \times A\ (S + V)\ V}{32} \quad . \ . \quad (17)$$

and R equals the same. The area of the propeller is

$$A = \frac{32 \times R \text{ or } T}{\cdot 08\ (S + V)\ V} \quad . \ . \ . \ . \ . \ . \ (18)$$

V and S are in feet per second.

The horse power required is from (5)

$$H.P. = \frac{R \times S + \frac{W\ V^2}{2g}}{550}$$

The resistance of air to a surface depends upon its shape, and we have no experience to guide us to actual values ; and experiments in tow rope resistance are required to ascertain values for resistance at various speeds and with different shapes as a means of checking statements made regarding the performance of engines, screws, and aeroplanes.

As in the aeroplane so in the helicoptere, two powers have to be provided—first, power for lifting

$$= \frac{W\ V^2}{2g\ 550},$$

and power for thrusting through the air horizontally equal to

$$\frac{R.S.}{550},$$

and these added give the total horse power required.

If it is stated that the engine is 25 H.P., at the driving propeller, and the propeller efficiency is 0·7, then $25 \times 0{\cdot}7 = 17{\cdot}5$ H.P. actually thrusting the machine through the air.

The thrust per horse power T equals, when S is the forward speed,

$$T = \frac{550}{S}$$

If $S = 50$ ft. per second, then

$$T = \frac{550}{50} = 11 \text{ lbs. per horse power,}$$

hence $T = 17{\cdot}5 \times 11 = 192{\cdot}5$ lbs. total thrust, and this thrust is expended in overcoming the whole resistance.

The helicoptere depends entirely for its success upon the ability of its constructor to manufacture large enough screw propellers for lifting.

In a helicoptere, the area swept by the screw blades must approach that swept over by an aeroplane per second. An aeroplane with 80 ft. span (total), flying at 50 ft. per second, sweeps over $50 \times 80 = 4000$ square feet per second.

If we consider the screw blades simply as rotating planes, and use 12 of them, of 6·6 ft. length, to get 80 ft. span, and to revolve them at 50 ft. per second at their mean radius with moderate revolution, say, one per second, implies using a circumference at the mean radius of 50 ft., or a mean diameter of 16 ft., and 22 ft. diameter from tip to tip.

Fig. 20A represents this idea ; it will be seen to be simply four sets of aeroplanes of the box kite type, mounted upon arms on a hub, so that it may be driven by power. On a vertical shaft this device would, it is supposed, give a greater lift than screw blades, but it has not come into use.

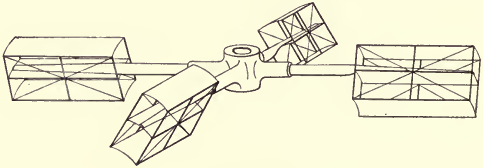

FIG. 20A.—Aeroplanes—Rotary.

The planes create eddy currents in the air, as shown in fig. 21 ; these in a straight line moving plane are left behind, and do not affect the motion of the plane, which goes forward into undisturbed air. But when the planes are in rotation

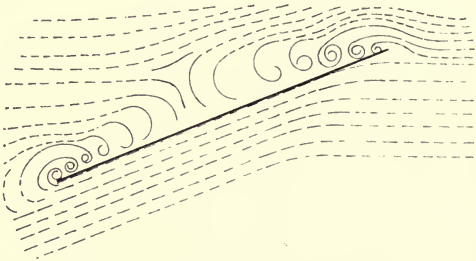

FIG. 21.—Air Disturbance by Moving Plane.

the eddy currents produced at the back by one blade come in front of the other, and the result is, that instead of a clean cut downwards, the air is churned up and the power expended in useless churning and turbulent movements of the air.

To some extent the same arguments and explanations apply to screw propellers in air.

It appears at present the propeller for lifting the helicoptere has not been invented or designed. It must be of immense diameter and pitch to move 40,000 to 50,000 cubic feet of air downwards per second at a low rate.

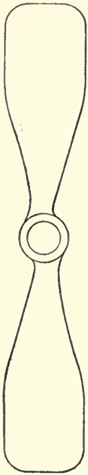

FIG. 22.—Air Propeller.

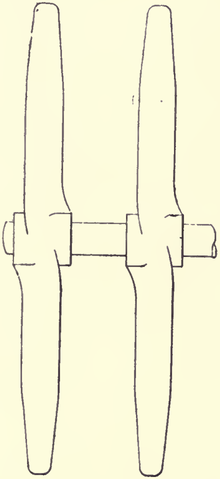

FIG. 23.—Double Air Propellers.

Even if we allow of a low efficiency, and drive the air down at three times the velocity it is driven down by the aeroplane, 13,000 to 16,666 cube feet per second at a velocity of, say, 32 ft. per second, requires an enormous diameter of screw, and that even when there are two or more employed.

### THE PROPELLING SCREW.

Wooden screw propellers have been found to answer very well up to 12 ft. diameter. The form is usually that shown in fig. 22. Sometimes double or treble propellers are used, narrow blades being used, one behind the other, with a space between, as shown in fig. 23.

In this way it is possible to act upon a greater mass of air with efficiency than by broad blades.

One string, wound spirally round a cylinder, makes a one-threaded screw; two strings, starting at opposite ends of a diameter, wound equidistant on a cylinder, make a two-threaded screw; and three strings, starting 120 deg. apart, wound on a cylinder, make a three-threaded screw. If,

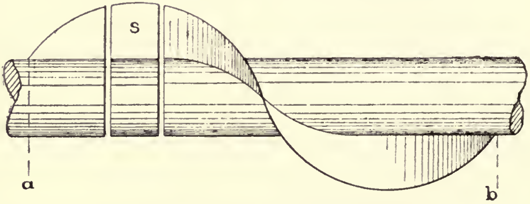


FIG. 24.—Length of Screw Blade.

instead of strings, a flat strip is wound on edge on the cylinder, as in fig. 24, and brazed thereto, we have an archimedian screw.

It was early found that for propeller purposes only a small slice of the complete thread was necessary. A piece cut out, as at S in fig. 24, would represent a one-bladed screw; if two strips were wound on, the slices would represent a two-bladed screw, and with three strips a three-bladed screw, and so on.

The "length of the blade" is equal to the length of the slice cut off. The pitch of screw blade is equal to the length of the cylinder occupied by one complete turn of the thread, from *a* to *b*. The face of blades which press against the air when propelling ahead is called the front or driving face;

the other side, "the back of the blade." The edge of the blade which cuts the air when driving ahead is the "forward" edge; the other edge is the "trailing" edge.

The disc area is the area of the circle swept by the blade tips.

The blade surface is the sum of the area of the blades, boss not included. The projected blade area is the same projected upon an athwart ship plane.

A screw turned in a solid nut advances the length of the pitch P for every complete revolution R; but in air there is slip—that is, the forward advance V of the screw is less than the pitch multiplied by the revolutions.

If P = mean pitch in feet,
N = revolutions per second,
S = speed of machine forward,

then
$$\frac{(P\,N) - S}{P\,N} \times 100 = \text{apparent slip per cent.}$$

If P = 10 ft., N = 3, then the advance V should be 30 ft. per second; but V may be only 20 ft., hence

$$\frac{30 - 20}{30}\,100 = 33 \text{ per cent slip.}$$

For propelling purposes in air probably two blades are best, with curved front faces.

Messrs. W. G. Walker and Patrick J. Alexander experimented with five different screws in air, and found that the driving force or thrust varies as the square of the revolutions, and the energy expended as the cube of the revolutions; and that the driving force varied, with respect to the work done, inversely as the number of revolutions.

A tabular statement of results is here set out.

There is room for improvement in air propellers. Tests on an accurate basis and a fairly large scale are necessary.

The efficiency is variously given from 50 to 70 per cent. It is not at all likely that the higher figure of efficiency is correct, for even in water it is seldom obtained.

## TABLE III.

TESTS OF SCREW PROPELLERS IN AIR.

(WALKER & ALEXANDER.)

| No. of test. | No. of blades. | Width of blade. Feet. | Disc area. Sq. ft. | Angle of blades to plane of rotation. | Thrust at 16 I.H.P. Lbs. | Remarks. |
|---|---|---|---|---|---|---|
| 1 | 4 | 6 | 350 | $12\frac{1}{2}$ deg. | 212 | For equal tip speeds the thrusts of 3 and 5 were equal per horse power. |
| 2 | 2 | 6 | 175 | $12\frac{1}{2}$ deg. | 132 | No. 2 was the least efficient. |
| 3 | 4 | 3 | 175 | $12\frac{1}{2}$ deg. | 212 | |
| 4 | 4 | 3 | 103* | $12\frac{1}{2}$ deg. | 192 | * In No. 4 the blades were cut away in the centre, leaving 12 ft. diameter clear, making blades $4\frac{1}{2}$ ft. long each. |
| 5 | 4 | 6 | 350 | 21 deg. | 260† | † Thrust at 18 I.H.P. The framework run without blades absorbed 7·8 H.P. |

These tests were made by Mr. W. G. Walker, A.M.I.C.E., under the same conditions as those of a lifting screw; that is, the propellers rotated in a fixed plane.

The inner ends of blades have little lifting force, as shown by No. 4, while, as was to be expected, increasing the pitch gave 260 at 21 deg., against 212 at $12\frac{1}{2}$ deg. for 5 and 1 respectively.

The following table (IV.) is given in a discussion of airship propellers by Calvin M. Woodward, LL.D., Professor of Mathematics in Washington University, U.S.A.

It gives valuable estimates of the power required for lifting propellers, or propellers simply supporting a weight in air.

## TABLE IV.

LIFTING PROPELLERS.

| Lift or pull. | $r$ = radius of equivalent propeller in feet. | A—total area of all the propellers in square feet. | H—Horse power required. |
|---|---|---|---|
| 1 | 1 | 3·14 | 0·029 |
| 4 | 1 | 3·14 | 0·23 |
| 100 | 1 | 3·14 | 29·00 |
| 1 | 5 | 78·53 | 0·006 |
| 100 | 5 | 78·53 | 5·8 |
| 400 | 5 | 78·53 | 46·4 |
| 400 | 10 | 314·2 | 23·2 |
| 650 | 8·1 | 206·00 | 59·5 |
| 900 | 10·4 | 339·93 | 75·5 |

Showing the proportion of increased power for increased lift, the propeller of 5 ft. radius lifting 100 lbs. takes 5·8 H.P., while lifting 400 lbs. takes 46·4 H.P., *i.e.*, eight times the power for four times the lift. But if we double the radius for the 400 lb. lift we require only four times the horse power, clearly showing the necessity for larger propellers for increasing lift.

### FOR PROPELLER DRIVING THROUGH THE AIR AT SPEED S.

P means the resistance of still air to the motion of an air-ship, moving S miles per hour, determined by experiment or calculated.

## TABLE V.—HORSE POWER TABLE.

| P | V | $r$ feet. | A sq. ft. | H′ |
|---|---|---|---|---|
| 100 | 10 | 10 | 314·16 | 5·58 |
| 100 | 15 | 5 | 78·54 | 9·8 |
| 650 | 15 | 8·1 | 206·00 | 85·5 |
| 400 | 20 | 10 | 314·16 | 44·51 |
| 900 | 30 | 10 | 314·16 | 150·5 |
| 1000 | 60 | 20 | 1256·64 | 206·— |

The general formula for the pitch of a propeller in air is according to the same authority,

$$P = \frac{\frac{16}{r}\sqrt{T} + \frac{22\,S}{15}}{N} \quad . \quad . \quad . \qquad (19)$$

$r$ = radius of propeller,
T = thrust,
S = forward speed of screw,
N = revolution per second.

A screw in practice should advance at the rate of its pitch multiplied by the revolutions per second, as it does in a solid nut, but working in air or water it slips. On an airship as a propeller the slip is a percentage. On a helicoptere the quantity P N is all slip

## CHAPTER III.

### Practical Flying Machines.

Although we have many possible modifications in the construction of flying machines, only one type has been evolved sufficiently for to accomplish actual flights of over a few hours' duration.

Professor Langley was undoubtedly the pioneer of the aeroplane type of machines. The mechanical transformer effect of the inclined plane, a simple contrivance by which a small thrust or pull along a horizontal path is converted into a large upward thrust, fired his imagination when it gave him the clue to the solution of the problem of flight. The same idea fascinated hundreds of others since, and before, his time.

The early workers in this field of investigation experimented largely with models called "gliders," arrangements of planes and weights which when launched from a height in the air

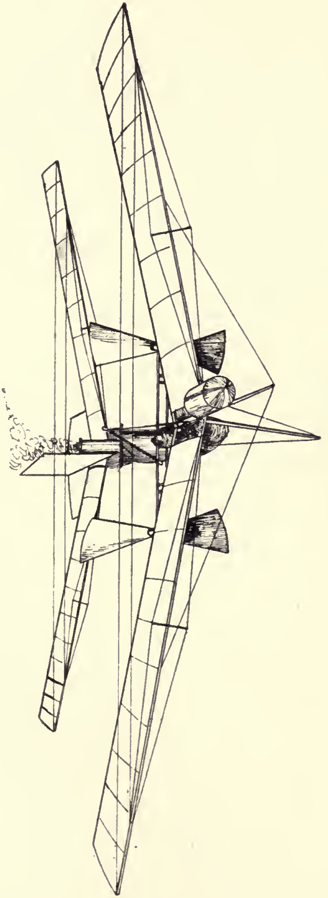

Fig. 25.—Langley's Flying Machine, 1896.

floated down an inclined path, inclined a few degrees to the horizon.

The only prime movers in these days available were the heavy steam boilers and engines. Sir Hiram Maxim's aeroplane machine was driven by what was then the lightest motor known, a very high-speed high-pressure steam engine of special design ; essentially, Maxim's flying machine was the same as the present day machines. The first recorded free flights of brief duration in Europe were made by Santos-Dumont with a petrol-driven engine and screw propeller aeroplane machine. Farman followed with much longer flights in public with a machine built by Voisins. The Messrs. Wright Brothers, in America, had built an aeroplane machine and obtained successful flights at early dates, but made no public exhibitions.

Professor Langley, the pioneer of the aeroplane, made the first flying machine which actually flew by mechanical power. Its design was not much different from present day machines, and is shown in fig. 25.

The frames were built of steel tubes and rods, the planes were of varnished canvas. There are two pairs of wings or planes, one pair behind the other, and the two screw propellers are between the pairs of planes. It was a small model, with an engine and boiler developing from 1 to 1½ H. P. ; total weight, engine and boiler, 6½ lbs. ; total weight of machine, 30 lbs. ; length 16 ft. ; span, 13 ft. The boiler could run the engine for two minutes, the two propellers going at 1,200 revs. per minute. On May 6th, 1896, this machine, in the presence of Prof. Graham Bell, of telephone fame, and Langley, flew a mile and a half. This was the first time a machine actually accomplished flight by mechanical power.

The U.S. American Government granted £10,000 to carry the invention into practice on a large scale, esteeming it of great value in warfare. There was difficulty in procuring an engine of small weight up till 1901, by which time a specially constructed one of 50 B.H.P. was built, and the large aeroplane

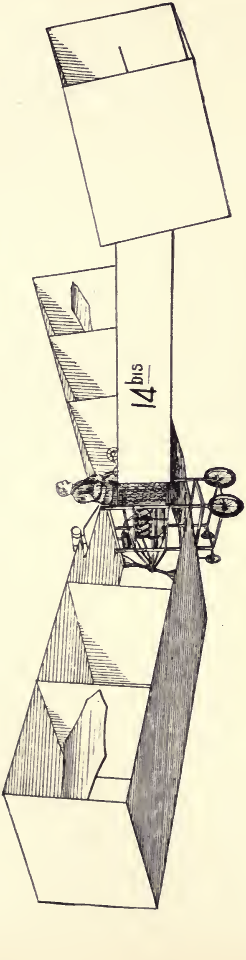


FIG. 26.—Santos-Dumont Flying Machine, 1906.

machine similar to the small one, but weighing altogether 830 lbs. with 1,000 square feet of plane surface, was finished.

This machine met with disaster at every attempt at flight. Unforeseen weaknesses developed in parts ; engine ignition troubles and instability at starting, and steering difficulties all followed in various attempts to fly it. There was no inherent defect in the design ; the failures were due to faults in the details, such as would naturally occur in a first attempt on a large scale, and Langley failed just within reach of success. The money was all spent, and he died shortly afterwards.

He advanced the science and art of mechanical flight very much, both practically and in writings. He was the first to point out that aeroplanes would require a starting-up device and that it would take great power to raise them direct from the ground.

Santos-Dumont, in November, 1906, with a petrol driven aeroplane machine, accomplished a short flight successfully, and so is probably the first man carried on a mechanically propelled flying machine. He accomplished a flight of 200 ft. at about 8 ft. from the ground, and secured the Archdeacon prize cup.

The machine was a biplane, with vertical partitions between the upper and lower planes, and had a long box tail in front of the driving platform. An Antoinette motor with eight inclined cylinders was used, giving 50 H.P., and driving an aluminium screw propeller, 6 ft. diameter, having two blades. The speed of the engine was 1,500 revs. per minute. The span of the wings was 39 ft. 4 in., and the total lifting surface 860 square feet. The weight of the machine without the operator was 352 lbs. The engine weighed only 3·16 lbs. per horse power. It made $24\frac{3}{4}$ miles per hour, with the propeller running at approximately 1,000 revs. per minute. At this speed it rose in the air and flew. Fig. 26 shows a drawing of this machine ; like Langley's it is not now of much interest.

Farman's flights made upon the Voisin machine were still more interesting. It also was a biplane machine, and had a box tail. It took a good deal of power to start it up, for, like Santos-Dumont, he started by running up to lifting speed along a level ground.

Farman won the Deutsch-Archdeacon £2,000 prize for a 1,000 metres flight on this machine.

The first trials of the aeroplane, constructed by MM. Voisin, at Billancourt, near Paris, took place on the parade ground at Issy, and resulted in short flights of from 30 to 80 metres being attained. During the following month experiments were continued daily. A flight of 285 metres was accomplished, and flights of 363 metres, 403 metres, 350 metres, and, finally, 771 metres (at a speed of 54·3 kilometres, or 33·7 miles, per hour) were made successively in the presence of the Aviation Committee of the Aero Club de France, who thereupon awarded to Mr. Farman the Archdeacon Challenge Cup, till then held by M. Santos-Dumont with his performance, just a year previously, of 220 metres at the rate of 42·3 kilometres (25·8 miles) per hour.

These flights were all made in a straight line at a height varying between three and six metres, and showed that the machine was under fair control. In the course of the next fortnight Mr. Farman devoted himself to the far more difficult problem of describing turns and curves in the air. And here, although he obtained a fair measure of success (he accomplished almost one kilometre in a circle, and succeeded in describing a double curve resembling an S), he failed in the end through the imperfect balance of his machine. Hereupon several minor alterations were made in the aeroplane ; the centre of gravity was shifted higher up, the large petrol tank was moved to the top of the upper sustaining-surface ; the cellular tail was reduced in size, and its arrangement altered ; and the front double-surface steering plane was replaced by a single one.

These alterations had the desired effect of improving the general stability of the machine ; and, after several further trials, the Deutsch-Archdeacon prize was won without difficulty on January 13, some 1,500 metres being actually covered in 88 seconds.

This was an aeroplane with two superposed surfaces, each surface being 33 ft. long by 6·5 ft. broad ; the vertical distances between the surfaces being 5 ft. A single plane situated in front, and controlled by a lever, effects up and down steering ; a large cellular tail situated 14½ ft. behind the main surfaces, and slightly lower, controls right and left steering. The 50 H.P. eight-cylinder "Antoinette" motor is fixed, with the operator's seat, between the two main surfaces, and drives a propeller 6·9 ft. in diameter with a 3·6 ft. pitch, situated immediately to the rear of the main surfaces and between them and the tail. The total carrying surface is 560 square feet ; the weight of the whole machine, including the operator, is 1,100 lbs.

The aeroplane is mounted on four wheels, two under the main body, and two small ones supporting the tail. An important point in the manipulation of the machine is that Mr. Farman, when sufficient speed has been attained on the ground (some 50 yards appear to suffice for this), rises into the air, not by moving his front rudder, but simply through the air pressure under the planes. This undoubtedly simplifies the subsequent manipulation of the steering plane, and consequently makes for increased stability.

Mr. Henry Farman's biplane "No. 3," fig. 27, is fitted with a much more elaborate under-chassis than previous machines. Not only does it now possess a set of four wheels under the main plane, but it also includes a pair of skis which are mounted between each pair of wheels, as seen in the illustration. Wheels and skis alike rise with the machine when in flight. The usual pair of small wheels are fitted to protect the tail. Inspection of the figure will show that the inner wheels of the front quartette are smaller in diameter than those on the outside. An interesting detail is the hinged flaps attached to the extreme rear edges of the main planes. These flaps, when set in position,

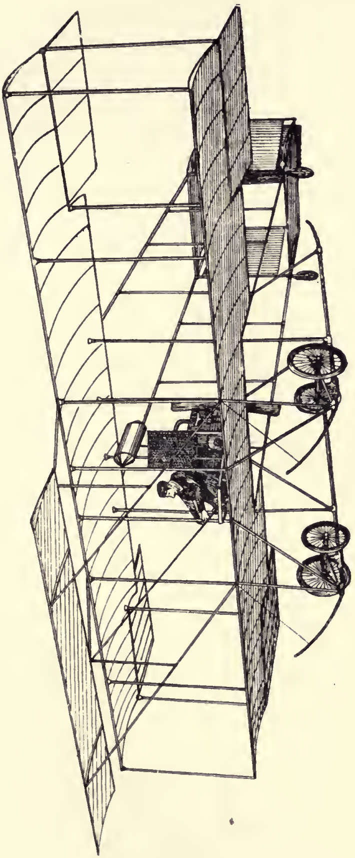

Fig. 27.—Farman's Biplane.

normally lie in the stream lines of the main planes, so that by flexing them up or down, as the case may be, the machine can be righted and steered. In his latest experiments Farman has abandoned the vertical rudder which formerly occupied a position inside the tail.

He also abandoned the steering wheel in favour of the simple bicycle handle control, and with the absence of any boat-like car, he is left quite free of any entanglement in the event of an accident. It has often been suggested that it is by no means wise for an aviator to sit in front of a horizontal steering column when learning to fly; in view of the frequency with which bodily damage has been caused by this member in motor car accidents.

The flier is fitted with a 50 H.P. Vivinus engine driving a two-bladed wooden propeller of 7 ft. 6 in. diameter. The span of the two main planes is 35 ft. each, and the overall length of the machine is 42 ft.

Into his new biplane he introduced several novel points. The main planes, which are 26 ft. by 6 ft. 6 in. broad, are not connected by vertical surfaces, but each is supported on a steel shaft running within the plane its entire length, and round about this shaft the plane can be pivoted to any angle. The machine has a box-kite tail and a front elevator, the total lifting surface being 355 square feet. The single wooden propeller is driven by a 45 H.P. Gnome rotary engine. The total weight is some 800 lbs.

The Wright machine, fig. 28, has made the best performances up till now. It is a biplane machine. Unlike the Voisin, it has no tail, but has in front large controlling, or height-governing, planes, on a rigging which carries them a considerable distance in front of the main planes. This gives them considerable leverage in lifting the machine up or down. It has also a vertical steering plane carried a distance behind, also for leverage purposes. It was designed to carry two persons of 175 lbs. each in weight, with fuel, for 125 miles.

The span is 40 ft., with 6 ft. distance between the two

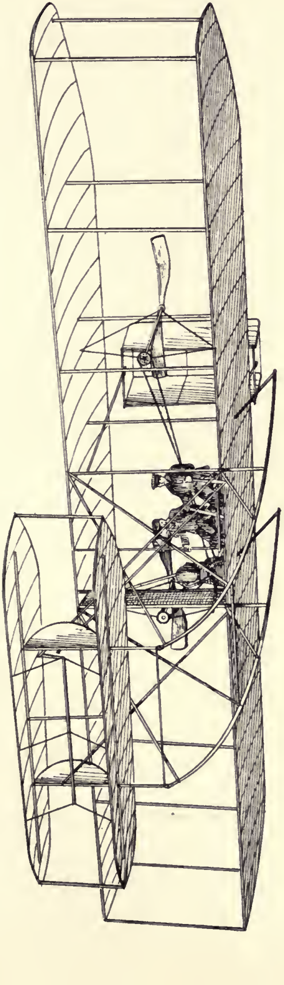

Fig. 28.—Wright Bros. Flying Machine.

main planes. The width of the plane is 6·5 ft., and total surface 500 square feet ; also, as already stated, the extremities of the planes can be warped into a less or greater plane angle when rounding curves.

A horizontal rudder of two superposed main surfaces, about 15 ft. long and 3 ft. wide, is placed in front of the main surfaces. Behind the main planes is a vertical rudder formed of two surfaces trussed together about 5½ ft. long and 1 ft. wide. The auxiliary surfaces, and the mechanism controlling the warping of the main surfaces, are operated by three levers.

The motor, which was designed by the Wright Brothers, has four cylinders and is water-cooled. It develops about 25 H.P. at 1,400 revs. per minute. There are two wooden propellers 8½ ft. in diameter, which are designed to run at about 400 revs per minute. The machine is supported on two runners, and weighs about 800 lbs. A monorail and heavy falling weight are used in starting.

The Wright machine has attained an estimated maximum speed of about 40 miles per hour. On September 12th, 1908, a few days before the accident which wrecked the machine, a record flight of 1 hr. 14 min. 20 sec. was made at Fort Meyer, Virginia. Since that date Wilbur Wright, at Le Mans, France, has made better records ; on one occasion remaining in the air for more than an hour and a half with a passenger.

We will refer to the starting device for this machine under that heading later on. Major Baden-Powell has given, in "Aeronautics," a very good description of the starting and manipulation of this flyer, and we quote from that journal, in the following :—

"The machine is housed in a large shed, the governing aeroplanes being telescoped into the frame. When the machine is hauled out these are drawn out to the full distance and fastened in position. Two cart wheels are lashed to the underframe, so that the machine may be trundled to the starting rail. This rail is strips of iron supported by wooden posts; it is about 100 ft. long altogether

"A little trolley is placed on the wheel track and carefully centred under the lower plane; this trolley is simply a piece of wood with a roller at each end. Across the centre of it is laid a stout beam like a railway sleeper; on this the machine rests. A small roller on the fore planes also rests on the rail to support these planes.

"Then the cart wheels are removed to keep the machine upright. One end of the lower aeroplane is supported by a light trestle. A few yards behind the rear end of the starting rail is the 'pylon,' consisting of four upright beams braced together, 25 ft. high, with a large pulley slung at the top.

"A heavy weight, consisting of about six large discs of iron, weighing 220 lb. each, is hooked on and drawn up to the top by a long rope passing round the pulley, and led from the bottom of the tower to the track.

"This operation is done either by a number of men hauling on the rope, or the latter is attached to a motor car, which moves off and draws up the weights.

"The end of the rope having been passed round a pulley attached to the far end of the rail is led back and attached by a ring to a hook on the aeroplane. The latter is temporarily anchored to the track by a loop of wire held by a small lever catch.

"The engines are now started by two men turning the propellers together. Mr. Wright generally lets the motor run for some minutes while he carefully watches it and examines all parts to see that everything is correct.

"Then comes the exciting moment for the passenger to take his seat. Having clambered in among various rods and wires one struggles into the little seat arranged on the front edge of the lower plane, and places one's feet on a small bar in front. A string is found crossing just in front of one's chest, and Mr. Wright gives directions that this must not be touched. It is a simple contrivance for cutting off the ignition and stopping the engine. In the event of any accident the body will probably be thrown forward and, pressing against the string, immediately stops the engine. Once Mr. Wright himself put up his hand to adjust his cap while in mid-air, and accidentally touched the string, and the machine landed unexpectedly (though, of course, quite smoothly).

" All being ready, coats are buttoned, and caps pulled well down to prevent being blown off. In one trip the passenger's cap was blown off and caught in one of the wire stays behind. Although the chains transmitting the power to the propellers are closed in tubes for most of their length, it seems possible that a cap might fall foul of them and be drawn into the gearing, which might have an awkward result.

" Then the driver bends down and releases the catch which holds the anchoring wire. The machine is off ! It bounds forward and travels rapidly along the rail. The fore planes are meanwhile pressed down to prevent the machine lifting prematurely, but when about half the length of the rail has been traversed, the lever is pulled back, the planes come into operation, and the whole machine rises, almost imperceptibly, off the track. The object of the starting device is to get up a sufficient speed to enable the aeroplane to rise in the air. If the speed is not quite sufficient the machine soon falls to the ground. From experience with bicycles and low-powered motors we can all realise how greatly a slight upward gradient detracts from the speed and calls for extra power, but one is apt to forget that the same applies to the flyer. The ascent must be very gradual. When the machine leaves the track it glides so close to the ground that one often doubts if it is really started in the air, but then it gradually mounts and steadily proceeds on its journey. So steady and regular is the motion that it appears exactly as if it were progressing along on an invisible elevated track. Only just now and again, as a swirl of wind catches it, does it make a slight undulation like a boat rising to a

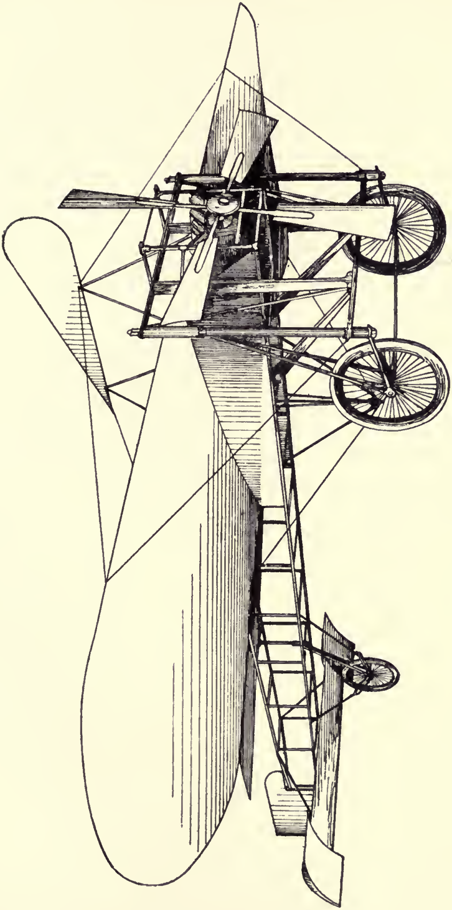

Fig. 29.—Blériot Monoplane.

big wave. Mr. Wright, with both hands grasping the levers, watches every move, but his movements are so slight as to be almost imperceptible.

"The run is completed. The machine is brought down close to the ground. It skims along only a foot or so above the sandy plain. Then the ignition is cut off, the propellers stop, and the machine lands on its skids, gliding for some distance along the ground."

This forward motion at landing is an essential feature in the safe downcoming of all aeroplanes. If they are stopped at such a height that the machine loses this forward speed before it lands, all control of it is lost, and a smash is the result. The aeroplane depends upon its motion for stability, and, like a ship, cannot be steered if it has no "way" on it.

The small monoplane "Blériot XI.," constructed and exhibited by Louis Blériot, made its first trial flight over a distance of some 300 yards. Further flights were made at Issy, and demonstrated that the stability of the machine was perfect. One of the most interesting features of the machine (fig. 29) is the small area of the main supporting surface; this has a span of 28 ft. The weight, including the driver, is 715 lbs.

The machine carries a monoplane tail with movable tips for steering, which are clearly shown in the figure; a small vertical rudder is fixed immediately to the rear of the tail surface. The small triangular vertical plane above the main surface is not now used. The four-bladed tractor screw is driven by a 3-cylinder 25-H.P. motor. As might be expected, the machine showed a high speed—over 43 miles per hour maximum being attained.

The design shown in fig. 30 is one by the author. It embodies the idea of adjusting the angle of the upper plane of a biplane, instead of tilting up the whole machine.

The machine is similar to the other biplanes in other respects, has a 25 H.P. engine and two 18 ft. diameter screw

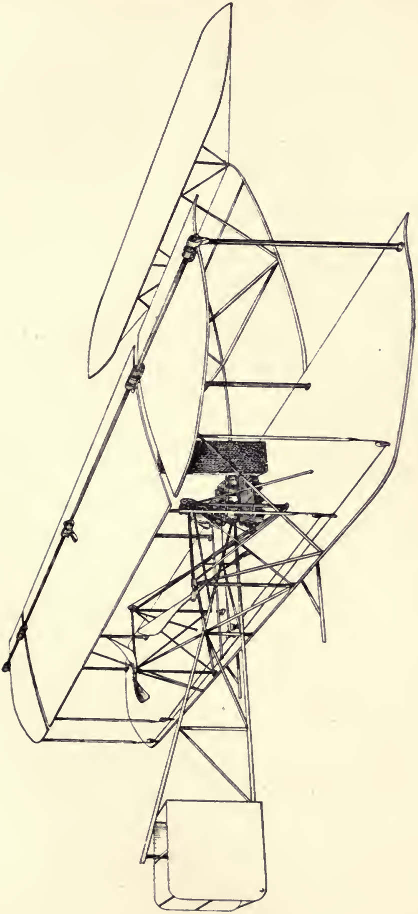

Fig. 30.—Rankin Kennedy Biplane—Movable Upper Plane.

propellers. The span is 38 ft., and the width 6 ft., the planes 6 ft. 6 in. apart. Like the Wright machine, it has no tail. The plane in front is carried well out beyond the main planes, giving the machine stability. The lower main plane is fixed in construction to the correct angle to the keel, and supports the engine, the driver, and other weights. The upper plane consists of three sections, a main central section and two tips. They are all three movable independently around a shaft, and by means of ropes or wires they can be set at various angles.

The two tips are interconnected by one wire and a lever, so that as the angle of the one is decreased the angle of the other is correspondingly increased in order to prevent rolling over in rounding a curved path.

The main section can be given a more or less angle of inclination to the keel, to accommodate it to varying velocities.

The governing plane to start with is fixed at a slightly greater angle to the keel than the lower main plane, and afterwards this angle is carefully adjusted by a lever and cords or wires. With this construction it is possible to maintain the machine on a fairly even keel, and without rolling, when flying at normal speed.

In soaring, the line of flight is inclined upwards, and so also is the keel; by manipulating the governing plane, this is brought about.

In the construction of an aeroplane the floor of the shop is the level of the line of flight, and the angles and measurements are taken from that or a datum line thereon, but when the machine is in flight the keel to which the machine has been built is not always level. This keel may not exist on the machine, but it is still possible to imagine an invisible keel to which the angle of the planes were originally set.

In the Wright Brothers' aeroplane, in order to steer the machine up or down, horizontal governing planes are employed, movable vertically by the driver. These tilt the whole machine so that the planes increase or decrease angle $a$ to line of flight. Referring to the diagrams, fig. 31, A C is the line of flight, and *a c* the keel of the machine. While building A C is the level line on the floor from which the angles and other dimensions are measured, and is represented in the plans and drawings as the line of flight.

Now in fig. 31, lower figure, at A the aeroplane is flying on an even keel; the keel and line of flight are parallel. At B the keel and line of flight are at an angle. At A the machine is flying with the plane at the angle designed by the engineer. At B it is at a greater angle to line of flight, although the

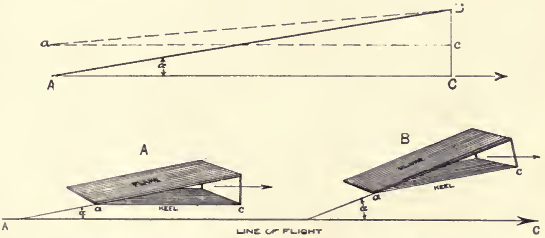


FIG. 31.—Alteration of Angle by Tilting of Machine.

angle with the keel is still the same. The aeronaut, by the outrigged planes in front or behind, can thus alter the lift at will; but it is done by tilting up or down the whole structure.

Much has been said and written about the "centre of gravity" and "centre of pressure" on aeroplanes, mostly nonsense. The centre of pressure shifts with alterations in forward speed. But in practice we are not concerned about the "centre of gravity" or the "centre of pressure" of the aeroplanes. What we have to deal with is the centre of pressure and gravity of the whole machine; the outrigger elevating and depressing planes enable the driver to maintain the two centres in equilibrium by tilting the whole machine to a greater or lesser angle to the line of flight.

For lateral balancing the planes are altered in angle at their outer extremities, or small planes on the extremities are varied in their angle to the line of flight.

In the Wright Brothers' aeroplane a rope and pulley system is employed, whereby the planes can be altered in their angle to the keel by bending them forcibly at their outer extremities. This is done to resist the tendency to turn over in rounding a curved course. The outer tips of the planes going at a higher speed than the inner tips of the planes have more lift, thus throwing the outer tips up. This can be counteracted by lessening the angle of the planes near the outer tip, and increasing the angle of the planes near their inner tips. It seems successful enough to bend them into the desired angle; but it is a crude device, and so is the bodily tilting of the whole machine in order to increase or decrease the angle of the planes.

The method of the future will be to mount the planes on pivots, or shafts, which can be rotated through a small angle, so that the aeronaut can readily trim his planes to any desired angle, and for any purpose, without much departure from an even keel parallel to the line of flight.

Naturally, of course, in the first machines, simplicity is everything, and nothing could be simpler than to make the planes fixed parts of the structure, serving a double purpose as planes and as structural elements.

But as advances are made from the primitive stages there can be no doubt that the planes, at any rate some of them, will be made independent of the structure, as the sails of a ship are.

In a biplane machine the lower plane may be part of the structure, and its keel always parallel to the line of flight, but the upper planes may be movable on hinges, pivots, or shafts, and their angle to the keel altered at the will of the aeronaut.

The height-governing planes and the steering planes are already independent of the structure, and adjustable in most machines.

Having obtained the dimensions of the planes, we next proceed to the disposition of them, and the general arrangement of the machinery, framework, and so on. All this is left to the designer, restricted to a weight limit, and this is where genius, talent, experience, training, and skill comes in.

From the designs shown by successful aeroplane machines, it is evident that with the present system of aeroplanes there is not much hope for improvement, for they are all pretty much alike. At present date the designers all follow the same general plan, distinguishing their machines from others by trifling details of construction. The biplane, with propeller and the elevating control planes in front, and a starting device to save engine power and weight, seems to be at this moment the best practice. But some radical improvement in the principles of flying machines, put into practice, are necessary before any general rules and guides to the constructional arrangements can be made of much value.

Much time and money is saved the experimenter who draws up a well-calculated set of plans, and arrives at close estimates of dimensions and weights, before proceeding with the construction.

An inventor may conceive a good idea and have some notions as to carrying it into practice ; but practicable plans can be made only by skilled, trained designers of structures and machines. The early motor cars were ridiculously designed by amateurs, but when they were taken up commercially, and trained engineers entrusted with their design, they very soon became models of good design.

In Britain the attempts at mechanical flight were, up till quite recently, treated with indifference or contempt, hence we have no distinctive British flying machines to refer to at present.

Now that actual practical flight has been attained, a considerable amount of interest has been aroused in the subject. Aëronautical clubs and societies are being formed all over

Britain, a Government committee has been appointed to do something or other, conferences are held by crowds of nobodies, two weekly and one monthly journal are devoted to flight, and everything possible is done except the one thing needful to make progress in the art and science of aeronautics, and that is to finance the inventors.

The real progress is left to the private speculator and inventor, and will therefore be exceedingly slow in this country.

There are probably about 40 or 50 aeroplanes in the world now, all bearing a strong family likeness to the original Langley. All the recent ones brought out, with the exception of the monoplanes, are copies of the Wright or Voisin machines, with some unimportant detail modifications.

There is a vast amount of work to be done on aeroplanes before they become useful machines. At present they are "fair weather" machines; they cannot work in anything but light breezes. They are not high flyers, due to the dangers in case of engine stoppage, they must keep down near enough to earth to land with "way" on.

The necessity for either a long run or a starting device, like the Wright Brothers' pile driver, to raise them to the flying speed, is a great restriction to their usefulness. They cannot get a long run everywhere, nor can they carry a pile driver about.

These and many other difficulties and disabilities show that there is considerable demand for further ingenuity and inventive ability.

The great thing at this juncture is for the engineer working at the problems to master the science of the subject and the principles, so far as they are known to date.

Experiments on a small scale are not expensive if properly planned with a definite object in view. These, with a well-reasoned description and scale drawings of a proposed machine, always have a good chance of financial support, especially if they are approved by an independent competent expert.

The publicity given to the aeroplane experiments has directed attention to the subject, and very likely more engineers of high abilities will now be attracted towards the solution of the problems still remaining.

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## CHAPTER IV.

### Some Possible Flying Machines.

In Britain at an early date the flying machine attracted the attention of several men of high inventive skill, F. H. Wenham and Horatio Phillips, to mention only two. Wenham proposed a machine and built a model. It was a multiplane machine; that is, the lifting apparatus was a frame carrying a great number of small planes. The same idea was worked out by Mr. Horatio Phillips on a larger scale and with engine power. Recently, M. Maurice Carron has made a model on this system with 72 small planes, in a frame looking like a venetian window blind.

Wenham's machine had a framework of thin planks, with binding bands of thin iron, with six tiers of planes.

The general design of the machine will be apparent from page 27, fig. 10, a plan and a rear elevation. The machine consists of six superposed aeroplanes of brown holland, 16 ft. long by 15 in. broad, kept in parallel planes by vertical divisions, 2 ft. wide, of the same fabric; the front edges of the aeroplanes being stiffened by bands of crinoline steel. The main spar *a a* had attached to it panels *b b*, with a base-board to support the body of the driver in a recumbent position; this was supported by a thin steel tie-band *e e*. The uppermost surface was stretched by a lath *f*, and the system kept vertical by staycords taken from a bowsprit carried out in front.

The two wing "propellers" turned on spindles just above the aviator's back; they were drawn up by light springs and pulled down by cords running over pulleys and fastened to the ends of a cross-piece worked by the feet. A longer stroke on one side would steer the machine to right or left. The propellers were made of fabric, stretched by elastic ribs, so that an up-and-down motion would produce a forward impulse. The machine was started by the aviator running against the wind. Trials of this machine were actually made by Wenham, but the structure proved too weak, the aeroplanes crumpling, and the experiments were never repeated.

There is little doubt that, provided Wenham had motive power, he would have succeeded there and then ; and this led him to turn his attention to devising an efficient light engine, and in so doing to construct the first light gas engine.

The Wenham machine had the same kind of wing propellers afterwards employed by Hargreaves.

In parenthesis, it may be remarked that Wenham was a remarkably gifted inventor. The author, more than 30 years ago, had to do with one of Wenham's engines, built about 1871. It was a gas engine and hot-air engine combined, and had a gas producer where the fuel was consumed. The upper part of the cylinder was an air pump, delivering a charge of air to the producer every stroke. This charge maintained the combustion and raised a pressure of the gases which drove the piston up by expansion.

As to Mr. Phillips' machine, a quotation from a letter of his will give an idea of its design and performance : " In previous machines I used only one frame of sustainers, but found the longitudinal stability defective. In my last machine I used four frames of sustainers, the front one of which is shown in fig. 32. The general dimensions of the machine is about 10 ft. high and about 19 ft. broad. The propeller is 7 ft. in diameter. The body of the machine consists of a triangular girder with lattice bracing of steel ribbon, the weight is supported by two 28 in. pneumatic tyred wheels ; there are two other smaller wheels to keep the machine upright when resting on the ground. The propeller is in front and is driven by an eight-cylinder diagonal air-cooled engine, giving from 20 to 22 B.H.P. at 1,200 revs. per minute. This engine was made several years ago, and has seen long and rough service; it is now being fitted with

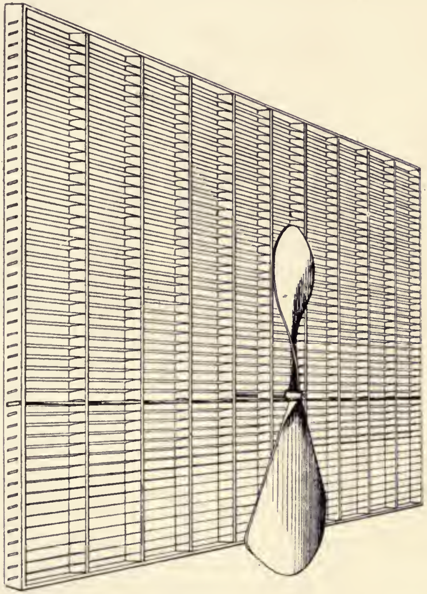

FIG. 32.—One Frame of Horatio Phillips' Multiplane Machine.

its fourth crankshaft. The propeller, being in front, is always the first thing to come to grief; one blade gets broken off, and the unbalanced weight of the other blade generally cripples the propeller shaft and crank. The planes are $1\frac{1}{2}$ in. wide and $\frac{1}{8}$ in. thick, with 2 in. spaces between them. On this occasion I used a very large amount of supporting surface, in order that the machine should not have to run far on rough ground before rising. When the machine was ready for trial it was started in a dead calm ; at first the jolting was terrific, and as soon as it was fairly off the ground the boundary of the field was nearly reached. The machine is provided with a vertical rudder. A low post was fixed in the centre of the field, and the machine tethered to it by steel wires 200 ft. long. On the first attempt to run the machine round the circle, the severe jolting broke the crankshaft in two places, and did considerable damage to the engine. Thus ended the trials.

Mr. Horatio Phillips did good work in investigating planes and their curves, and strongly held the view that the planes should be wooden, without any canvas or cloth about them.

The span of the blades is 19 ft. ; total size of each frame, 19 ft. by 8 ft. in depth ; sustaining and lifting surface equals 140 square feet area. Each blade has a maximum thickness of one-eighth of an inch. The concave side is hollowed to a depth of one-sixteenth of an inch, they are made of wood, and fixed in a steel frame. When these blades are propelled in a horizontal direction they are really moving through a current of air, the velocity of which will depend upon the speed at which the blades are moved.

The total weight of this machine was 360 lbs., and carried a load of 56 lbs. ; 416 lbs. on 140 square feet = 3 lbs. per square foot of plane. In a test, in which it flew 1,000 ft., the weight carried per square foot was $2\frac{1}{2}$ lbs.

On the whole, looking to the results of biplanes and monoplanes, there does not seem to be much greater lift per square foot with these multiplanes than with the simpler biplanes ; whether there is any reduction of horse power per ton lifted is not clearly given. The design is more rigid however, and wooden planes are preferable to canvas planes in any case if the weight can be kept down. It is a design worthy of study, in the light of recent experience. It would be better to use a number of planes about 3 in. broad with a perpendicular of $\frac{1}{2}$ in., and 3 in. between each blade clear.

$l$ would $= 912$ ft.

A = the area of the blades would be $= 912 \times 0{\cdot}25 =$ 228 square feet,

which, at 3 lbs. per square foot, would lift 684 lbs.

Calculated out by the formulæ we get

$$l = 912,\ S = 60,\ V = 10,\ B\,C = 0{\cdot}04;$$

$$L = \frac{.\,V\,.\,A\,.\,BC\,.\,0{\cdot}08}{32} = 688 \text{ lbs.}$$

Mr. Phillips experimentally found the best form of blade for these multiplane machines, but on large machines it does not seem to make much difference whether the planes are mathematically exact in curve form or not. In steam turbines, where the velocity of the fluid is enormously greater, not flowing at speeds under 100 ft. per second, but as high as 2,000 ft. per second and more, exact form of blade is imperative, but it is not so important in dealing with the low velocities of fluids in connection with aeroplanes.

However, it cannot be said that the multiplane machine has had an exhaustive investigation. Tried on a large scale, with proper design, it may reveal valuable properties at present unthought of.

Instead of building up a venetian blind arrangement of tiers of small blades, it is more likely to be necessary to put aeroplanes in tandem in the way Major-General Baden-Powell put up tandem kites, and for the same reasons, the size of kites soon become unmanageable.

The sizes of aeroplanes for two men are now bordering on the unmanageable. Hence, it will be necessary to put the driver and a guard and all the power on one plane, and the passengers on another plane, without power, the two planes being rigidly fixed together by cradle feet, somewhat after the manner of fig. 33. More than two planes may be so fitted together, forming a train of aeroplanes.

The aeroplanes are rather farther apart than their width, so that the one does not blanket the other.

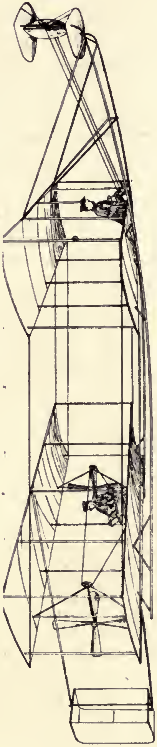

FIG 33.—Tandem Aeroplane.

A rectangular framework resting on the cradle feet carries the planes, which are fastened to the frame and stayed thereto.

The starting up of such large planes, like the starting of all other aeroplanes, must be made at specially appointed places where means for starting are provided.

Due to this starting difficulty the success of the aeroplane cannot be achieved at present as a useful machine. It was the cause of all Langley's disasters, and stands in the way, a very stiff problem still to be overcome.

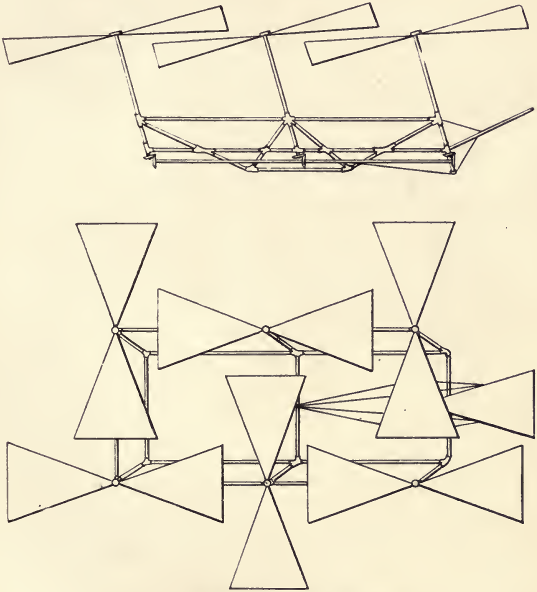

FIG. 34.—Multiple Screw Helicoptere.

Hence a machine which would have no starting or landing difficulties would be preferable, even though it should take twice the power to work it.

The helicoptere would have no starting or landing troubles.

But it has inherent difficulties of its own, not the least of which is the immense screw propellers necessary to lift the weight with any reasonable expenditure of power.

There are no details of any flying helicopteres to enable us to make an illustration of an actual machine which has flown in the air.

We have already, in Chapter II., discussed the principles of the screw propeller. Made of large size, with blades same as aeroplanes, say with 80 ft. of leading edges, angle of blades the same also, they may be regarded simply as aeroplanes moving in a circle.

Despite the large diameter required it is not beyond the power of the inventive mind to conceive a rotating structure which would solve the difficulty.

The work need not be done by one propeller ; it may be divided between two, four, or six propellers, one half left hand and the other half right handed.

Fig. 34 is a design by Mumford of a six-screwed machine, and fig. 35 is a design tried by the author with two 6-ft. screws. They were not really screw blades, but planes adjusted at an angle giving a constant inclination of the blades to the line of flight of six to one, as in planes. These gave a most decidedly greater lift than helical blades.

Transmitting the power to the propellers by a propeller shaft is bad practice, for the torque on a shaft carrying such large planes is great, the number of revolutions per second being small.

A rope drive is always better. A rope rim fastened directly to the planes, and of large diameter, transmitting the power with a large rope velocity and a small pull, the propeller may simply rotate upon a fixed shaft on ball bearings

In this way a rope speed of 3,000 ft. per minute or more may be obtained, and the pull reduced to less than 11 lbs. per horse power transmitted.

The machine shown in fig. 35 has two lifting propellers running in opposite directions, the rope passing round both

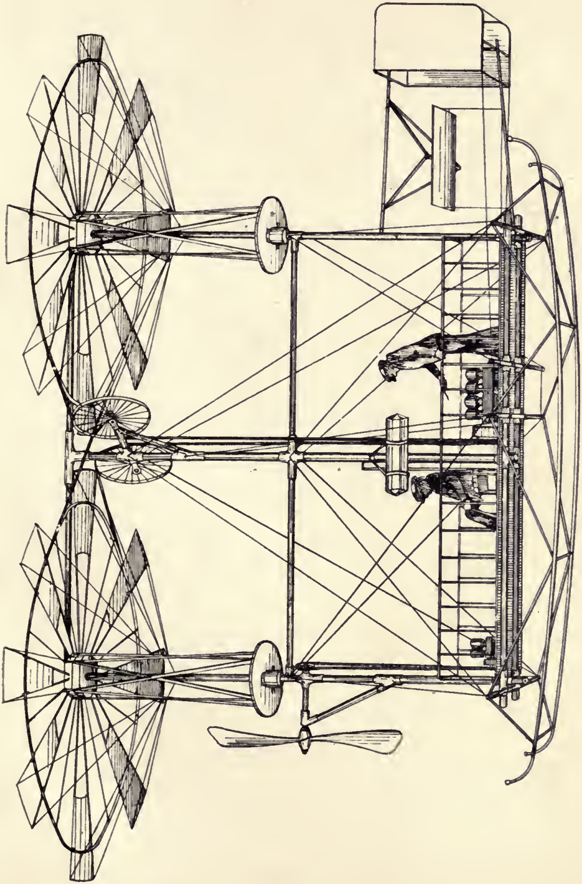

FIG. 35.—Twin Screw Helicoptere.

rims and round the driving pulley on the engine. With large propellers at high peripheral speeds, 5,000 ft. to 6,000 ft. per minute, and a fine angle of blade from 9 deg. to 12 deg., the aeroplane effect in multiplying the thrust into lift is obtained. The expense, however, of going on with the experiments on a scale large enough for a man-carrying machine prohibited further progress. It may be regarded as a possible flying machine.

Another possible direction of invention is the machine as projected by Wenham, shown in Chapter II. ; also by Lawrence Hargreaves. A diagram, fig. 36, shows this proposition on a three-decker plane, with steering tail and height-governing plane ; the wings are shown on levers vibrated by crank and connecting rods from a shaft driven by the engine. These diagrams are suggestive only, and are given to show that there are directions open for much original work by inventors with the necessary means.

Hargreaves concluded that the two propellers, the screw, and the flapping wing, or trochoidal plane, so called, were about equally powerful and efficient. He gives a table of results of his tests between two propellers of following dimensions : The screw propeller was 28 in. diameter, 7 ft. 6 in. pitch (an extraordinarily long pitch), two blades 6 in. long, 6 in. wide at the outer tip, 3 in. at the inner end.

TABLE VI.

HARGREAVES' RESULTS OF TRIALS BETWEEN A SCREW BLADED PROPELLER AND A FLEXIBLE WINGED PROPELLER.

| Particulars. | Screw | Trochoided plane. |
|---|---|---|
| Total area in square inches | 2090 | 2130 |
| Square inch area per lb. weight | 1045 | 1019 |
| Weight in pounds | 2·00 | 2·09 |
| Power used in foot-pounds | 196 | 470 |
| Horizontal distance flown in feet | 120 | 270 |
| Distance flown in feet per foot-pound of power | ·61 | ·57 |

Finally, there is the fish-tail propeller referred to, page 29, Chapter II. It is a plane swung to and fro on the end of a long lever by means of connecting rods from an engine shaft, fig. 37. Two such propellers would be used, moving oppositely to annul the momentum effect on the body of the aeroplane ; and a cylinder could be used with a piston in order to conserve the energy at the reversal by compressing air for cushioning.

Besides these, there are hundreds of impossible machines, which have been patented or proposed—machines displaying

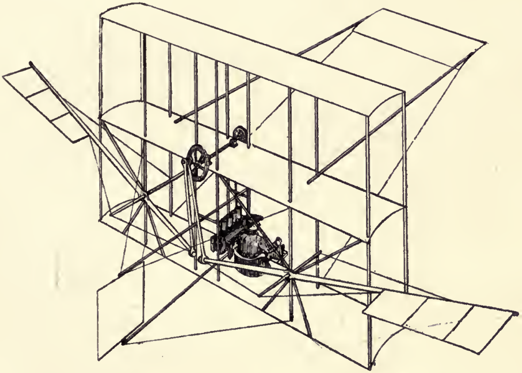

FIG. 36.—Diagram of Winged Aeroplane.

utter ignorance by their designers of the most elementary scientific knowledge of the subject. Others show a scientific knowledge, but a complete absence of any knowledge or skill in machine designing.

The problems still to be practically solved in the construction of machines are the most difficult the mind and hand of man have ever tackled, and all the science and art available is required to be brought to bear upon them by anyone attempting the design of a new machine.

The evolution of the motor car was child's play compared with that of the flying machine; the motor car is merely an assemblage of old, well-known, well-proved mechanical appliances. In flight we have a number of entirely new

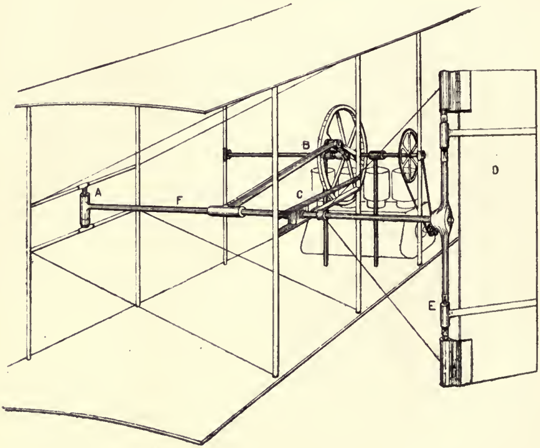


FIG. 37.—Diagram of Aeroplane and Fish-tail Propeller.

problems, requiring the creation of new devices; that is, real invention and real discoveries, not merely the combination of old and well-known appliances.

As an instance of this, the Wright Brothers having found that the power required for a few seconds to start the machine was far greater than that required for flight, they invented an auxiliary stationary power in the form of a falling weight, which acts efficiently to give them the additional power required for the send off. What a difference it would have made on the results of Langley, Maxim, and Phillips, and other early machines, if they had invented an auxiliary starter, can easily be imagined. Again, the flexure of the plane tips to steer round a curve and for balancing was a real invention, a new thing for a new purpose, by Wright Brothers.

Immediately we see these devices we are astonished at their not being foreseen ; but man is not far seeing, in these matters the best intellects are working in a feeble light.

The merits of the aeroplane as a means of multiplying the thrust of a screw propelling it, up to 10 times or more, was early perceived by scientific men. It was beyond all doubt that a thrust of 10 lbs. would produce a lift of 100 lbs. if the forward speed were high enough—this theoretically. At present, we get a lift of 4 lbs. with a thrust of 1 lb., but this will improve as time goes on, and aeroplane designs are taken in hand by skilled structural engineers. Present-day designs are very primitive, and not much in advance of Langley, only at this date we have found the motive power, which the great men of the past had not. However good their plans were, they had no motor but the steam engine and boiler.

They studied and experimented with planes, and became well acquainted with their properties and powers, and their works left behind them are of value to this day. We cannot take up the historical part of the subject here, but we may refer the reader to the work of Sir George Cayley, Professor Langley, Lillienthal, Horatio Phillips, and Sir Hiram Maxim. They have left their mark on aeronautical science.

An examination of the aeroplanes offered to the public reveals a great lack of originality and scientific knowledge of design. The slight variations which distinguish one make from another are mostly whimsical, and their exact purpose not very apparent.

Theory is very useful, but for improvements and progress, invention and skill, and designing, talent must be engaged on the work, combined with the means to carry it through.

It would be interesting to obtain results of a comparative test of a monoplane and biplane of same surface area. $A\ C = 3$ and $B\ C$ 0·5 ft., span 10 ft.; biplane $A\ C = 1{\cdot}5$ and $B\ C$ 0·25 ft., two spans 10 ft. each. The lift should be the same, at same speed, if the narrow plane is as good as the wide one.

Smaller planes might be tested on Lord Rayleigh's method of balancing on a rotary spindle.

Many people set out to build a flying machine without the least idea of employing skilled designers, artisans, or the most suitable materials. The results are to be seen in the exhibitions, and in the illustrations of them in aeronautical papers. It would pay better in the end to have everything done in the best style, from the plans and drawings down to the smallest piece of rope.

As to the general design of aeroplanes, experience alone can finally decide between monoplanes, biplanes, and multiplanes. Within limits the multiplane should have greater stability, for the planes are very narrow, so that the centre of pressure does not shift to the same extent as in wide planes; and they can be made more rigid, so that they retain their shape better at high speeds and pressures.

The advantages of the curved plane are exactly those well known to water turbine engineers, by which they have raised the efficiency immensely by a proper application of the principles of reaction on curved surfaces.

The fundamental principle is that the air should not be suddenly struck by a flat surface, but should be gradually accelerated as the plane traverses it, from zero to a downward velocity, as already explained.

Much experimental work requires to be done upon this subject; we can, of course, to some extent be guided by the hydraulic turbine curves.

It has been shown by M. Jose Weiss that a current of air passing over the back of a curved plane (see figs. 15 and 16,

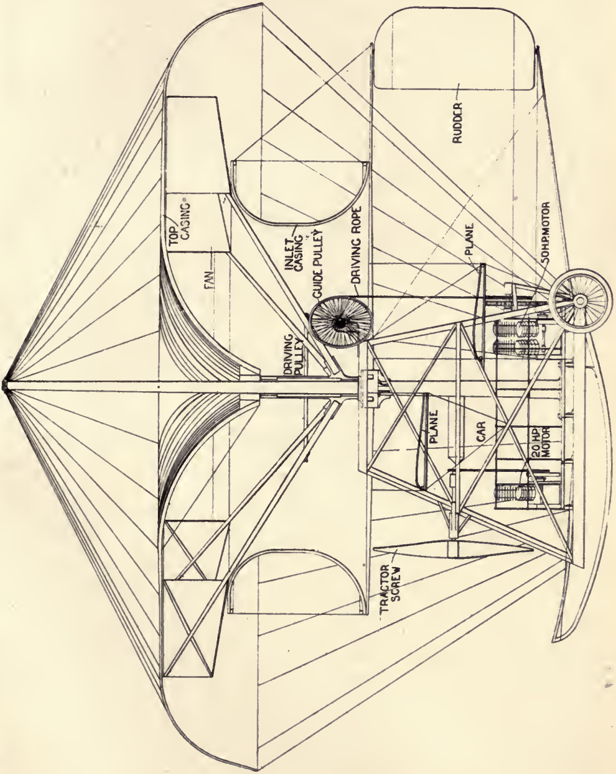


Fig. 38.—Floating Flying Machines; Dirigible.

page 35) produces a lift by creating a partial vacuum. Here, again, we require investigation.

The main question, however, is whether blades curved to give a maximum of lifting effect on their backs give a total lift (back plus front) than other blades of different shape. Phillips' experiments go to show that they do give a greater lift under the conditions of his tests.

But it is a question still open whether in a large-sized machine the results would be better with a large number of small blades properly curved for back lift to give better results than a curve of other shape. The results given for Mr. Horatio Phillips' own complete machine do not show any advantage.

## A Fluid Reaction Flying Machine.

An elementary principle in the flow and pressure of fluids teaches us that if a stream of fluid flowing with a velocity V, and a sectional area A in square feet, and a density D, the value of which for water is 62·5 and for air 0·08, the weight of a cubic foot meets with a curved blade and is turned aside through an angle of 90 deg., it will exert a pressure in the original direction of the stream or jet equal to

$$L = \frac{D\,A\,V^2}{g}$$

or in other words, if P is the pressure producing the velocity V, the force of reaction due to turning the jet or stream through 90 deg. is equal to twice the pressure multiplied by area $L = 2\,A\,P$; and if a jet or stream is turned twice through 90 deg., as shown in diagram fig. 39 by a cup-shaped bucket, conical in the centre, the lift or driving force in the cup will be equal to

$$L = \frac{D \times 2 \times A \times V^2}{g}$$

or $$L = 4\,A\,P.$$

If the stream of air shown in the diagram were 50 sq. ft. in sectional area, and had a velocity, due to a difference of pressure P, of 5 lbs. per square foot, it would lift the cup with a force of

$$L = 4 \times 50 \times 5 = 1000 \text{ lbs.}$$

On these principles the author has designed a flying machine, fig. 38, intended to replace the dirigible balloon—that is to say, it may do all the dirigible balloon can do, and that without the huge gas bags and expenditure on gas.

A stream of air caused by a difference of pressure set up by a fan, whose blades are in the crown of the cup, is designed to support the weight of the flying machine and its contents in the air by the reaction of a large current of air set in motion

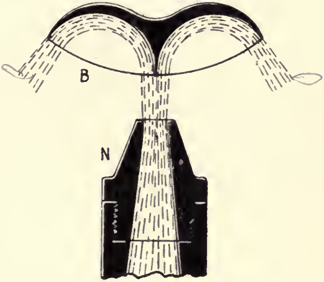


FIG. 39.—Reaction of Fluid Jet.

by a centrifugal fan in accordance with the aforesaid principles, said large current of air being twice deflected through an angle of 90 deg., first by being projected on the apex of a cone, and secondly by being projected against a cup or umbrella-shaped surface. The umbrella surface and cone are one structure, with the fan blades in the crown thereof, and a casing fixed beneath the fan wheel guides the large current of air flowing vertically upwards against the apex of the central cone. The current of air is thereby deflected through 90 deg. into the horizontal fan blades; by this deflection the momentum of the mass of air is destroyed and converted into a pressure, lifting the machine upwards.

The current of air having received an impelling force in the fan, strikes against the downward turned inside of the umbrella surface, and is deflected downwards ; its momentum is destroyed, and becomes a pressure upwards, lifting the machine upwards.

The fan is cased partly by the umbrella surface above, and the guiding entrance below, and its casing. The fan is carried upon a sleeve with radial arms, running upon a central pivot, or pin, with roller or ball bearings, and is driven preferably by rope gearing.

The engine, crew, and other contents are carried upon a platform suspended from the umbrella and cone structure, and a separate screw propeller is applied to drive the machine horizontally through the air.

The umbrella surface, and fan casing and cone, all act as retarding surfaces when the machine is descending through the air.

The principles made use of in this flying machine are the same as those employed in the Pelton water-wheel bucket.

## CHAPTER V.

### Starting up Aeroplanes.

Many are the devices proposed by inventors to obtain lifting force from the inertia of the air. Nearly all of them neglect the fact that the air must not be moved with any great velocity, and that the lift must be obtained by moving a great weight of air per second.

Feathering paddles have been proposed, also reciprocating parachutes—reciprocating aeroplanes—flapping wings—but hitherto with no encouraging results.

Probably, if we could act upon the air with very rapidly moving wings, or other device, so that it would be compressed, as in sound waves, and take advantage of the elasticity of the air instead of its weight, smaller machines would result. Insects and humming birds' flight is based on this compression and expansion principle of the air by the wings.

So long as flight depends upon moving a huge mass of air at a slow velocity for sustaining the weights, the flying machine must be of gigantic dimensions. The density of air is so little in value that the weight must be obtained by acting upon a huge mass of it under the planes.

There are other systems of operation possible, but as yet they appear to have met with no success. Experimenters prefer to take the line of least resistance to their researches, and all of them are at present engaged upon aeroplanes, very few with any definite aim or object in view further than making short flights.

All aeroplane machines have a minimum forward velocity below which they cannot rise from the ground, and this velocity, plus a little more, must be imparted by some means. The-foot pounds of work required to accelerate a body from rest to a given velocity V is equal to half the weight of the body multiplied by $V^2$.

In the Farman experiments and Santos-Dumont tests the machine was accelerated by running along a level plane by its own power driving the screws. In others the machine is mounted on a carriage on rails at an incline, so that it gathers speed in running down the incline and rises from the carriages. Messrs. Wright Bros. employ a falling weight, which starts the machine along rails and accelerates it to speed by pulling on a rope passed over pulleys.

Starting appliances require much attention, and no doubt some more efficient and portable affairs will be invented. The Wright Brothers' machine, the pylon for starting, and the rail is shown in fig. 40, with the aeroplane on, ready for the start. The rail is a fixture apart from the pylon. It would obviously be better to build the pylon on the end of an inclined rail, pivoted at the pylon end, so that the rails could be run round a circle on rollers on the outer end.

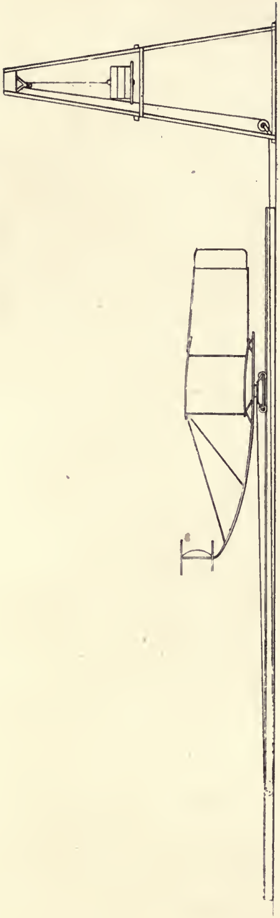

FIG. 40.—Wright Bros.' Starting Pylon.

The start could then be made always against the wind, which is the most favourable direction.

M. Jose Weiss has invented an inclined plane starting machine which presents some advantages for fixed stations from which aeroplanes are intended to start from and return to.

Fig. 41 gives the general lines of this launching way. It is a rigid structure made of light steel joists and resting on a pivot; it is steadied by four rollers running on a circular rail placed on the ground. At the top is a small platform reached by means of a ladder. The floor runs from that platform and has at its lower end, and hinged on to it,

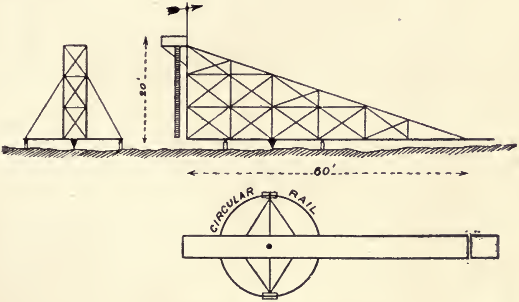

FIG. 41.—Weiss' Starting Inclined Plane.

a short prolongation, kept away from the ground by a balance weight. This prolongation is there merely to land the machine safely on the ground if no start is obtained. The cradle is dispensed with and the aeroplane is run down the floor on its own wheels. The initial thrust (if any is required) is obtained by a weight made up of movable cast-iron discs, and by means of a very simple system of ropes and pulleys. The aeroplane to be launched is brought to the foot of the ways and hauled up backwards by means of a windlass, and whilst it is being hauled up, the impelling rope is attached to it by means of a special catch, so made that as soon as the least lift is produced the machine is released automatically and the start is effected.

The machine is capable of turning round on a circular rail, as shown in the plan, so that the incline may always face the wind, and a ladder is provided for reaching the top platform. The falling weights and pulleys and ropes for giving the initial impulse are not shown.

The author's auxiliary starting device consists of a rope drum which can be clutched to the engine flywheel, a rope to be wound up by the engine, on to the drum, and a peg or post driven into the ground, as shown in fig. 42.

When a start has to be made the rope is unwound from the drum and looped over the peg or post at a distance of 30 or 40 yards or thereby. The engine is then started and the clutch gradually put in to drive the rope drum,thereby hauling and accelerating the flying machine up to the speed at which it lifts from the ground ; when the machine comes over the peg the loop slips off and the rope is all wound on the drum.

Thus is provided a portable starting apparatus which can be used almost anywhere with wheeled or skated aeroplanes.

Properly, the rope drum when worked by the petrol engine should be a " fusee " drum, in order to regularly accelerate the rope pull.

It enables a plane to start in a much shorter distance of run. But the engines require more power than that used with the pylon or inclined plane starters.

In M. Jose Weiss' paper to the Royal Aeronautical Society the starting-up problem is so well treated that we may quote some of it here.

" The very first condition required for raising an aeroplane, viz., its passage from standstill to flight speed, is purely a question of foot-pounds. No aeroplane can ever be raised (that is in calm air) until the full number of foot-pounds have been expended ; and it matters little how this is brought about, either by a falling weight or by running the

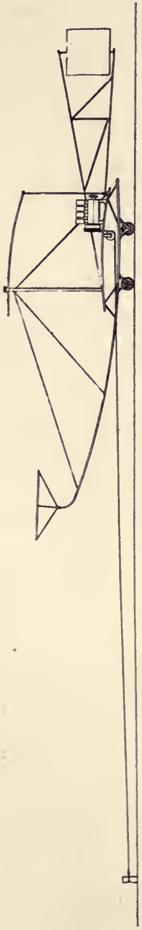

FIG. 42.—Rope Haulage Starting Device, Portable.

machine down an inclined plane, or simply by the mere power of the engine.

"The principle is only theoretical; it does not include the additional number of foot-pounds required to overcome the friction on the ground. So that a well-made machine, having ample power to fly, but depending only on its engine for raising itself, although quite capable of doing so on a good surface, might be utterly hopeless on a bad one, in exactly the same manner as a cyclist, who could get up a pace of 25 miles an hour on an asphalte track in a few seconds, could not reach a speed of ten on a ploughed field if he were to try the whole day. If, for instance, the Wright machine was placed on a light trolley fitted with good bicycle wheels, and if that trolley was running on asphalte, the falling weight and the rail could quite well be dispensed with, and the machine, in calm air, would leave the ground after a run of about 70 yards. Let us say the machine weighs, roughly, 1,000 lb., and the speed, as taken from the published records, is 60 ft. per second, and we have for

$$\frac{Wv^2}{2g} \quad \frac{1000 \times 60^2}{64} = 56250 \text{ ft.-lbs.}$$

Taking, then, the 24 H.P. motor to yield an actual efficiency of no more than two-thirds, or 16 H.P., the time required for developing the above 56,250 ft.-lbs is

$$\frac{56250}{16 \times 550} = 6{\cdot}4 \text{ secs.},$$

and the space covered $6{\cdot}4 \times 30 = 192$ ft. By using the falling weight, viz., 1,500 lbs. falling 20 ft., and supplying 30,000 ft.-lbs.—the work left for the engine is reduced to 26,250 ft.-lbs., which gives for time

$$\frac{26250}{16 \times 550} = 3 \text{ secs.},$$

and for space $3 \times 30 = 90$ ft.

"This allows nothing for frictional loss or air resistance; and still Wilbur Wright manages all right with his 70 ft. rail, showing that the figures for a start without the falling weights are well on the right side. In the total absence of wind, however, the shortness of the rail must cause, and does cause, an occasional mis-start.

" It is very clear that there would be no need for launching appliances of any sort if we had for the start a perfectly smooth and hard surface on which the necessary speed could be reached with a minimum of frictional loss.

The question which presents itself is this : Do we want a machine capable of rising unassisted from any rough surface ? The Voisin type is of this class, the high-power type. Or a lighter machine requiring a minimum of power, but capable of rising from a perfect surface only ? The Brothers Wright flyer belongs to this second class, the low-power type.

One of the greatest drawbacks of the first class of machine is that, in order to overcome the initial resistance, they require a great stationary thrust which can only be obtained by a short pitch screw at high rotary speed. This involves direct coupling, and, consequently, small diameter propellers, giving a great thrust at the start, but a reduced one in flight ; hence a considerable waste of power. If, on the other hand, the starting ground be such as to cause very little resistance, we can use, by gearing down, large, long-pitched propellers with low rotary speed which give comparatively little thrust at standstill, but become highly efficient as soon as the machine is under way.

In reference to this point, the author's auxiliary rope and drum starter would enable the machine with the large coarse-pitch slow-speed propellers to gain sufficient velocity to bring the screws up to their efficient speed.

To start up a machine to sufficient velocity on rough ground requires more power of the engines than is afterwards required to propel the aeroplane ; and to get sufficient thrust from a screw or screws stationary or advancing slowly, the screws must have a high rotary velocity.

The advantage of the inclined rail and carriage, or the falling weight for starting, is that large, coarse-pitch, slow-speed screw propellers can be used.

Smaller engines can, therefore, be used in machines to be started up by extraneous means. But neither a falling weight apparatus, nor a running carriage on rails, can be carried about with the aeroplane, so that they must always return to a place where these are available. The machine which can start up under its own power is, therefore, preferable in respect of starting, but it requires a wide, clear space for the initial run.

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## CHAPTER VI.

### Miscellaneous Appliances.

Experiments with small planes, without any power but that due to their own weight falling from a height, are interesting and instructive. Set at proper angle and properly ballasted they fly away down a sloping path to the ground. Gliders, large enough to carry a man, can be used for sport, and also for experiments on steering and balancing ; see fig. 43, a drawing of the Wright Bros. glider.

The small gliders are useful in teaching lessons upon balancing, stability, angles of planes, and their position. No one's aeronautical education is complete without a course of experiments with "gliders," as these small flying planes are called. Beginning with Mr. Lanchester's simple single plane, as shown in fig. 44, a thin sheet of mica, about 9 in. by $1\frac{1}{2}$ in., loaded at the front edge with a few strips of lead foil bent over it, can be launched from a height, and its gliding observed. Then more elaborate models may be made with more than one plane. An authority on gliders, Mr. A. V. Roe, in a paper to the Aeronautical Society, shows the importance of a governing plane—that, is a horizontal plane—which can be tilted up or down at different angles to the line of flight, with single plane weighted on the front edge, maintaining its flight by giving it an initial start forward, the momentum of the weight on the front edge keeping it from tumbling over. According to Mr. A. V. Roe, if a single aeroplane be released in the air it will simply fall anyhow to the ground, but on fixing an elevating plane fore or aft, as in fig. 45, there will be a tendency for it to glide, but sooner or later one side will dip downwards, owing to the two planes not being in the same straight line or being improperly balanced. If the left side dips the whole will circle to the left and gradually fall in towards the centre of the circumference it is describing. If the front plane is fixed with

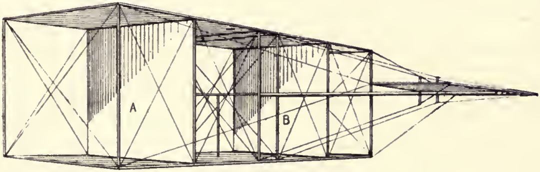


FIG. 43.—Wright Bros.' Gliding Machine

a slightly upward angle relatively to the main planes, the forward movement is quickly checked, owing to the air pressure forcing upwards the front plane and, consequently, the whole glider. In order to counteract this lifting-up tendency, the centre of gravity is brought more forward until a suitable position can be determined, when it will be found to make a straight glide at a definite speed. If the centre of gravity is not brought sufficiently forward the glider will take an upward course, the speed being thereby reduced until the pressure on the forward plane is not sufficient to keep it up. The result is the speed is accelerated, the glider once again takes an upward course, and the whole series of undulating glides is repeated until the ground is reached. It is to this horizontal adjustable plane in front or behind the main planes that the success of the aeroplane is mostly due.

There are several ways of steering the machine laterally; vertical planes fore or aft may be used for this purpose, but they have their disadvantages, and if forward a side puff is apt to blow the machine from its course; also a vertical plane is naturally flat, causing eddies when used for steering.

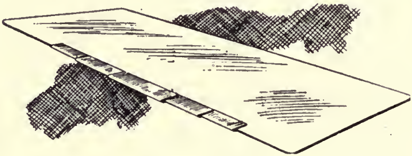

Fig. 44.—Lanchester Plane.

Lateral steering planes should be double, one fore and one aft, coupled to act in unison. Side puffs of wind do not then twist the machine out of its line of flight.

If the horizontal plane be fitted at the rear the centre of gravity still remains forward, but the plane requires to

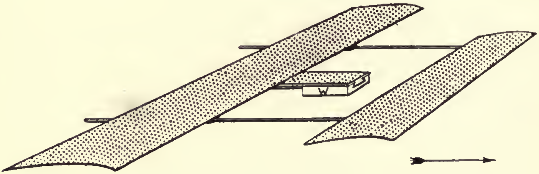


Fig. 45.—A. V. Roe's Glider Planes.

be turned up at the posterior edge, giving the glider an upward tendency, as in the case of the forward plane. The disadvantage of this type is that the air acts on the upper surface pressing the tail downwards; consequently, it does not act as a supporting surface, but contrary.

The proportions of a satisfactory glider are as follows: Width of main aeroplane, $\frac{1}{6}$ of the tip-to-tip measurement; steering plane, $\frac{2}{3}$ tip-to-tip and about $\frac{3}{4}$ the width; fore and aft measurement being about $\frac{1}{2}$ the tip-to-tip of main aeroplane. Of course, these are approximate and can be varied. For instance, the larger the steering plane the nearer it may come to the main aeroplane, and for even speeds the pressure per square foot appears to remain constant on various-sized and positioned horizontal planes.

By constructing the main aeroplane so as to take various-sized elevating horizontal planes, and adding or substracting the weight so as to keep the average of $\frac{1}{4}$ lb. per square foot, then some very interesting experiments may be tried. A good method of testing their respective merits is to drop the model head downwards from a certain point and note which combination gives the best results.

On experimenting with a glider weighted to $\frac{1}{4}$ lb. per square foot and dropped head downwards (not thrown) from a height of 7 ft., it will be found to swerve down within about 3 ft. in advance of the starting point, by which time it will have assumed a horizontal position, skimming along, and finally landing 20 ft. from the starting point.

A question that will naturally be asked is: "How is a sudden diving tendency to be avoided?" The planes can be so arranged that this will be impossible, so long as the machine retains its rigidity, for the horizontal elevating plane is so set that it cannot be turned beyond a certain point, this point being the least possible uplifting angle.

Many small designs for gliders are now to be had, from which they may be made cheaply. It is as well for the experimenter to provide a model starting appliance on the system of the Wright Bros., or M. Jose Weiss, a model rail with a system of cords and pulleys and a falling weight.

For small models the only motive power is twisted rubber cords. Most of the rubber motors are poorly designed, the rubber cords being fixed at one end and the propeller at the other end. When it is wound up, a great end pull comes upon the propeller end bearing, causing enormous friction.

There should be seven rubber cords of pure para rubber. These should be from $\frac{1}{4}$ in. to $\frac{3}{8}$ in. diameter, according to power required, and from 10 in. to 12 in. long, measured on the total twisted parts. The propeller should be made with the boss in two halves, with a blade upon each half, and clamped to the rubber cords in the middle position.

The longer the rubber the longer the screw will run at one winding, and the thicker the rubber the more power is required to wind it up, giving, of course, more power for driving.

It has been suggested by some people to use electro-motors for trials, and to save the weight of the batteries by con-

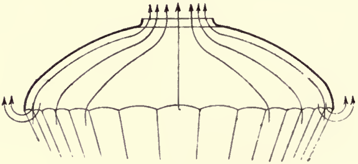

FIG. 45A.—Top of Parachute.

necting the motor by flexible wire to a fixed source of electricity ; but even then the electro-motor is the heaviest of all motors. They, in small size, run to 56 lbs. to 80 lbs. per horse power.

After a course of experiments in gliders, with and without power, on a small scale, and also on screw and other propellers, models for actual flight on a scale sufficiently large to carry a petrol engine may be made ; these engines are of little use with single cylinders, they have so few impulses that a very heavy flywheel is necessary.

There is room for a small four-cylinder engine of extremely light weight for aeronautical experiments. It would pay a maker to take it in hand.

While on the subject of miscellaneous devices we may consider the parachute, fig. 45A. It is a very large affair; a disc of canvas or cotton fabric with a large hole in the centre; ropes passed over it sustain the weight whose fall is to be retarded. The disc diameter to carry one man is 40 ft.

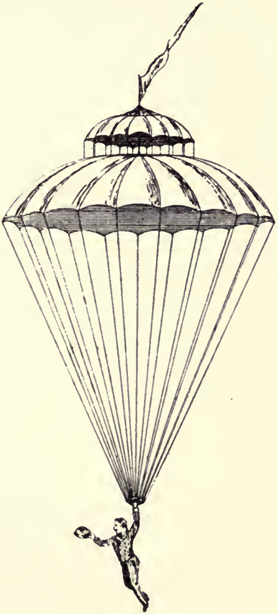

FIG. 46.—Kennedy's Parachute.

and about 30 ft. when arched out. The rate of fall depends upon the size of the hole in the centre, for it is governed by the velocity of the air escaping through this opening. If the opening is too small the air will escape round the outer edges and cause the parachute to oscillate dangerously; if too large the fall is not sufficiently retarded.

The writer has improved the parachute by enlarging the opening and attaching a second small parachute over the opening, fig. 46. By this means the escaping air reacts on the small parachute and adds largely to the retardation. Perhaps a third division would still more retard the fall.

The action of the parachute may be best explained by considering it as a piston falling through a cylinder of air, and having a hole in its centre regulating the flow of the air from the under to the upper side of the piston, see fig. 47. The piston is, say, about 500 square feet area, so that it displaces 500 cubic feet of air through the central hole, or orifice, for every foot of its fall.

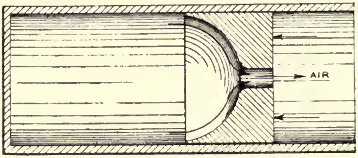


FIG. 47.—Diagram of Parachute.

The orifice can be adjusted to get any velocity of fall desired, and its area could be calculated for the piston in the cylinder. But the parachute has no cylinder, so that a large volume of the air escapes round the edges, besides what escapes the orifice.

The ratio of surface to weight to be carried is about as three is to one, that is about 3 ft. area of parachute to 1 lb. weight of load, the area being calculated from the diameter when arched, giving about 3 square feet per pound weight of parachute and load, at the very least; some allow 4 square feet per pound.

A parachute without a central orifice tends to turn upside down, and oscillates violently as the air acts unequally on the edges ; but with a central opening the air flows along the curved surface from the edge to the orifice, where it should escape at a velocity due to the pressure and its volume.

A parachute with about 600 ft. area should have an orifice from 4 ft. to 6 ft. diameter, or even larger, when a second small parachute may be added above the orifice. The current of air in a properly dimensioned parachute should follow the dotted lines shown in fig. 45. An inverted

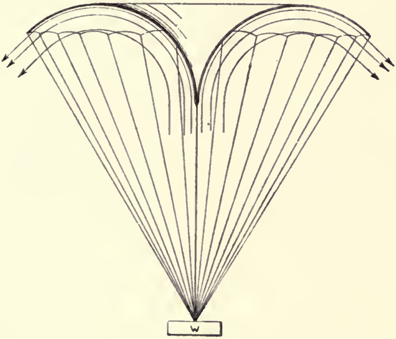


FIG. 48.—Bicusped Parachute.

parachute, like an umbrella (fig. 48) turned outside in, is a more stable form, but mechanically is difficult to construct on a large scale, as it requires a frame.

The velocity of fall of a parachute may be from 4 ft. to 5 ft. per second.

The French naval parachutes are 40 ft. diameter when flat, and 33 ft. when descending, giving 855 square feet area ; they carry, with their own weight and a man, 225 lbs., nearly 4 square feet per pound carried.

## KITES.

These are not strictly flying machines, but closely related thereto. They are useful, and for military purposes have been made to carry a man for observation purposes.

The box kite was the germ from which the aeroplane sprung; it illustrates the effect of the air stream upon flat planes.

Undoubtedly, many interesting and valuable results can be obtained by kites regarding aeroplanes, and experiments can be made at small cost on reduced models of proposed aeroplanes by constructing them of light materials and flying them in the wind; it is only necessary to use an anemometer

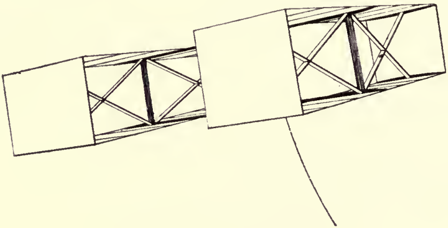

FIG. 49.—Tandem Box Kite.

to get the average velocity of the wind and measure the pull on the string to get data for calculations. Kites may be put to more uses than they have been in the past. They may be used to drag a raft or boat on water, to raise a man or instruments of observation to certain heights, and to study the effect of wind streams on different forms and structures of aeroplanes.

Kites have been designed for life saving from wrecks on the coast by different inventors. They can be used to send the end of a line ashore from the wrecked ship, for which purpose they can be guided by a bridle and reins, two strings attached to right and left side; by these its direction can be directed at least 15 deg. from the direction of the wind, and when over the land it can be dropped by slacking off one of the side strings.

The box kite is by far the best form. It is usually made up as shown in fig. 49, consisting of two oblong boxes joined at the corners by four light wooden bars, the box sides being of light fabric or paper. A bridle is attached, as shown, for the string. A section is shown in fig. 50 showing how the sides act as aeroplanes and deflect the wind, the arrows representing the air streams. They are made up in various other forms ; two cylinders are sometimes used.

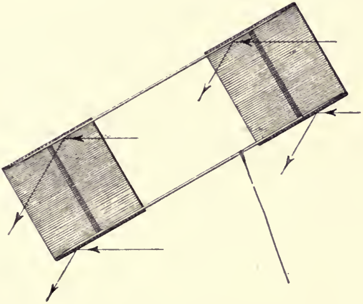

Fig. 50.—Section of Tandem Box Kite.

A single box may be used with oblique sides, as shown in fig. 51 in section, showing the air stream and bridle and string. They can be made with curved top and bottom planes, fig. 52, when their resemblance to the common biplane is complete.

Kites above 70 square feet in area become clumsy and difficult to strengthen ; when more area is required they are made multiple, two or more being attached to one string, either in series order or parallel order.

It is, however, much better to use a large size of box kite on the Marvin systems. This kite is the same in construction as the Hargreaves box kite, but large enough to carry a man inside. Other two may be attached in series to get the necessary lift.

Man-lifting kites require about the same area as an aeroplane if flat, or of the Baden-Powell type, who used kites about 120 square feet in area, and in series giving 480 square feet total.

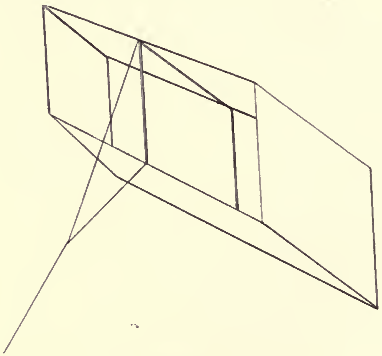

Fig. 51.—Single Box Kite.

These large kites, in the light of aeroplane results, would be perhaps better made up of two or three biplanes in series, with the occupant in the first one, and with lines attached so that he could adjust the angle of the planes to the direction of the wind.

Of course, in handling large kites a wire is used instead of string—a tinned-steel wire wound upon a winch, and the winch should turn upon a central pivot or turntable, so that the wire may always be paid out or wound up parallel with the wind blowing at any time.

Kite experiments on a smaller scale are interesting and instructive. In fact, the young aeronaut should begin the practical part of his studies with kites of his own construction, and fly them himself. Photographs may be taken by cameras attached to kites, the snap-shot being worked electrically

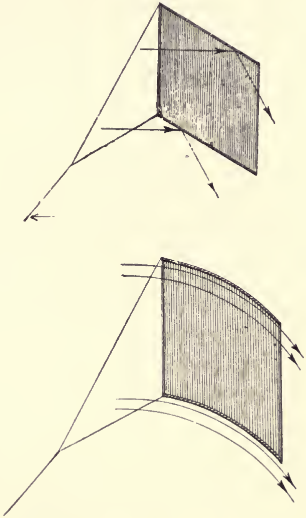

FIG. 52.—Simple Plane Kites.

through two fine wires in the string. Meterological instruments can be sent up on kites to discover the barometric and thermal conditions at greater heights.

By two wires insulated from each other an electric lamp on a kite can be used to send signals at night to a long distance.

In fine weather, in open country, or on the links by the sea, kite flying is a healthy, pleasant, and instructive pastime.

## CHAPTER VII.

### Materials for Construction of Aeroplanes and other Flying Machines.

Naturally all materials employed in the construction of flying machines must combine a minimum of weight with a maximum of strength.

One horse power can lift just so much weight and no more, so that the combination of engines, screws, and planes which give the greatest lift per horse power is the best machine.

Suppose a machine itself without load or driver weighs 600 lb. and can sustain 1,200 lb. in the air, we get a lift coefficient of 1 lb. per lb. of machine; and further, suppose the horse power with the full load of 1,200 lb. is 25 H.P., the sustaining coefficient is

$$\frac{1,200}{25} = 48 \text{ lbs. per horse power.}$$

Half of this power is employed to carry the load, the other half to sustain the machine in this case.

Some writers imagine that weight will not matter much in future machines, but that is entirely an erroneous view. Unlike other modes of locomotion the power has to provide the support against gravity, hence weight is of first importance in all flying machines.

Besides the necessity for material of small specific gravity and high tensile strength, it is a still greater necessity to see that the material is used to the best advantage, which means careful and skilled design and calculation.

Metals cannot enter to any extent into the construction. Steel wire and thin sheet steel is used for strengthening, but in very small quantities. Aluminium alloys and magnalium—all light metals—are used to some small extent.

We have shown in Chapter II. that screw propellers must be of large size when working in air, hence metal cannot be used in their construction. We are therefore driven to the use of wood of different kinds, canes, bamboo, and textile materials—materials with which the boat builder is better acquainted than the engineer.

The weight of steel wire is given in Table VII.

TABLE VII.

WEIGHT OF WIRE IN POUNDS PER 1,000 LINEAL FEET.

| S.W. Ga'ge | Iron. | Steel. | Brass | Copp'r | S.W. Gauge | Iron. | Steel. | Brass. | Copp'r |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 278·8 | 285·7 | 305·2 | 317·8 | 16 | 10·88 | 11·15 | 11·91 | 12·40 |
| 1 | 239·1 | 244·9 | 261·7 | 272·4 | 17 | 8·33 | 8·54 | 9·12 | 9·49 |
| 2 | 202·3 | 207·3 | 221·5 | 230·6 | 18 | 6·12 | 6·27 | 6·70 | 6·98 |
| 3 | 168·7 | 172·8 | 184·6 | 192·2 | 19 | 4·25 | 4·35 | 4·65 | 4·84 |
| 4 | 143·0 | 146·5 | 156·5 | 162·9 | 20 | 3·44 | 3·53 | 3·77 | 3·92 |
| 5 | 119·4 | 122·3 | 130·7 | 136·0 | 21 | 2·72 | 2·79 | 2·98 | 3·10 |
| 6 | 97·9 | 100·3 | 107·2 | 111·6 | 22 | 2·08 | 2·13 | 2·28 | 2·37 |
| 7 | 82·3 | 84·3 | 90·1 | 93·8 | 23 | 1·53 | 1·57 | 1·68 | 1·74 |
| 8 | 68·0 | 69·7 | 74·4 | 77·5 | 24 | 1·29 | 1·32 | 1.41 | 1·47 |
| 9 | 55·1 | 56·4 | 60·3 | 62·8 | 25 | 1·46 | 1·09 | 1·16 | 1·21 |
| 10 | 43·5 | 44·6 | 47·6 | 49·6 | 26 | ·86 | ·88 | ·94 | ·98 |
| 11 | 35·7 | 36·6 | 39·1 | 40·7 | 27 | ·71 | ·73 | ·78 | ·81 |
| 12 | 28·7 | 29·4 | 31·5 | 32·7 | 28 | ·58 | ·60 | ·64 | ·66 |
| 13 | 22·5 | 23·0 | 24·6 | 25·6 | 29 | ·49 | ·50 | ·54 | ·56 |
| 14 | 17·0 | 17·4 | 18·6 | 19·4 | 30 | ·41 | ·42 | ·45 | ·47 |
| 15 | 13·8 | 14·1 | 15·1 | 15·7 | | | | | |

When steel wire is used it ought to be tinned. Fine tinned steel wire is practically same weight and strength as steel only, and has the advantage that when used for binding purposes it can be soft soldered into a solid ferrule.

Weight and strength of various useful woods are given in Table VIII.

Poplar is not given in the list; its specific gravity is 0·4 when fully seasoned, and (dry) weighs about 41 lbs. per cubic foot, and has about the same strength as ash.

Bamboo has been tried in many flying machines, and seems to be condemned as unreliable; but this is due, in all probability, to want of skill in working it. To make joints in bamboo work requires skill and knowledge, just as in working other materials.

## TABLE VIII.

### Weight and Strengths of Various Woods.

| | Specific gravity. | Weight of a cubic foot. | Weight of a cubic inch. | Tensile strength per sq. in. | Crushing weight per sq. in. | Transverse strength. |
|---|---|---|---|---|---|---|
| | | | lb. | | | |
| Ash | ·69 | 43 | ·025 | 12,000 | 8,600 | 2,000 |
| Ash | ·76 | 47 | ·027 | 17,000 | 9,300 | 3,000 |
| Beech ............from | ·69 | 43 | ·025 | 11,000 | 7,700 | 1,500 |
| Beech.............to.. | ·696 | 43 | ·025 | 22,000 | 9,300 | 2,000 |
| Birch | ·711 | 44 | ·026 | 15,000 | 3,300 | 1,900 |
| Birch | ·730 | 45 | ·026 | .. | 6,000 | 1,930 |
| Cedar, West Indian | ·748 | 47 | ·026 | 5,000 | 5,700 | 1,443 |
| Cedar, American | ·554 | 35 | ·020 | .. | .. | 766 |
| Cedar, Lebanon | ·486 | 30 | ·017 | 11,000 | 5,800 | 1,300 |
| Cork | ·240 | 15 | ·008 | .. | .. | .. |
| Deal, Christiana | ·689 | 43 | ·025 | 12,000 | 5,850 | 1,562 |
| Fir, Spruce | ·512 | 32 | ·018 | 10,100 | 6,500 | 1,490 |
| Larch | ·543 | 34 | ·019 | 8,900 | 3,200 | 1,330 |
| Larch | ·556 | 35 | ·02 | 10,200 | 5,500 | 1,660 |
| Mahogany, Honduras | ·560 | 35 | ·02 | 21,000 | 8,000 | 1,910 |
| Maple | ·675 | 42 | ·025 | 10,600 | .. | 1,694 |
| Oak, American red | ·85 | 53 | ·03 | 10,000 | 6,000 | 1,680 |
| Oak, American white | ·779 | 49 | ·028 | .. | .. | .. |
| Oak, English | ·777 | 48 | ·028 | 10,000 | 6,400 | 1,600 |
| Oak, English | ·934 | 58 | ·034 | 19,000 | 10,000 | 1,690 |
| Pine, red | ·576 | 36 | ·021 | 12,000 | 5,400 | 1,200 |
| Pine, red | ·657 | 41 | ·024 | 14,000 | 7,500 | 1,530 |
| Pine, white | ·433 | 37 | ·015 | .. | .. | 1,229 |

All ends of bamboo rods should be plugged with glued wood plugs after carefully removing the inner skin of the bamboo, and then the outside of the end should be carefully wound with a tinned steel binding wire. This effectually strengthens the weak points in bamboo—the ends, where it is apt to split. The wire binding should be finally soldered up solid.

Properly used it is a useful material for struts and frames.

Of all the aluminium alloys magnalium is the most useful. It consists of an alloy of magnesium and aluminium. It can be readily melted, cast, milled, wrought, pressed, welded, and soldered. Specific gravity about 2·5.

# MAGNALIUM TABLE.

WEIGHTS OF MAGNALIUM SHEET, TUBE, AND WIRE (PREPARED BY THE GERMAN MAGNALIUM-GESELLSCHAFT OF BERLIN).

| MAGNALIUM SHEET | | TUBE. | | | | | | | | | WIRE. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Thickness in mm. | Weight per sq. m. in kg. | Outer diam. in mm. | Thickness in mm. | | | | | | | | Diameter in mm. | Weight per m. in gm. |
| | | | 1 | 1·5 | 2 | 2·5 | 3 | 3·5 | 4 | 5 | | |
| 0·1 | 0·25 | 10 | 0·085 | 0·133 | 0·185 | 0·241 | 0·301 | 0·365 | 0·432 | 0·579 | 0·1 | 0·02 |
| 0·125 | 0·313 | 12 | 0·100 | 0·157 | 0·216 | 0·280 | 0·330 | 0·418 | 0·494 | 0·656 | 0·15 | 0·046 |
| 0·2 | 0·50 | 14 | 0·116 | 0·180 | 0·247 | 0·318 | 0·393 | 0·473 | 0·556 | 0·733 | 0·2 | 0·08 |
| 0·25 | 0·625 | 16 | 0·131 | 0·203 | 0·300 | 0·359 | 0·440 | 0·527 | 0·618 | 0·811 | 0·25 | 0·126 |
| 0·3 | 0·75 | 18 | 0·147 | 0·228 | 0·320 | 0·396 | 0·486 | 0·580 | 0·685 | 0·888 | 0·3 | 0·18 |
| 0·4 | 1·00 | 20 | 0·162 | 0·248 | 0·340 | 0·434 | 0·533 | 0·635 | 0·741 | 0·965 | 0·4 | 0·32 |
| 0·5 | 1·25 | 30 | 0·240 | 0·365 | 0·494 | 0·627 | 0·786 | 0·888 | 1·05 | 1·351 | 0·5 | 0·50 |
| 0·6 | 1·50 | 40 | 0·316 | 0·480 | 0·682 | 0·820 | 0·997 | 1·16 | 1·36 | 1·737 | 0·6 | 0·72 |
| 0·75 | 1·875 | 50 | 0·394 | 0·597 | 0·805 | 1·013 | 1·230 | 1·43 | 1·67 | 2·123 | 0·7 | 0·98 |
| 1 | 2·50 | 60 | 0·471 | 0·712 | 0·957 | 1·20 | 1·460 | 1·70 | 1·97 | 2·510 | 0·8 | 1·28 |
| 1·25 | 3·125 | 70 | 0·550 | 0·830 | 1·110 | 1·40 | 1·691 | 1·97 | 2·286 | 2·897 | 0·9 | 1·62 |
| 1·5 | 3·75 | 80 | 0·626 | 0·944 | 1·266 | 1·60 | 1·923 | 2·24 | 2·872 | 3·28 | 1·0 | 2·00 |
| 1·75 | 4·325 | 90 | 0·700 | 1·060 | 1·420 | 1·79 | 2·155 | 2·51 | 2·9 | 3·67 | 1·5 | 4·52 |
| 2 | 5·00 | 100 | 0·800 | 1·172 | 1·560 | 1·98 | 2·386 | 2·8 | 3·21 | 4·05 | 2·0 | 8·00 |
| 2·5 | 6·25 | | | | | | | | | | 2·5 | 12·50 |
| 3 | 7·50 | | | | | | | | | | 3 | 18·04 |
| 3·5 | 8·75 | | | | | | | | | | 4 | 32·00 |
| 4 | 10·00 | | | | | | | | | | 5 | 50·00 |
| 4·5 | 11·25 | | | | | | | | | | 6 | 72·00 |
| 5 | 12·5 | | | | | | | | | | 7 | 98·00 |
| | | | | | | | | | | | 8 | 125·00 |
| | | | | | | | | | | | 9 | 162·20 |
| | | | | | | | | | | | 10 | 200·00 |

It has been argued by some authorities that rigid wooden planes should be used, but they are too heavy. A light wooden framework of finest material, and well fitted together by skilled workmen, and upon a design from the best technical talent in structural construction, has nothing objectionable about it. The surfaces can then be formed of light waterproof textile materials laid on.

Among other suggestions for materials to form surfaces on aerial machines, some were made by Mr. G. Crossland Taylor, in a paper read to an International Congress in Chicago, 1893.

In this paper he proposes wire gauzes, among them one made of aluminium wire, which he explains is very expensive and could not be woven in England, at that date, over 3 ft. wide. Wire of this description, it is stated, can be obtained ·007 in. diameter, and the finished web weighs from 1½ to 4 ozs. per square foot, according to the thickness and mesh. When varnished with linseed varnish containing a sicative, the pores are closed, and the surface sheds water for an indefinite period. Very fine phosphor bronze web, such as is used for dynamo brushes, can be obtained weighing about 4 ozs. per square foot, and the same material less closely woven so as to be proportionally lighter would possibly be suitable. Iron wire gauze, weighing 3 ozs. per square foot, can be obtained, and could be woven in a suitable mesh at 1½ ozs. per square foot. Aluminium gauze could be obtained as light as 0·6 of an ounce per square foot, which, when varnished, would not weigh more than ¾ of an ounce per square foot. With aluminium wire at 25s. per pound, a hand-woven web, 3 ft. wide, would cost about 2s. per foot. The varnish would cost about 15s. per gallon, and would add from 15 to 30 per cent to the weight of the web itself.

In addition to wire web, he mentions other materials as being worth experimenting with, and makes the following remarks about them :—

"Vulcanised fibre ·035 in. thick: A piece, 6 ft. by 3 ft. 6 in., weighs 5 lbs., or 0·238 lb. per square foot. When 0·28 in. thick, the weight would be reduced to 0·174 lb. per square foot. If of good quality, this material stands the weather well. It is tough and strong, can be moulded, and may be bent to shape in hot water. It will hold screws well, and will also take a thread.

"Ebonite: A sheet of 18 standard wire gauge weighs 3·283 lbs. per square foot. It is very useful for model work, as it can be bent or moulded in boiling water, and keeps its shape well when cold.

"Celluloid: This has the same qualities as ebonite in respect to moulding in hot water. It can be obtained in sheets $\frac{1}{32}$ of an inch thick, measuring 26 in. by 20 in., and costing 4s. 9d. per pound. In course of time this material is liable to shrink and become brittle, although it is impervious to the wet during its life.

"Brown paper: Canvas-backed packing paper, about 24 standard wire gauge, has a weight of $\frac{2}{3}$ of an ounce per square foot. The canvas is of the lightest description, but will not separate unless wet, and the material is very useful for experimental work, as it does not easily tear.

"Oiled canvas, linen, &c.: The weight runs from $1\frac{2}{3}$ oz. to 2·6 oz. per square foot. The material is reliable in wet weather and high winds.

"Willesden canvas: Costs about 2s. per yard, and is very useful on account of its durability in bad weather.

"Proof silk: Weighs ·34 of an ounce per square foot, and can be obtained in rolls about 5 ft. wide at about $2\frac{1}{2}$d. per square foot.

"Proof cotton sheeting can also be obtained, but is heavier."

## Engine for Flying Machines.

The only engine for flying machines at present is the petrol engine, or motor, as it is popularly called. For flying machine purposes, of course, weight is of great importance;

it must be reduced to a minimum value, but at the same time it is not to be forgotten that reliability is of even greater importance, and that in reducing weight strength of structure may be sacrificed. For motor cars and motor boats small weight is also desirable, and there seems little doubt that the petrol motor, which has had so much time, skill, and money spent upon it, and which has been made in thousands, has reached a point of perfection where there is little room for improvement. On the whole, nothing better than the four-cycle four-stroke petrol engine has been brought out ; this engine, with four, six, and eight cylinders, V arrangement, has been used by most of the pioneers on flying machines of the present day.

The flights hitherto made have been of such brief duration that we cannot know much about engine performances in the air. We know, however, that engine failure in the air is a very much more serious accident than on land or water ; in fact, is almost certainly sure to be disastrous.

Absolute freedom from failure is not of course to be looked for in any mechanism, but we may feel more confidence in well-tried types of best design made by experienced firms, with the best appliances and in large numbers. No doubt, if there were a demand for large numbers of engines, especially designed and built for a minimum weight per horse power, it would be forthcoming, but it is doubtful if the design would differ much from the best motor car practice.

This work does not include engine construction and design in its scope, which is a special art and science. We can only give a brief indication of some proposed special designs for flying machine engines. Those readers who wish to study them specially will find information easily in other special works.

Nearly all the leading motor car engine makers offer engines for the purpose, modifications of their standard designs. The list below refers to the more noticeable engines differing from ordinary practice. Whether the differentiation results in better performance and smaller weight does not appear to be authoritatively decided.

Green aeromotor: Copper water-jackets, provided with sliding expansion joints, are employed, and many other original details have been embodied into the design of this engine, which is otherwise of the orthodox four-cylinder vertical type.

Miesse aeromotor: 8-cylinder radial engine, having the cylinders arranged in pairs and in an horizontal position. The crankshaft is vertical, and has two cranks, to each of which the four connecting-rods of the cylinders occupying that plane are connected. A special feature of the construction is the use of combined inlet and exhaust valves, both of which are operated mechanically and by the same tappet rod, the cam mechanism being so arranged that the stroke of the tappet rod differs for the inlet and the exhaust.

Ripault: Small single-cylinder engine developing $1\frac{1}{4}$ H.P., specially constructed with a water-jacket instead of air-cooling, in order to ensure sustained output without over-heating during experimental work. This little engine, which is very light, has an aluminum crank chamber, and is designed for use on models, and in other flight experiments, which only require a small amount of power.

Gnome rotary engine, with seven rotating cylinders, constructed of steel, and mounted in a special manner on a steel ring which is faced with steel plates on both sides to form a crank chamber. The carburetter, which is, of course, stationary and external, feeds through the hollow crankshaft to the crank chamber, from which the moisture enters the next working cylinder during its suction stroke through an atmospheric valve in the piston head. The exhaust valves, which are situated in the cylinder head are each operated by a separate cam ring.

The International rotary motor: Rotary engine with opposed rotary cylinders; in all sizes the cylinders are in the same plane. In one type the crankshaft is stationary, and in another carries a flywheel, so that it rotates in the opposite direction, and thus reduces the speed of each member by 50 per cent. A special feature of the engine from a constructional point of view consists in the mechanical operation of the inlet and exhaust valves by means of a set of skew gear-driven cam shafts.

There is a cam shaft for each cylinder, and it is placed tranversely to the axis of the crankshaft, so that the skew gear pinion which it carries can run in contact with the skew gear wheel on the latter member.

Properly classified, these two engines are not within the rotary engine class as understood by mechanical engineers. They are rotary cylinder engines, and are certainly unique among internal-combustion engines

The true rotary engine is the fluid-pressure turbine, which has no cranks connecting rods, pistons, or cylinders.

Another class of rotary engine has a rotating piston or cam in a crescent-shaped cylinder; some have sliding shutters, but none of these rotary engines have been worked by internal combustion with any success.

The chief difficulty with true rotary internal-combustion engines is to get compression before ignition, and when that difficulty is overcome, the next one, rapid ignition, crops up. In any rotary motor the cycles must occur much more rapidly than in piston engines; then there is the cooling question. But for all that, we may yet have the internal-combustion turbine, and when it does come it will solve a great many of the problems of flight.

The engine employed by M. Bleriot in his monoplane has not been very minutely described, but from all accounts it seems to have the great merit of simplicity. There are three cylinders on one crank, all air cooled, and a port on each cylinder at the end of the outstroke of the piston for the release of the first hot blast of exhaust gases.

The remaining exhaust in the cylinder is pushed out of a mechanically-opened valve in the cylinder head.

The writer, in the years 1904-5, made several engines of this same type. The idea of the two exhaust ports was not new even then, for there are several old patents for the two exhausts, but I found that all of them had a valve in both ports, and so had my first experimental engine. Fig 53 shows the general arrangement. The valve at the end of the piston stroke has been called the "auxiliary valve," and the ordinary valve the main valve. In fact, however, it is the other way about. The port uncovered by the piston is the main exhaust, the mechanically opened one the auxiliary.

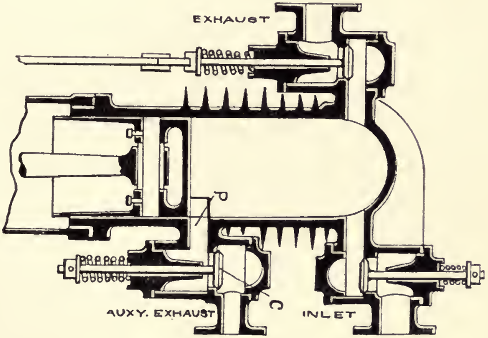


FIG. 53.

The valve C in uncovered port P, fig. 53, was latterly removed altogether, and worked with a "free open port" into a silencer, or exhaust pipe. The idea of the valve C in port P was to prevent re-entry of the exhaust through port P at end of the suction stroke. It was found, however, that working without the valve had no appreciable effect on the suction stroke. A small amount of exhaust may be drawn in at the end of the suction stroke, but it is apparently too small in amount to have any effect.

The improvements in the air-cooled cylinder made by the free exhaust at the end of the working stroke are very con-

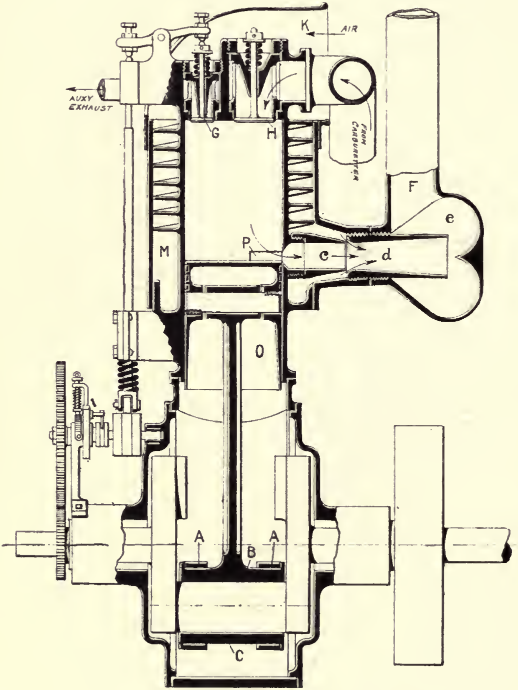


FIG. 54.

siderable, for the instant release of the exhaust carries off heat which would otherwise go through the cylinder walls.

The mechanically-opened valve in the head opens after the lower port, in fact just after the piston begins its in-stroke; by that time the temperature and pressure of the remaining exhaust have fallen very much.

The engine which was finally patented, No. 22,390 (1905), is shown in diagrammatic figure 54 in section. In this engine the blast of the exhaust from the uncovered port P, escaping from nozzle C, created a suction in nozzle *d*, which drew down a current of air through the cylinder jacket M. This

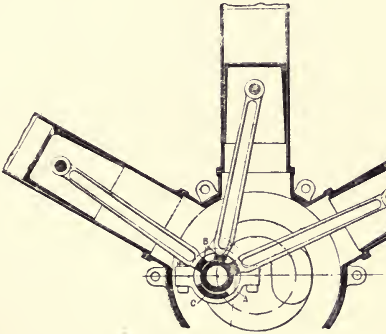


Fig. 55.

air enters by a hood on the top of the cylinder K. The cooling ribs are not circumferential, but helical, like screw threads, so that the cooling air circulates around the cylinder as it flows from K to M. The expansion chamber *e* silences the exhaust, which finally escapes by pipe F.

The valve G in the head for the auxiliary exhaust is small, not having much gas to deal with.

Now for aerial motors this system seems to meet the demand for a simple four-stroke air-cooled engine, and to save in size and weight it should be a V-type two-cylinder, or ⊥

three cylinders, with pistons working on one crank. The reduction of cranks is of great importance.

For a three cylinder design fig. 55 is a diagrammatic section. The middle cylinder is vertical, and the two side cylinders 120 deg. from each other.

The connecting rod ends B are held to the crank pin by split ring A ; C is a bush to keep rings A concentric when taking up slack.

The engine may of course be operated without the blast of the exhaust by removing *d*, *e*, and F, and on an aeroplane going 30 to 40 miles per hour, turning the mouth of the hood K forward, sufficient air would blow down through the jacket to keep it cool, the lower exhaust passing freely through orifice C.

The spiral or helical radiators can be cast with the cylinder ; their effect is to cool the cylinder uniformly all round. The great secret of air cooling is plenty of air and plenty of room for its movement, uniformly bathing the cylinder from top to bottom.

The simple exhaust blast-air ejector on the lower port aids greatly in obtaining a plentiful current of air, while the helical ribs distribute the air current all over the cylinder. This, together with the release of the exhaust top and bottom, enables the engine to run as safely over as long periods as a water-cooled engine.

It is intended to make the engines one, two, or three cylinders, giving 8, 16, and 24 B.H.P.

### Engine Power and Weight of Machine.

It can be deduced from the principles given in Chapter II. that by increasing the angle of the plane, and consequently B C, the perpendicular, the square feet area of the planes can be reduced. All the small aeroplane machines made are produced by this means. But in proportion as we increase the angle of the planes and reduce their span and area, the power required to operate them also increases. If, instead of an angle of 6 to 1, we employ 3 to 1, the planes might be reduced in span by one-half, but the power required would be doubled, for the thrust would be multiplied into a lift of only 3 to 1, instead of 6 to 1.

The Santos-Dumont latest machine weighs only 490 lbs. (it is said), with a surface of 96 square feet; the span is 18 ft. It has flown at 30 miles per hour for six miles with an engine of 30 H.P.

The Blériot machine weighs 715 lbs., total spans about 38 feet, area surface about 180 square feet. This larger machine does 40 miles per hour with a 22 H.P. engine.

And larger machines show a saving in power per ton mile of total load carried.

There is no mystery about making small machines; it is all a question of big powered engines of small weight per horse power.

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## CHAPTER VIII.

### Dirigible Balloons.

The dirigible balloon is a flying machine in which the weight of the machine is supported by a balloon. The principles of the balloon are well known. It floats because the air it displaces is equal to or greater in weight than its own weight. If a balloon and its appendages weigh two tons, then it must displace more than two tons of air in order to float, and it must displace these two tons while its own weight is less than two tons. This displacement must evidently be effected by a substance of less weight than the air per cubic foot.

It is, therefore, important to know the weight of gases. The following table shows the weights of a few:—

TABLE X.—GASES.

| | Specific gravity. | Weight of a cubic foot. | Weight of a cubic inch. |
|---|---|---|---|
| | | lbs. | lbs. |
| Air | ·001293 | ·08072 | ·00004655 |
| Carbonic acid | ·00197 | ·123 | ·000071 |
| Hydrogen | ·0000895 | ·0056 | ·0000032 |
| Nitrogen | ·00125 | ·078 | ·000045 |
| Olefiant gas | ·00127 | ·079 | ·000046 |
| Oxygen | ·00143 | ·089 | ·000051 |
| Steam (at one atmosphere) | ·00061 | ·038 | ·000022 |

Thirty-six cubic feet of hydrogen displace 36 cubic feet of air, but the hydrogen weighs only 0·2 lb., while the air displaced weighs 2 lbs., giving a margin for lift of $2 - 0{\cdot}2 = 1{\cdot}8$ lbs.

It is safe to take as the lifting power for

hydrogen = 1 lb. per 16 cubic feet ;

coal gas = 1 lb. per 24 cubic feet.

The weight W which a balloon of volume V can raise, with gas of a lifting power L to a given height, is given by the general formula—

$$W = \frac{V\,L}{n}$$

$$n = \frac{P}{P^1}$$

The pressure on the earth's surface shown by barometer P, divided by the pressure calculated at the height the balloon $P^1$ is to rise to, L, is the lifting power of the gas.

Ordinary balloons are spherical, as that form presents the least surface, but dirigible balloons are usually egg-shaped with the blunt end in front, or fish-shaped. The fish shape presents least resistance to going ahead.

The volume of these irregular shapes can be calculated by working out the areas at many of the sections.

In all dirigibles the balloon is calculated to support the whole of balloon and machinery and a considerable amount of ballast, in order to compensate for loss of gas; this is a serious difficulty with balloons. At the beginning of the voyage of a balloon there is a surplus of gas provided, and balanced by ballast, generally bags of sand. If the balloon shows any reluctance in rising, the sand is thrown overboard to lighten the ship; it then rises and may rise too high, in which case gas must be allowed to escape to bring it downwards. Thus, by throwing off ballast and gas, the height of the balloon may be regulated by a method which entails loss of gas.

Leakage of gas also occurs; the balloon may be gas-tight to start with, but the straining and wear and tear of a voyage starts leakages. These have to be counterbalanced by throwing out ballast.

Again, changes of temperature must be compensated for; gas rapidly and largely expands or contracts under a few degrees change of temperature. To allow of this expansion the balloon is made larger than necessary, and not entirely filled by the gas, leaving room for expansion. This method is not entirely satisfactory.

The envelope of a balloon not filled up has a considerable amount of slack, and if the balloon sways about or rolls, this slack moves about and increases the swinging and rolling.

It is therefore better to use a full balloon to start with, and this may be done by employing a smaller balloon called a balloonet inside the larger one, and filled with air under pressure maintained by a small pump driven by the engine of the airship. This pump can maintain a pressure equal to that on the balloon inside, due to the gas; hence if the temperature rises the gas expands, and its pressure slightly increasing, squeezes the air out of the balloonet, and thus finds room for expansion. Then if the temperature falls, the gas contracts and falls in pressure slightly; the pump then forces air into the balloonet, and so keeps the balloon with a taut skin.

An automatic method of regulating the height of the balloon has been employed, which uses a trail rope depending from the car and trailing on the ground.

When the rope is full out, perhaps 10 lbs. weight of it may trail on the ground. If, now, the balloon tries to rise, it must lift the weight of this trailing rope off the ground, and that soon checks its upward progress. If it should try to fall, the rope between it and the ground shortens, lessens in weight, and so checks the downward movement.

The first practicable dirigible balloon was designed and built by Mr. Henry Giffard, of steam ejector fame, in 1852

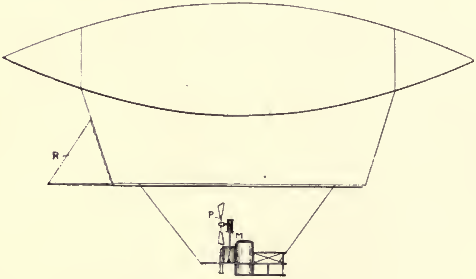


FIG. 56.—Giffard Balloon, 1852.

(fig. 56). Hull of fabric covered with netting, from which was suspended a rod 65 ft. long and 20 ft. below the balloon. Again, 20 ft. below this, and suspended from it was the car. The car carried the engine and boiler M and supported the propeller P, which was mounted between the car and the balloon.

*Stability and Manœuvring Planes.*—Only a rudder R in the form of a sail fixed at the after end of the rod between it and the balloon was provided for steering.

*Hull.*—Length, 144 ft. ; diameter, 40 ft. (greatest) ; volume, 70,650 cubic feet.

*Motor.*—Steam engine and boiler, 3 H.P.; coke fired; boiler chimney bent downwards and draught produced by steam blast.

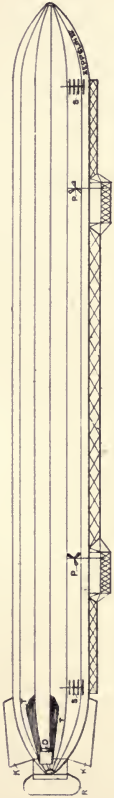

Fig. 57.—German Zeppelin Dirigible, 1908.

*Propeller.*—One, two-bladed, 11 ft. 6 in. diameter, mounted above car between car and the balloon.

*Speed.*—Average five miles per hour ; attained seven miles per hour greatest velocity.

With the exception of the rigid hull type of balloon, modern dirigible balloons are designed on similar lines to the Giffard.

The following are the chief modern dirigible balloons, or airships, as they are now called. They belong to the Governments of the country under which they are named, and are attached to the Balloon Corps of the army for use in warfare.

## GERMANY.

"*Zeppelin IV.*" (fig. 57).—Designed and constructed by Count Zeppelin. First ascent, June, 1908.. Rigid aluminium hull, framing covered with rubber fabric, containing 17 compartments, holding each a small balloon. Attached to the bottom framework or keel are two cars 26 ft. 3 in. by 6 ft. 6 in. Each car contains a benzine motor. Each motor drives two propellers P, one on each side of the hull above the car. There is a small cabin in the centre of the keel communicating with each car.

*Stability and Manœuvring Planes.*—There are two sets of four superposed horizontal planes S for vertical steering, fixed forward, one set on each side, and two similar sets for the same purpose are fixed aft. At the after end there are also two sets (one on each side) of two large superposed horizontal stability planes T T. Between these two large planes, near the after ends, is mounted a double movable vertical plane D for steering, and right at the end of the hull a large rudder R is placed also for steering. There are two vertical planes K K fixed at the after end, one at the top and one at the bottom.

*Hull.*—Length, 450 ft. ; diameter, 43 ft. ; volume, 460,000 cubic feet.

*Weight of Ballast.*—1,100 lb.

*Motors.*—Two Daimler, 110 H P. each ; total horse power, 220.

*Propellers*.—Four, three-bladed aluminium, 7 ft. diameter; two placed above the forward car, one on each side of the hull, and two in a similar position above the after car. Revolutions per minute, 820.

*Speed*.—Average 25 miles per hour; attained 33 miles per hour greatest velocity.

FRANCE.

"*Republique*" (fig. 58).—Constructed by MM. Lebaudy to the designs of M. Henri Julliot. First ascent, June, 1908.

Hull of rubber fabric, "Continental," with a rigid keel, from which the car is suspended, The car is 19 ft. 6 in. by 5 ft., and contains the motor and carries the two propellers P, one on each side of the car.

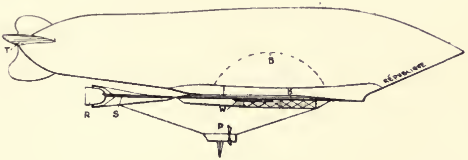


FIG. 58.—French Republic Dirigible.

*Stability and Manœuvring Planes*.—One large plane K, part of the keel, 70 ft by 20 ft., 1,050 square feet area. Two planes W, one on each side below K and above the car for vertical steering; rear tail T and a secondary tail S, with a rudder R, for steering, 135 square feet.

*Hull*.—Length, 200 ft.; diameter, 35 ft. 6 in. (greatest); volume, 130,700 cubic feet.

*Weights*.—Balloon car, motor, &c., 5,950 lbs.; trail ropes, &c., 200 lbs.; water, 80 lbs.; petrol, 220 lbs.; passengers (four) and instruments, 660 lbs.; sand ballast, 1,800 lbs. Total weight, 8,910 lbs.

*Balloonet*, B.—23,000 cubic feet, divided into three compartments.

*Valves.*—One hand valve on top for emptying, two automatic or hand valves underneath, and two automatic valves in balloonet.

*Motor.*—Four-cylinder Panhard, 70 H.P.

*Propellers.*—Two, two-bladed, steel, 8 ft. diameter. The propellers are carried one on each side of the car. Revolutions per minute, 850.

*Speed.*—Average 26 miles per hour.

UNITED STATES, AMERICA.

"*Baldwin*" (fig. 59).—Designed and constructed by Captain Thomas S. Baldwin. First ascent, August, 1908.

Hull of fabric consisting of two layers of silk with india-rubber between, covered with netting from which the car is

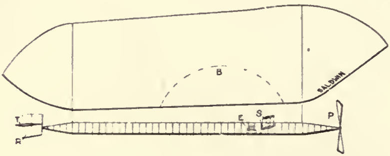

FIG. 59.—U.S.A Baldwin Dirigible, 1908.

suspended by single cords. The car is 70 ft. long, made of a framework of spruce trussed with steel wires. The motor E is situated forward, and right at the forward end is the propeller P.

*Stability and Manœuvring Planes.*—Two sets of two superposed horizontal planes S are placed forward of the motor, one set on each side of the car, for vertical steering. Rudder R for steering. A horizontal stability plane T extending across the centre of the rudder on each side.

*Hull.*—Length, 96 ft. ; diameter, 20 ft. (greatest) ; volume, 20,000 cubic feet.

Designed to carry a weight of 450 lbs., comprising 100 lbs. ballast and two passengers, besides weight of car, motor, &c.

*Balloonet*.—3,000 cubic feet.

*Motor*.—Four-cylinder Curtis, 30 H.P., weighing with radiator, 175 lbs.

*Propeller*.—One, two-bladed, 10 ft. diameter, carried at the forward end of the car. Revolutions per minute, 1,500.

*Speed*.—Average 17 miles per hour. Attained 20 miles per hour greatest velocity.

GREAT BRITAIN.

"*Dirigible III*." (fig. 60).—Designed and constructed by R.E. Balloon section, South Farnborough. First ascent, May, 1909.

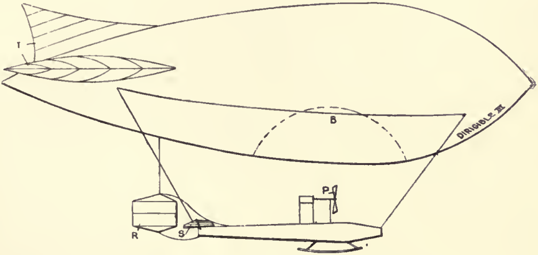


FIG. 60.—British Dirigible III., 1909.

Hull of goldbeaters' skin. The car is suspended by steel cables, attached to a series of silk loops fixed by a special method along the meridian of the balloon on each side. The car is made of a framework of hickory and steel tubing, and is covered with a silk envelope. The motors are carried in the forward end of the car, and the propeller P is mounted above the motors between the car and the balloon. Skids are fixed to the bottom of the car for landing.

*Stability and Manœuvring Planes*.—Two horizontal planes S, at the after end of the car, one on each side, for vertical steering. Large balanced rudder R still further aft for steering.

Rear tail, consisting of two horizontal fins, and one vertical on the top, all ribbed in the direction of the stream lines.

*Hull.*—Length, 84 ft. ; diameter, 26 ft. (greatest) ; volume, 21,000 cubic feet.

*Balloonet.*—4,200 cubic feet.

*Motors.*—Two, three-cylinder Buchet, 8 H.P. each. Total horse power, 16.

*Propeller.*—One, two-bladed, 6 ft. diameter, mounted above car between car and balloon.

*Speed.*—Ten miles per hour.

## CHAPTER IX.

### Some Notes on Air Pressures, Wind, and Atmosphere.

The flying machine's element is the atmospheric air, and some knowledge of atmospheric conditions, facts, and data is necessary. A few notes are given in this concluding chapter.

All aerial machines are at the mercy of high winds, especially those of balloon type. One of the problems for future solution will be to make the flying machine reasonably safe in high winds, a problem which will likely be left over until the less difficult ones are solved.

The balloon shows a decided preference for going with the wind, while the aeroplane machine, on the contrary, prefers a head wind if not too strong ; both of them are helpless in a side wind of any appreciable velocity. The aeroplane, with a wind abaft, would require to travel faster than the wind to keep afloat. If her floating velocity were 30 miles an hour, she would require to fly 50 miles an hour to keep afloat in a 20-mile wind abaft.

## Wind.

The pressure of the atmosphere varies, as indicated by the barometer. At different places it is not of the same pressure; hence we have "wind" which is air moving under a difference of pressure.

The difference is principally due to heating by the sun and cooling by radiation and convection. The inconsistency of the wind is due to the varying conditions, the change of seasons and clouds Air currents do not flow steadily like water currents. This is due to the elasticity and compressibility of the air. Throughout, a mass of moving air portions become compressed and other parts expanded; the compressed parts then expand and the expanded parts contract, and this internal motion accounts for the fact that the wind blows by fits and starts or in gusts, varying both in strength and direction in the course of a few seconds A vane or weathercock shows the direction of the wind A flag shows its inconstancy by its continual fluttering A flag in a stream, flowing steadily like a water stream, does not flutter.

This compressibility of air also accounts for the fact that the air issuing from a fan or air blower is warmer than the air entering. The difference in temperature can be measured by a thermometer, and represents loss of power which increases with the pressure. This has a bearing on air propellers, and shows that high pressures would entail losses from compression.

One of the chief difficulties the flying machine has to face is the wind pressure. The machine is immersed in the air, and, of course, tends to move along with it; and the only thing we can look to, in order to steer the machine across or against the wind, is the motive power on board, and to employ sails or planes to help to guide it. Storms of wind, of course, would entirely stop flying machinery, and might destroy any machine exposed to them.

The various velocities of the wind and corresponding pressures are given in Table XI.

TABLE XI.

| Miles per hour. | Feet per minute. | Feet per second. | Force in lbs. per sq. foot. | Description. |
|---|---|---|---|---|
| 1 | 88 | 1·47 | ·005 | Hardly perceptible. |
| 2 | 176 | 2·93 | ·020 | Just perceptible. |
| 3 | 264 | 4·4 | ·044 | |
| 4 | 352 | 5·87 | ·079 | Gentle breeze. |
| 5 | 440 | 7·33 | 0·123 | |
| 10 | 880 | 14·67 | 0·492 | Pleasant breeze. |
| 15 | 1,320 | 22 | 1·107 | |
| 20 | 1,760 | 29·3 | 1·968 | Brisk gale. |
| 25 | 2,200 | 36·6 | 3·075 | |
| 30 | 2,640 | 44 | 4·428 | High wind. |
| 35 | 3,080 | 51·3 | 6·027 | |
| 40 | 3,520 | 58·6 | 7·872 | Very high wind. |
| 45 | 3,960 | 66·0 | 9·963 | |
| 50 | 4,400 | 73·3 | 12·300 | Storm. |
| 60 | 5,280 | 88·0 | 17·712 | Great storm. |
| 70 | 6,160 | 102·7 | 24·108 | |
| 80 | 7,040 | 117·3 | 31·488 | Hurricane. |
| 100 | 8,800 | 146·6 | 49·200 | |

At first it is not likely machines will be brought out capable of taking flight in any weather, except what may be called moderate, say, up to a wind velocity of 25 ft. to 50 ft. per second.

It is clear that to navigate a machine in the air is a totally different affair from navigation on the surface of land or sea. The navigator in the air must not only have a reliable compass, sextant, charts, and astronomical knowledge, but some special apparatus, to enable him to feel his way when neither the sun, moon, or stars are visible.

Under such circumstances, a knowledge of the direction in which the wind is blowing is absolutely necessary, and also its velocity in order to steer the machine. Then, again, the buoyancy of the machine must be capable of regulation, either automatically or by hand, not difficult to do with a balloon, but at present we have no suggestion as to how we are to adjust the level at which a heavier-than-air machine is to fly on long journeys.

The air varies in density, and the machine on a voyage will vary in weight, due to loss of fuel and provisions, and to increase of weight when wetted by rain, so that some sort of governor will be necessary to keep up to a safe level. In all probability flight will be kept to as low a level as possible for safety, more especially as the winds are not so strong at lower levels. Only for military reasons high flight is necessary, to keep clear of shot and shell. In all these operations the behaviour of the wind must be considered.

The winds are due to the difference of temperatures on the face of the earth. In clear atmospheres a great deal of the sun's heat passes through the air without heating it, and falling on the surface of the earth the whole of the heat is, in most cases, absorbed, raising the surface temperature. The air in contact with the surface is heated by contact, and that above the surface by the dark, long wave rays radiated from the surface. The heated air rises, being rarefied, and air from the side flows in to take its place. This goes on producing an upper current or currents, outward, of warm air, and a lower current of cold air inwards.

The land and sea breeze is a wind which blows on the sea-coast, during the day from the sea towards the land, and during the night from the land to the sea. For during the day the land becomes more heated than the sea, in consequence of its lower specific heat and greater conductivity, and hence, as the superincumbent air becomes more heated than that upon the sea, it ascends and is replaced by a current of colder and denser air flowing from the sea towards the land. During the night the land cools more rapidly than the sea, and hence the same phenomenon is produced, but in a contrary direction. The sea breeze commences after sunrise, increases to three o'clock in the afternoon, decreases towards evening, and is changed into a land breeze after sunset. These winds are only perceived at a slight distance from the shores. They are regular in the tropics, but less so in our climates; and traces of them are seen as far north as the coasts of Greenland.

Regular winds are those which blow all the year through in a virtually constant direction. These winds, which are also known as the *trade winds*, are uninterruptedly observed far from the land in equatorial regions, blowing from the north-east to the south-west in the northern hemisphere, and from the south-east to the north-west in the southern hemisphere. They prevail on the two sides of the equator as far as 30 deg. of latitude, and they blow in the same direction as the apparent motion of the sun—that is, from east to west.

The air above the equator being gradually heated, rises as the sun passes round from east to west, and its place is supplied by the colder air from the north or south. The direction of the wind, however, is modified by this fact, that the velocity which this colder air has derived from the rotation of the earth—namely, the velocity of the surface of the earth at the point from which it started—is less than the velocity of the surface of the earth at the point at which it has now arrived; hence the currents acquire, in reference to the equator. the constant direction which constitutes the trade winds.

Periodical winds are those which blow regularly in the same direction at the same seasons and at the same hours of the day; the monsoon, simoom, and the land and sea breeze are examples of this class. The name monsoon is given to winds which blow for six months in one direction and for six months in another. These winds blow towards the continents in summer, and in a contrary direction in winter. The simoom is a hot wind that blows over the deserts of Asia and Africa; at a very high temperature, it raises sand in the atmosphere and carries it with it.

Ascending and descending air currents are, of course, necessary, but we do not observe them readily. The ascent and descent is slow and in large volume, and goes on continually, but the winds come from regions of high pressure to the regions of low pressure horizontally at greater velocity near the surface, where the density is greatest and the difference of temperature is also greatest.

To find the force of the wind, let

$P$ = pressure in pounds per square foot,

$V$ = velocity in feet per second,

$v$ = velocity in miles per hour;

$$\text{Hence } P = 0{\cdot}002288 \times V^2,$$

$$\text{or } \quad 0{\cdot}00492 \times v^2;$$

and if the angle of incidence is $= \phi$, then

$$P = 0{\cdot}002288 \times V^2 \times \sin \phi.$$

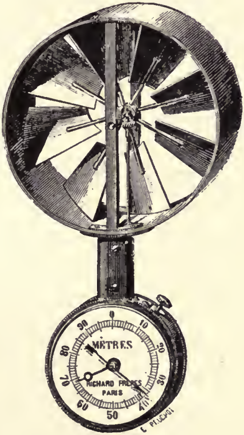


Fig. 61.—Anemometer.

A useful instrument, the anemometer, for measuring wind velocity is that shown in fig. 61, and is well-known; this one has a separate registering train which has undoubted advantages.

The instrument is composed of an extremely light aluminium vane, which rotates under the influence of extremely small currents of air. This vane drives, by means of a gearing, a small wheel, the spindle of which is long enough to transmit its motion to a meter contained in a watch-case held in the hand.

This instrument has the advantage over those in which the meter is placed at the centre of the vane of not producing any air waves, therefore allowing an entirely free passage of the air through the vane.

In the watch-case is a meter which totalises the number of revolutions of the anemometer. When measuring, the meter is started by pressing the knob with one finger, and, after a run of ten seconds, stopped by again pressing the same knob ; the velocity per second is then averaged. A correcting table gives the exact velocity.

This instrument may be provided with an electric contact, and connected to a registering apparatus ; in this case it is permanently fixed in the air current to be measured.

A barograph or statoscope indicates the height above the sea level ; the common aneroid barometer is so used, and is available for measuring heights up to 10,000 ft.

Much more sensitive instruments are made which indicate slight changes in elevation, such as we wish to observe when in the air at great heights. It is difficult to estimate whether the balloon or flying machine is rising or falling. Statoscopes are used to indicate the rise or fall.

The statoscope consists of a series of very sensitive boxes (somewhat like the vacuum chambers of aneroids), contained in a hermetically sealed reservoir, which is placed in a box thickly surrounded by wool so as to prevent the disturbing influence of change of temperature during any experiments. It is, in fact, an air barometer from which the normal pressure (15 lbs. per square inch) of the atmosphere is excluded. With this instrument a change of $\frac{1}{1000}$th of an inch of the barometer is represented by a motion of the needle of 0·025 in., or

25 times as great; consequently, if the instrument is raised 3 ft. the indicating pen traverses an angular space of nearly a tenth of an inch.

Fig. 62 shows the instrument with spring suspension.

Probably some invention can be devised or discovered whereby the statoscope will actuate a governor, automatically regulating the level at which it is desired to fly the flying machine. This is one of the many problems for solution in connection with mechanical flight.

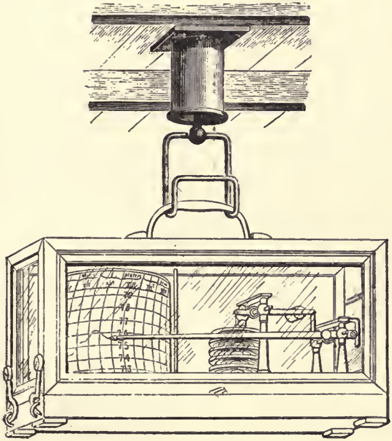

FIG. 62.—Statoscope.

## ATMOSPHERIC ELECTRICITY.

Flying machines floating in air, which is a very good electrical insulator, naturally become charged electrically when they come between the earth and charged clouds. They are in an electric field of force, and anything thrown out of the machine, such as water, sand, or exhaust gases, will carry off a charge of one kind, leaving the machine charged with the other kind of electric charge. And even in a strong field, if nothing is thrown out, the electric glow from points will carry off a charge into the air, leaving the machine charged. It is not likely that such a charge of high potential would have any effect on passengers. Sparks and discharges would take place only upon landing, or in coming near to another machine.

Sparks are always about balloons, especially at the valve on the top, when letting off gas in descending. These may ignite the gas, and such an accident has been recorded.

Connecting the various parts of the balloon and the valve with fine copper wires would likely divert the sparks from the discharge valve.

### Air and the Atmosphere.

At the sea level the pressure of the atmosphere has a mean value of 14·17 lbs. per square inch, or 2,116 lbs. per square foot; roughly, one atmosphere of pressure equals 14 lbs. per square inch, and is due to a column of air of uniform density equal to that at sea level and 5½ miles high, or 27,801 ft. ordinary temperature.

The water barometer has a column 33 ft. high. A pressure of 1 lb. per square inch is measured by a column of air 1,891 ft. high of uniform density, or by a column of mercury at 62 deg. Fah. 2·04 in. high, or by a column of water 2·3 ft. high.

A pressure of 1 lb. per square foot is measured by a column of air 13·13 ft. high, or by a column of water 0·1925 in. high very nearly 0·2 in.

The weight of a cubic foot of air has been taken as 0·08 lb. The exact volume and weight at different temperatures is given in Table XII. Air compared with water at 60 deg. Fah. has a volume 800 times that of water.

The specific heat of air at constant pressure is 0·2377, at constant volume 0·168. Water equals 1.

Air is a mechanical mixture of the gases oxygen and nitrogen: 21 parts O and 79 parts N by volume, 23 parts O and 77 parts N by weight.

The volume of 1 lb. at 32 deg. is 12·387 cubic feet; at any other temperature and barometric pressure its weight in pounds per cubic feet is

$$W = \frac{1\cdot3253 + B}{459\cdot2 \times T},$$

where B = height of barometer, T = temperature Fahrenheit, and 1·3253 = weight in pounds of 459·2 cubic feet of air at 0 deg. Fah.

Air expands $\frac{1}{491\cdot2}$ of its volume for every increase of 1 deg. Fah., and its volume varies inversely as the pressure. At a quarter of a mile above the sea level it has a pressure of 14·02 lbs., and at half a mile 13·33, at three-quarters of a mile 12·66, at one mile 12·02, and so on.

Barometer in inches × 0·4908 = pressure in pounds per square inch.

One ounce pressure per square inch is equal to 1·729 in. of water.

The quantity of air discharged from equal openings varies as the velocity.

One gallon of air = 277·27 cubic inches = $\frac{1}{97}$ lb. = $1\frac{2}{7}$ oz. The theoretical horse power of a fan blower may be found by the following rule:—

$$H.P. = \frac{Q \times 5\cdot2\, h}{33000},$$

where Q cubic feet of air per minute 5·2 constant h = inches of water gauge; or if we call the pressure P, then

$$H.P. = \frac{P\,Q}{33000};$$

or, if Q is given per second,

$$H.P. = \frac{P\,Q}{550}$$

In estimating approximately the flow of gases through an orifice it is usual to make the same hypothesis as that adopted in finding the height of the homogeneous atmosphere, viz., that the gas is incompressible and behaves as a liquid.

Let the pressure of air support 1 in. of water. One inch of water will balance 64·4 ft of air. This fact will be easily remembered. Or we may say that the density of air at 32 deg. Fah. is ·08 lb. per cubic foot, and that of water at 39·4 deg. F. is 62·425 lbs. per cubic foot.

Suppose the air to be contained in a vessel A and to flow into a vessel B. Let the difference of pressures in A and B, as measured by a water gauge, be $x$ inches. Then the velocity $v$ of issue is approximately given by the formula

$$v = \sqrt{2\,g \times 64{\cdot}4, x} = 64{\cdot}4 \sqrt{x}$$

Air is about $\frac{1}{800}$th the density of water; or what we might term the levity of the air is 800 times that of water. If we compressed the air to half its volume, its pressure would be one atmosphere above the external pressure, and its density twice that of the external air, or its levity half that of atmospheric air. If $z =$ levity, $h$ the height of the water barometer, and $p$ the pressure in atmospheres in a vessel of air, the velocity of efflux from an orifice would be equal to

$$V = 8 \sqrt{z\,h\,p},$$

Suppose 2 cubic feet of air to be compressed to 1 cubic foot, the levity would be $z = 400$, $h = 33$, and $p = 1 = 1$ atmosphere above external pressure, then

$$V = 8 \sqrt{400 \times 33 \times 1} = 920 \text{ ft. per second.}$$

In aeronautics we deal with pounds per square foot, hence the formulæ

$$V = 64 \sqrt{x} \text{ is used mostly.}$$

1 lb. per square foot equals ·1925 in. of water column, hence V for 1 lb. pressure would be

$$V = 64 \sqrt{0{\cdot}1925} = 28, \text{ nearly };$$

or, by the other formula,

$$V = 8 \sqrt{800 \times \frac{1}{2116} \times 32} = 28, \text{ nearly,}$$

1 lb. per square foot being $\frac{1}{2116}$th of an atmosphere

## TABLE XII.

VOLUME AND WEIGHT OF AIR AT VARIOUS TEMPERATURES.

| Deg. Fah. | Volume at atmospheric pressure. | | Density or weight in lbs. per cubic ft. at atmospheric pressure. | Pressure at constant volume. | |
|---|---|---|---|---|---|
| | Cubic feet in 1 lb. | Comparative volume | | Lbs. per sq. in. | Comparative pr'ss're 62 deg. Fah. = 1. |
| 0 | 11·583 | ·881 | ·08633 | 12·96 | ·881 |
| 32 | 12·387 | ·943 | ·08072 | 13·86 | ·943 |
| 40 | 12·586 | ·958 | ·079439 | 14·08 | ·958 |
| 50 | 12·840 | ·977 | ·077884 | 14·36 | ·977 |
| 62 | 13·141 | 1·000 | ·076097 | 14·70 | 1·000 |
| 70 | 13·342 | 1·015 | ·074950 | 14·92 | 1·015 |
| 80 | 13·593 | 1·034 | ·073565 | 15·21 | 1·034 |
| 90 | 13·845 | 1·054 | ·072230 | 15·49 | 1·054 |
| 100 | 14·096 | 1·073 | ·070942 | 15·77 | 1·073 |
| 110 | 14·344 | 1·092 | ·069721 | 16·05 | 1·092 |
| 120 | 14·592 | 1·111 | ·068500 | 16·33 | 1·111 |
| 130 | 14·846 | 1·130 | ·067361 | 16·61 | 1·130 |
| 140 | 15·100 | 1·149 | ·066221 | 16·89 | 1·149 |
| 150 | 15·351 | 1·168 | ·065155 | 17·19 | 1·168 |
| 160 | 15·603 | 1·187 | ·064088 | 17·50 | 1·187 |
| 170 | 15·854 | 1·206 | ·063089 | 17·76 | 1·206 |
| 180 | 16·106 | 1·226 | ·062090 | 18·02 | 1·226 |
| 200 | 16·606 | 1·264 | ·060210 | 18·58 | 1·264 |
| 210 | 16·860 | 1·283 | ·059313 | 18·86 | 1·283 |
| 212 | 16·910 | 1·287 | ·059135 | 18·92 | 1·287 |

For our worked-out examples of calculations we take the density always at 800 times less than water, or 0·08 lb. per cubic foot; but for greater accuracy in actual calculations, the real values as given above.

## CHAPTER X.

### The Practical Engineering of Flying Machines.

The student who would become a proficient, practical aeronautical engineer, capable of designing and dimensioning a flying machine, must, like all other members of the engineering profession, have a good foundation knowledge of the sciences—geometry, mathematics, applied and theoretical mechanics, machine construction and drawing, with some special knowledge of the design of structures of great strength and small weight, and of materials of small specific gravity—pretty much that sort of knowledge of these things required by an expert sailing yacht designer.

Most of the sciences are easily acquired now in technical schools, and an apprenticeship, if not available in an actual flying machine factory, could be profitably put in at either a yacht builders', a coach body builders', or some other works where the manufacture is much the same as in making flying machines.

A knowledge of the manual labour in fashioning the materials, jointing them together, bending and shaping into required forms, and of the working nature of the materials, the tools required, and how to use them, can only be acquired by actual experience, and such knowledge is of great value to the designing and managing engineer.

At present the author would choose for flying machine work educated men from the yacht building or coach body building trades for building the hull, planes, and frames of a machine ; very little of the iron or metal trades' skilled labour is necessary for these members of the design.

While the aeronautical engineer should have sufficient knowledge of the petrol engine to know the functions of its different parts, and to locate and remedy slight faults, it is not necessary he should be able to design and construct petrol engines. The engines for flying machines will be better made and cheaper to buy from special manufacturers, who have years of experience as specialists in these engines and their manufacture.

The screw propeller is also a member of the machine about which the aeronautical engineer should know something of its elementary principles. Its design and construation is a difficult art and science, only to be mastered by deep study and long experience by those who intend to devote themselves as specialists to screw propellers. It may be said that there need be no difference between the air screw propeller and the water screw propeller, so that the engineer has all the experience of the marine engineer to draw upon on the question of the screw propeller.

There are only the flapping wing and fish-tail propellers remaining to be tried in practice. There is no experience to draw upon of any value with these. They await the attentions of engineers who are bold enough and clever enough to leave the ranks of the camp followers, and strike out on a campaign of their own and become pioneers.

The inclined plane principle is the only successful one upon which the machines of to-day are based, and the method of applying that principle as shown in the various designs seems, at present, the only method. The flying machine which is to be of any military, naval, or commercial use must either be upon a new principle, or upon the inclined plane principle, carried into practice in a machine of a very different design and construction from those we now know of.

The results so far have fully confirmed all that was predicted of the aeroplane, but leaves a great deal of room for further advances.

It is, therefore, of more importance to the aeronautical engineer to be well grounded in the sciences and arts more particularly related to the subject of aeronautics than to confine his researches to existing types of machines.

At the same time, he should keep well informed of all that is being done now, and be well informed also as to what was done in the past.

Many propositions brought forward as new are quite ancient, and many good suggestions are buried in old specifications of patents.

The aeroplane type of machine presents the following problems for solution :—

1. A method of starting up from rest, within a small space, and without a special station, with fixed starting appliances.

2. Coming down and landing safely on any chosen spot.

3. Stability in high winds and gusty winds.

4. Safety of descent when engine stops at high altitudes.

5. Fuel-carrying capacity for long journeys.

6. Passenger, mail, or military carrying capacity, to make the machine of some utility.

These and other problems are obviously yet to be solved in aeroplanes.

Both propellers and aeroplanes would work to greater advantage if the planes were driven forward at double the speed they are now capable of doing. In a fluid of such small specific gravity as air, a high velocity forward increases the efficiency of both the screw propeller and the planes, for T, the thrust of the propeller, and L, the lift of the planes, are increased by high speed ahead. With the screw propeller we have seen that the thrust T of an advancing propeller is equal to

$$T = \frac{W (S + V) V}{32}$$

With very high speeds, say over 120 ft. per second, two or four large aeroplanes would not be satisfactory. This can be seen if we work out the spans, and *l*, their lengths. They would have to be less in breadth, longer, and of a smaller angle. Therefore we arrive at multiplane machines for high speeds. And with aeroplane machines the only direction for improvement in carrying power, in stability and economy of power for driving, lies in higher speeds.

The power required to lift the machine against gravity does not increase with higher speeds, while the screw acts with greater efficiency, and so do the planes.

As to other possible types of machines, they, at present, offer other difficult problems. Their chief difficulty at present is lack of lifting power. Nothing equals an inclined plane for multiplying a small "thrust" into a large "lift," so far as we can at present see. But other means of solving the problem are bound to be found.

On the question of fuel, it may be said that at present a journey would be limited by the fuel it could be done upon.

A Wright machine takes 25 H.P., it is said, and carries one passenger and driver; average speed, say 30 miles per hour. One horse power hour takes (roughly) one pint of fuel petrol. The engine will then require 25 pints per hour, and for 300 miles at 30 miles an hour it would run 10 hours, taking 250 pints of fuel in all, or say 30 gallons, weighing about 200 lbs.

A Farman machine has 50 H.P., and, flying quicker, would cover the ground in less time. It would be very interesting to know how much fuel was consumed in some of the long distance flights which have recently been recorded. Any amount of useless information is published about these performances, but the really interesting facts are carefully suppressed, and many of the journalistic accounts are contradictory and erroneous.

One enthusiastic aeroplane driver has announced he can fly across the Atlantic. May be so; but if he takes 200 lbs. of fuel for 300 miles, he will require 2,000 lbs. for 3,000 miles, without taking any margin of supply for accidents, head winds, or leeway. He will require an aeroplane of slightly greater dimensions, more reliability, and under better control than any yet produced.

As for dirigible balloons, their fragility and their enormous expense in first cost, and in their maintenance, are prohibitive for experimentalists, with the exception of wealthy belligerent governments.

The rapid multiplication of experimental aeroplane machines, and the prize-hunting exhibitions of them, has aroused a good deal of popular enthusiasm and interest; and the machine is fast becoming an object of attraction at open-air places of amusement and watering places, many of them making tempting offers to aeroplaners to make exhibitions, and no doubt that will be their first sphere of usefulness.

Meanwhile, however, there is evidence that engineers of high abilities, and well equipped for tackling the problems yet to be solved, are taking a more rational and sober interest in the subject, and the evolution of a useful flying machine is probably not far off.

The propulsion of flying machines is an important question in the near future; with the machines of to-day the single screw propeller is doing very well for machines of the carrying capacities for which they are designed. A thrust of from 200 lbs. to 350 lbs. is obtained, and a lift of from 40 lbs. to 50 lbs. per horse power at forward speeds of about 35 to 40 miles per hour. The most economical drive is that of the Wright machine, with two large propellers at moderate revolutions, 450 per minute; other machines with one smaller propeller waste a considerable amount of power in slip.

Although it is futile to discuss bird flight as an example for man to follow, yet there is something about the wing propulsion which mechanics, practical and theoretical, cannot satisfactorily explain. From all the investigations on the subject it can be gathered that there are very small losses in this wing propeller; and the velocities attained by birds, with comparatively slow wing beats, is astonishing; not only considering the higher velocities, but also considering how slow they can move when they desire to do so. Many inventors have wrestled with the problems of wing propellers, but none have penetrated to the secret of its power. Some imagine the arrangement of overlapping feathers is the key to the discovery of its action ; but nature negatives that supposition by employing wings of membrane-like leather in the bat's wing. It is more than likely that the wings used by Wenham and by Hargreaves are really rudimentary bird wings. The fish-tail propeller is of the same order, and from the weight and dimensions of a full grown whale, and the speed it can go at, it must exert great powers, calculated at as much as 250 H.P.

The only approximation to the fish-tail propeller in practice is the oar used over the stern of a small boat, moved to and fro by a man who, at the same time, feathers the blade—"stern sculling" it is called. With only one oar a good "sculler" can propel the boat almost as easily with the one oar as another rowing with two oars. There is matter for investigation in the propulsion problems. As time goes on and progress is made in other details, aeronautical engineers will run up against the propeller limitations. The peripheral speeds of screw propellers is already pretty near the outside limit, so that for higher thrusts than those now required propellers must be multiplied, and two, three, and four used. This means mechanical complications.

Some inventors imagine the rotating screws act as gyroscopes in balancing an aeroplane, but under the conditions on a horizontal shaft they have very little effect ; with the shaft fore and aft, they tend to keep the machine on an even keel ; but the effect is not great even in that direction. Some propose to use gyroscopes for balancing ; but they do not understand the gyroscope. To have any balancing effect, it must be heavy and continuously driven at a high speed, and hung in gimbals to which a powerful brake (or dash pot) is applied, to prevent the violent swinging of the flywheel frame. The high forward speed of an aeroplane has more steadying effect than any gyroscopic effect. A mass moving at 60 feet per second, and weighing about half a ton, takes some considerable force to move it suddenly out of its line of flight, but even this effect does not prevent rolling or pitching motions. An arrow shot from a bow is a case in point. Like the aeroplane, it has a heavy head, a long body, and the feathers at the end set to guide it straight ; with its high velocity it takes considerable force to deviate it from its course.

Balancing will, no doubt, be made automatic by a gyroscope, not by applying the gyroscope directly by its own force to do the work of balancing, but by using the gyroscope of small size to set in motion powerful levers to pull up the machine whenever it tends to roll or pitch. For instance, a small gyroscope could open and shut a small valve on a cylinder and piston admitting compressed air or gases under pressure, thereby moving the piston with enough power to warp the Wright Brothers' planes, on whichever side it was necessary, or to operate the balancing planes on other machines. The whole affair would not weigh 20 lbs. for a large flying machine, while a gyroscope to have any effect would, if applied direct, weigh over 200 lbs., and besides taking a large power continuously driving it.

Finally, we may hope for a flying machine on a different principle than that of the aeroplane. The aeroplane is the easiest solution of the problem of mere flight, but something more than a short flight at high velocity with two or three men aboard is desirable. High speeds are no doubt also desirable, but at present it is high speed or nothing with aeroplanes.

The safety of all power-driven flying machines heavier than air depends entirely upon the reliability of the prime mover and the mechanism, hence the mechanical engineering of a flying machine is of far more importance than that of a motor car, a steamship, or a locomotive ; these may have failures and breakdowns without serious consequences, but with flying machines failure is fatal.

## Examples of Arithmetical Calculations on Flying Machine Design.—Aeroplanes.

It may be of interest to some readers to give three examples of aeroplane design by calculation on the theory given in Chapter II.

First, for a small plane of, say, total lift 500 lbs., speed 44 ft. per second.

In such small machines the inclination of the plane is necessarily great in order to get sufficient lift from the small surfaces. This entails waste of power, which is sacrificed to obtain small sizes. 4 to 1 would be as great an incline as we could use without too great a loss. A C may be 6 ft.

$$B\,C = \frac{6}{4} = 1{\cdot}5.$$

The thrust of the screw would be

$$T = \frac{500}{4} = 124 \text{ lbs.}$$

if the plane were perfect, but as it has an efficiency of probably on 0·6, the thrust for lift alone would be

$$T = \frac{124}{0{\cdot}6} = 206 \text{ lbs.}$$

$$V \text{ would } = \frac{S}{4} = \frac{44}{4} = 11 \text{ ft. per second.}$$

$$W \text{ would } = \frac{W\ 32}{V} = \frac{500 \times 32}{11} = 1454 \text{ lbs.}$$

$$A \text{ would } = \frac{W}{V\ B\,C\ {\cdot}08} = \frac{1454}{11 \times 1{\cdot}5 \times {\cdot}08} = 1100 \text{ sq. ft.}$$

$$l \text{ would } = \frac{A}{S} = \frac{1100}{44} = 25 \text{ ft.}$$

The head resistance equals

$$R = S^2\ l\ B\,C\ {\cdot}003\ \sin\alpha\,;$$

$$R = 44 \times 44 \times 1{\cdot}5 \times {\cdot}003 \times {\cdot}24 = 20{\cdot}9 \text{ lbs.}$$

Total horse power without losses equals

$$\frac{T + R \times S}{550} = 18$$

The efficiency of a small machine propeller and engine combined is not more than 0·6, hence brake horse power

$$\text{H.P.} = \frac{18}{0·6} = 30 \text{ brake horse power,}$$

the minimum power necessary.

Now to take a medium-sized aeroplane, total lift 1,000 lbs., speed 60 ft. per second.

A C = 6 ft., B C with an incline of 6 to 1 = 1 ft. as before' and

$$V = \frac{60}{6} = 10\,;$$

$$W = \frac{1000 \times 32}{10} = 3200\,;$$

$$A = \frac{3200}{10 \times 1 \times ·08} = 4000\,;$$

$$l = \frac{4000}{60} = 66 \text{ ft.}\,;$$

too long for a monoplane, but will give a biplane of 33 ft. each plane.

The horse power can be found in same way as previous example, but the efficiency will be higher—0·66 for machines over 800 lbs. lift.

$$\text{Thrust or lift} = \frac{1000}{6 \times 0·66} = 250 \text{ lbs.}$$

R is also less in proportion for larger machines, hence we make the constant ·0026 instead of ·003 H.P.

$$R = 60^2\ l\ \text{B C}\ ·0026\ \ 0·166 = 100 \text{ lbs.}$$

$$\text{B.H.P.} = \frac{250 + 100 \times 60}{550 \times 0·66} = 58.$$

These powers are high, as the formulæ for R is calculated to provide for ample margin of power, and allows for losses, and R is less in proportion as the weight is increased.

If now we take a large machine and a higher speed ahead, say total lift 2,400 lbs., speed 72 ft. per second, A C 6 ft., B C 1 ft.,

$$V = \frac{72}{6} = 12\,;$$

$$W = \frac{2400 \times 32}{12} = 6400 \text{ lbs.}\,;$$

$$A = \frac{6400}{12 \times 1 \times \cdot 08} = 6666 \text{ sq. ft.}\,;$$

$$l = \frac{6666}{72} = 92 \text{ ft.}\,;$$

say three spans of 31 ft. each, a triplane.

The lifting thrust will be nearly

$$\frac{2400}{6 \times 0 \cdot 6} = 666 \text{ lbs.}$$

R can be calculated as before, but a large machine has less R in proportion to its weight, so that the constant may be ·0024 in this case.

$$R = S^2 \times l \times BC \times \cdot 0024 \times \sin \alpha\,;$$

$$R = 72^2 \times 92 \times 1 \times \cdot 0024 \times 0 \cdot 166 = 190\,;$$

$$\text{B.H.P.} = \frac{666 + 190 \times 72}{550} = 110.$$

The resistance formula is worked out on the principle of the resistance being as the square of the speed and directly as the front area of planes, and the sine of the angle of the plane, and a constant which is less as the weight of the machine is increased. It is entirely empirical, but in the absence of any more accurate means of estimating the resistance it may be used as giving results practically correct.

Probably if machines were made of two or three tons lift the constant would become about ·0015. The big machine at high velocity is the machine of the future. Sir Hiram Maxim's machine, with its 350 H.P. and total lift of 7,000 lbs., if calculated out on the above principles, comes out very different in dimensions than those given from the actual machine, but the idea of the large machine with plenty of power was correct. What the speed was to be we do not know, but it might be 44 ft. per second. A C should have been 6·6 ft., which would make $V = 11$, with a 6 to 1 incline, and

$$W = \frac{7000 \times 32}{11} = 20000\,;$$

$$A = 20000, \text{ nearly};$$

$$l = \frac{20000}{44} = 454 \text{ ft.}$$

A manageable length or span of planes would have been about, say, ten planes of 46 ft. each.

The student can calculate out the horse power as an exercise.

Ordinary British workmen, and many others, still use English weights and measures, while there is a tendency in describing flying machines to use the metric system. A table for conversion of one into the other is here given.

## CONVERSION TABLE.

Millimetres × ·03937 = inches.
Millimetres ÷ 25·4 = inches.
Centimetres × ·3937 = inches.
Centimetres ÷ 2·54 = inches.
Metres = 39·37 inches.
Metres × 3·281 = feet.
Metres × 1·094 = yards.
Metre per second = 3·28 feet per second.
Kilometres × ·621 = miles.
Kilometres × 3280·7 = feet.
Square Millimetres × ·0155 = square inches.
Square Millimetres ÷ 645·1 = square inches.
Square Centimetres × ·155 = square inches.
Square Centimetres ÷ 6·451 = square inches.
Square Metres × 10·764 = square feet.
Square Kilometres × 247·1 = acres.
Hectares × 2·471 = acres.
Cubic Centimetres ÷ 16·383 = cubic inches.
Cubic Metres × 35·315 = cubic feet.
Cubic Metres × 1·308 = cubic yards.
Cubic Metres × 264·2 = gallons (231 cubic inches).
Litres × 61·022 = cubic inches.
Litres × ·2642 = gallons (231 cubic inches).
Litres ÷ 3·78 = gallons (231 cubic inches).
Litres ÷ 28·316 = cubic feet.
Grammes × 15·432 = grains.
Grammes (water) ÷ 29·57 = fluid ounces.
Grammes ÷ 28·35 = ounces avoirdupois.
Grammes per cubic cent. ÷ 27·7 = pounds per cubic inch.
Joule × ·7373 = foot pounds.
Kilograms × 2·2046 = pounds.
Kilograms × 35·3 = ounces avoirdupois.
Kilograms ÷ 1102·3 = tons (2,000 pounds).
Kilograms per square millimetres × 1422·3 = pounds per square inch.
Kilograms per square cent. × 14·223 = pounds per square inch.
Kilo-watts × 1·34 = horse power.
Watts ÷ 746 = horse power.
Caloric × 3·968 = B. T. U.
Cheval vapeur × ·9863 = horse power.
Centigrade × 1·8) + 32 = degrees Fahrenheit.

## Conversion Table—Metres into Feet.

| Metres. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | .. | 3·281 | 6·562 | 9·843 | 13·124 | 16·404 | 19·685 | 22·966 | 26·247 | 29·528 |
| 10 | 32·809 | 36·090 | 39·371 | 42·652 | 45·933 | 49·213 | 52·494 | 55·775 | 59·056 | 62·337 |
| 20 | 65·618 | 68·90 | 72·18 | 75·46 | 78·74 | 82·01 | 85·29 | 88·57 | 91·85 | 95·14 |
| 30 | 98·427 | 101·71 | 104·99 | 108·27 | 111·55 | 114·82 | 118·10 | 121·38 | 124·66 | 127·95 |
| 40 | 131·236 | 134·51 | 137·79 | 141·08 | 144·36 | 147·63 | 150·91 | 154·19 | 157·47 | 160·76 |
| 50 | 164·045 | 167·32 | 170·60 | 173·89 | 177·16 | 180·45 | 183·73 | 187·01 | 190·29 | 193·57 |
| 60 | 196·854 | 200·13 | 203·41 | 206·69 | 209·97 | 213·26 | 216·54 | 219·82 | 223·10 | 226·38 |
| 70 | 229·663 | 232·94 | 236·22 | 239·50 | 242·78 | 246·07 | 249·35 | 252·63 | 255·91 | 259·19 |
| 80 | 262·472 | 265·75 | 269·03 | 272·31 | 275·59 | 278·87 | 282·15 | 285·44 | 288·72 | 292·00 |
| 90 | 295·281 | 298·56 | 301·84 | 305·12 | 308·40 | 311·68 | 314·96 | 318·25 | 321·53 | 324·81 |

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