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PRINCIPLES AND DESIGN

OF

AËROPLANES.

BY

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USE WATER POWER," "[illegible]," "HOW TO
BUILD AND DESIGN IN STEEL," &c.

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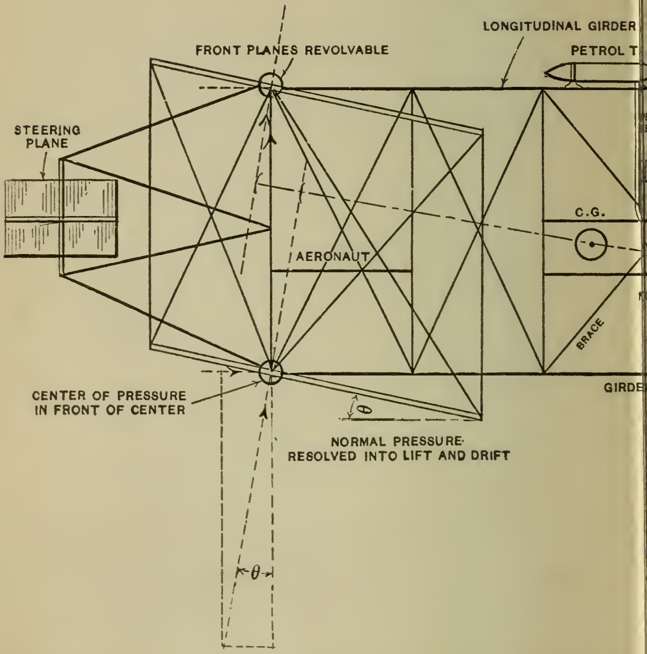

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The planes are usually curved, the motor and propeller
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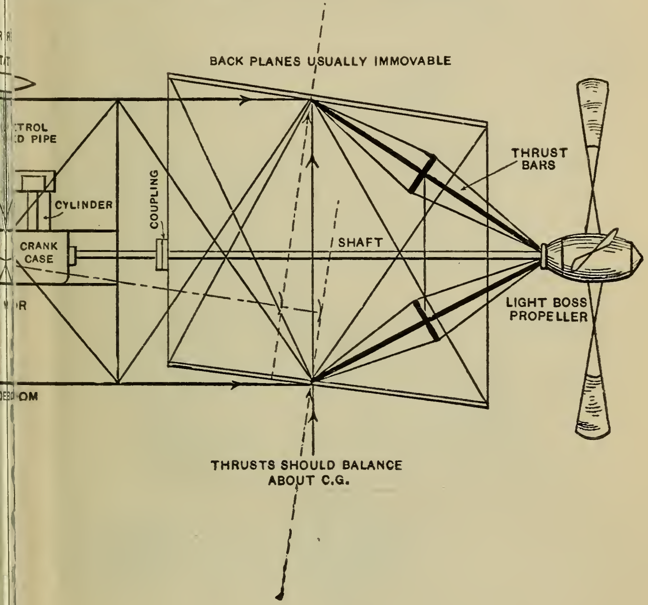

out only to indicate the mechanical conditions of balance. e usually not separated in the manner shown and the oted.

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PREFACE TO SECOND EDITION.

The first edition of this book was much criticised for its omission of reference to modern machines. I venture to think that the essential features of all the machines which have had any measure of success are to be discovered just as well in the earlier machines as the later ones. At present the construction is in a state of steady evolution which has not yet attained any finality, and I have therefore deliberately abstained from specifying many particulars of actual machines. The main questions of automatic stability and perfection of control are by no means settled, and I would refer the reader to the now extensive aëronautical press for current particulars.

Longitudinal stability has three lines of development at present: The rear tail as seen in the Bleriot and Antoinette machines, the front balances as seen in the Valkyrie and the old Wright machines, and the reflex curvature as seen in the Weiss and Dunne machines. Control may be effected by the three-rudder system or by warping or rotating the main surfaces. All these are points for experiment, and I think it is best not to hamper the student with a preconceived idea as to the best type of machine. The somewhat bizarre frontispiece is not a design at all, but simply a mechanical diagram.

Herbert Chatley.

March, 1912.

PRINCIPLES AND DESIGN

OF

AËROPLANES.

CONTENTS.

ILLUSTRATIONS.

CHAPTER I.

THE AËROPLANE.

During the first decade of the twentieth century another great stride in mechanical science has been taken. Machines have been constructed which will carry a man through the air, both lifting and propulsion being performed by self-contained mechanism.

For very many years this achievement had been expected. The experiments of Sir Hiram Maxim and Professor Langley had shown the result to be possible, but it was left for Messrs. Wright, Santos-Dumont and Henry Farman* to demonstrate the practical fact on a large scale.

There are three types of machine for

---

* Bleriot, Esnault-Pelterie, Ferber, Vaija, Gastambide-Mangin, Roe.

performing mechanical flight, each depending on a different principle:

(1) The gyroplane, or helicoptere, which uses vertical lifting-screws.

(2) The ornithoptere, which has flapping wings like a bird.

(3) The aëroplane, kite, or glider, which is a surface pulled or pushed through the air.

Although the first two types are very promising, yet it is the last which has done definite work, and it is with this variety I propose principally to deal.

It will be noticed that the title "kite" is also applied to this type, and, as a matter of fact, in its essential principles the aëroplane is merely a large variety of kite.

It therefore behooves to study briefly the action of the ordinary kite and then consider in what manner the kite may be modified to act as a flying-machine.

Taking the very simplest type of kite

as shown in sketch, we notice three features:

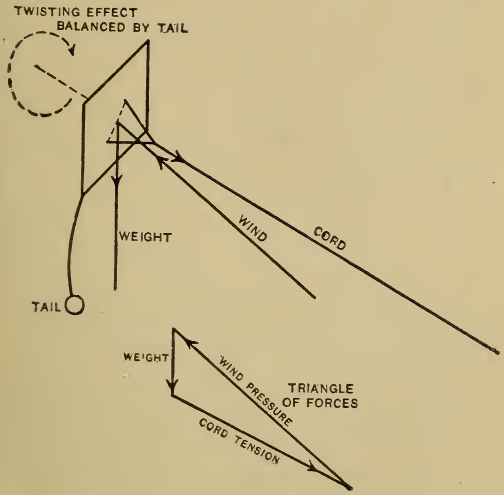

Fig. 1. KITE

(1) A more or less rigid surface.

(2) A cord tying this surface to the earth.

(3) A continuous motion of air against the surface.

It follows from the simplest mechanical principles that there are three forces in this case, the wind pressure on kite, the pull in the cord, and the weight of the kite. These three are in equilibrium if the kite is stationary. If the kite ascends then the vertical component of the wind pressure exceeds the weight and downward component of the cord pull. This vertical force is termed "lift." If the kite travels with the wind the component of the wind in the direction of the cord exceeds the pull in the cord. This lateral force is called "drift" or "waftage."

Since the air is almost frictionless the pressure of the kite is practically normal to its surface, and this surface, if there is any lifting force, must be inclined to the horizontal, and if the wind is horizontal the surface must therefore be inclined to the direction of motion of the wind. Actually the wind (especially near the ground) is slightly inclined upward.

Another feature we notice in the common form of kite is the weighted tail.

Owing to irregular distribution of the wind pressure a tailless kite tends to spin on the cord; and since the centre of pressure on an inclined surface is usually eccentrically placed (see later chapters), such a kite loses balance, is overturned by the wind, and plunges to the ground.

Having travelled so far, we can now enumerate the principal points to be considered:

(1) The weight of the kite.

(2) The pressure produced by air moving against a surface generally inclined to the horizon.

(3) The distribution of the pressure on that surface.

(4) The pull available on the cord.

(5) The provision of a righting moment to prevent overturning.

All these we will shortly treat in detail, merely premising that on a correct understanding of the value of each depends the whole problem of aërial navigation.

If we substitute for the cord a screw propeller, or a "tractor" (pulling screw), we have an "aëroplane." By cutting our connection with the ground, however, we have made an enormous difference in one of the conditions and it behooves us to go very warily. The pressure of the air depends on the square of the velocity with which the air strikes the surface, i.e., the relative velocity, and it is necessary to realize at the outset that it is this relative velocity which has to be considered and *not the velocity as measured on the ground.* This problem is further complicated by the fact that the velocities we wish to obtain are necessarily measured on the ground. To give a definite example, let us suppose there is a wind travelling south with a velocity of 30 miles per hour. If we wish to travel north with a velocity of 20 miles per hour, we have to obtain a relative velocity of 30 + 20, i.e., 50 miles per hour. That is, the machine will be carried with the air at a speed of 30 miles per hour in a S. direction and must proceed in N. direction *as if in still air* with a speed of 50 miles per hour.

Again, if we wish to travel S. in the same wind with a velocity of 30 miles per hour, our relative velocity will be zero and so no lifting force will be available. We shall, in other words, simply be carried by the wind, and under such circumstances the only pressure on the aëroplane will be due to local variations in the velocity, and a heavy machine would probably quickly descend; its downward speed being only checked by the resistance caused by the gravitationally acquired velocity. In such a case we should endeavor to get a further velocity to provide lifting pressure of say 25 miles an hour. Our actual velocity *as compared with the earth* would then be 30 + 25 = 55 miles per hour, but *as compared with the air* it would only be 25 miles per hour.

This point should be very carefully considered, since *with the wind* enormous velocities, as compared with the earth, might be obtained; but contrary the wind there can be no advance as compared with the earth unless the speed of the vessel compared with the air exceed that of the wind compared with the earth. In fact, under such circumstances it is quite feasible to be lifted and at the same time drift with the wind but at a lesser velocity.

The wind velocity varies from a very small quantity (it is rarely zero) up to more than 100 miles per hour.

The key idea is, of course, this:

Lifting pressure can only be obtained from velocity *relatively to the air,* and the actual motion over the earth can only be obtained when the velocity of the wind is combined with the velocity of the plane as compared with the air.

Another peculiarity in connection with relative motion occurs in the propeller. It will be remembered that this mechanism, being a variety of screw, will either move through a nut or the nut will move from the screw. The air being a nut of rather less solid character than those used for fixing purposes causes the actual action of a propeller to vary considerably from this simple motion of nut or screw. Thus a ventilating fan does not propel all the air which passes through, and a propeller does not screw through the air without moving it at all. If we multiply together the "pitch" and "revolutions" (see later) we get the speed at which the propeller should screw its way into the air (pushing or pulling with it the aëroplane). Generally, however, the speed at which the plane travels is less than this propeller velocity. (By speed of the plane we, of course, mean as compared with the air.) The air will then slip through the screw and be wasted for propulsive purposes. Further practical difficulties occur in the churning of the air by the screw and also the inefficiency of the central parts of the screw.

The next problem, which until quite recently presented insuperable difficulties, is that of weight. The plane has to carry in addition to its own weight that of the prime mover and the propeller, together with other small items, such as aviators. Since the thrust from an air propeller is usually small as compared with the power required to drive the propeller, and since, further, this thrust acting on the aëroplane has to indirectly produce the whole of the lifting pressure, the weight has to be very small as compared with the power. Sir Hiram Maxim's steam-engine, weighing 2 lbs. per H.P., and certain petrol motors, weighing from 5 to 10 lbs. per H.P., have brought us within the limit of weight, but in all other respects as well we have to make the weight a minimum.

The final difficulty, the importance of which has long been underestimated, is that of balancing, i.e., preserving a level course. We have already seen that there are some difficulties with this in the case of the kite, and when we have an aëroplane moving through air of constantly varying velocity, the machine possessing considerable momentum and wind surface, these difficulties are greatly increased. Later on we shall consider in what manner righting forces can be obtained, but in any case the engineer who designs an aëroplane cannot give too much attention to this question of balancing.

A general survey has now been made of the more crucial problems which the inventor has to consider, and in the following chapters these will be considered in detail. Too much stress should not be laid on mathematical calculations, since the bulk of our knowledge of this subject is empirical rather than analytical. Nevertheless certain calculations can and must be made, more particularly in regard to the angle, area, and weight of the plane, and with these I will next deal.

CHAPTER II.

AIR PRESSURE.

In all cases of flying apparatus the actual lifting effect is derived from the pressure produced on a surface by the relative motion of air, and it is therefore necessary to have exact notions of the pressures produced on planes of different areas and shapes, and with different relative velocities.

If we consider that the whole of the momentum lost per second is the force exerted, we get the following value (for ordinary temperature and barometric pressure) for pressure on a plane at right angles to the direction of motion:

Pressure (lbs. per sq. foot) = .0023
× area of plane (in sq. feet)
× square of velocity (ft. per sec.).

It is a common practice to subtract from this 50 per cent. for the kinetic energy given to the air in the direction of motion, so that the constant then becomes .0011. As a matter of fact practical experiment shows that a constant .0017 is more correct, there being an additional pressure due to suction on the back of the plane.

This feature of "suction" or "negative pressure" on the back of the plane has long been recognized, and is due to the eddying of the air which has been separated by the passage of the plane, and also to the fact that the space swept out by the plane takes a small but appreciable time to fill, so that the pressure is less than atmospheric.

Furthermore, there is friction, so that we may say

Pressure on plane = windward pressure + leeward negative pressure + friction.

(Some experimenters neglect the latter, but it is occasionally very important.)

At the outset we must realize that each and every part of a machine which is moving with a velocity relative to the air will experience this resistance. The actual magnitude is in general absolutely dependent on the area exposed in the direction of motion. If the surfaces be normal to this direction, then the value will be that given. If inclined, the resistance in the direction of motion will be less. If outwardly curved (i.e., convex) or pointed it will be less still, but if concave to wind the pressure will be more.

It is however, with inclined surfaces that we are principally interested, and it should first be noticed that in all cases the pressure is perpendicular to the exposed surface, so that a surface inclined forward and upward is subject to a backward and upward pressure. In the case of concave to wind surfaces the pressure is directed a little forward of the perpendicular to the chord.

As stated in the last chapter, the upward component is called "lift" and the backward "drift" or "resistance." Roughly the normal pressure varies as the sine of the angle between the plane and the direction of the impinging air-stream. More exactly for square planes it varies as

$$\frac{2 \sin \theta}{1 + \sin^2 \theta}$$

[Duchemin and Langley.]

or for long, narrow planes with narrow width in direction of motion it varies as

$$\frac{(4 + \pi) \sin \theta}{4 + \pi \sin \theta}.$$

[Lord Rayleigh and Gerlach.]

For general purposes, however, we use simply the sine law, so that

Normal Pressure = .0017 × area × velocity^2 × sine θ × 2.5.

Drift=.0017×area× velocity^2 × sine^2 θ × 2.5.

Lift=.0017 × area × velocity^2 × cos θ, sin θ × 2.5.

[For small angles sin θ. cos θ = sin θ.]

In all practical cases, however, the rules are not to be quite so simply expressed, but the following will serve generally:

Net lifting force (i.e., producing upward velocity) = weight of aëroplane and its load — [.0017 × area of plane × $(\text{velocity})^2 \times \sin\theta \times \cos\theta \times 2.5$.]

If the weight is just supported, then of course this net lifting force is zero. The plane is then said to soar, and the velocity which corresponds to this condition is termed the "soaring" or "critical" velocity.

It can be found easily as follows:

Soaring velocity^2 (feet per sec.) =

$$\left(\frac{\text{weight (lbs.)}}{.0017 \times \text{area (ft.)} \times \sin\theta \cdot \cos\theta \times 2.5}\right).$$

Since when θ is small, $\cos\theta = 1$, we have practically the following variations to notice:

Soaring velocity increases with square root of weight supported;
decreases with square root of area;
decreases (at first) with square root of sine θ.

In other words, the greater the area or the angle, or both, the less may be the soaring velocity. As far as the angle is concerned the minimum soaring velocity occurs about 30°. This corresponds to a maximum lift with minimum drift or resistance. By increasing the area we can decrease the velocity to some extent, but of course the weight must increase less rapidly.

An "angle of attack" of about 3° to 6° gives the maximum lift-to-drift ratio and is therefore the most efficient.

A very important point to notice is that since soaring velocity depends in the manner indicated upon the angle, when high speeds are attained the angle may be flattened, so obtaining the same lift with less resistance and therefore less work (since work is product of resistance and velocity). This is termed "Langley's paradox," and has been much dilated on by some authorities. It applies, however, only to the plane neglecting friction. Other parts (framing, etc.) will increase in resistance with the velocity, and Langley's paradox ceases to be true for very small angles of attack.

For starting purposes it is obviously desirable to have the initial velocity as small as practicable, and so the best arrangement would seem to be, one (1) with sufficient power to overcome the resistance when the plane has an angle of 30° and is moving at soaring velocity, and (2) with a mechanism for rotating the plane so that as soon as flight commenced and by reason of the starting acceleration the velocity increased, the resistance could be decreased.

The constructional difficulties have led to the use of "elevators" instead of movable main surfaces, but many arguments may be adduced in favor of the latter.

A further practical point of great moment is the resistance of curved surfaces. Mr. Phillips, of Wealdstone, has made a large number of experiments with slightly curved planes and has found that a plane slightly curved downward in front (approximately "cissoidal" in form) gives a greater lift and a smaller drift than a similar true plane of the same area at any angle of inclination. This fact has been applied in the construction of many aëroplanes with satisfactory results. Mr. Phillips' own machine is exceptional in that he uses a large number of very narrow surfaces superposed. He has obtained a lift of 3 lbs. per square foot.

It should perhaps be noted that the wings of birds have this slightly curved section, and the parachute also gives a good example of the greater lift obtainable with such curvature.

A camber of about $\frac{1}{12}$ the chord of the curve gives the least resistance with appreciable lift. On such surfaces there is a disadvantage in that the center of pressure recedes when the angle of attack decreases so that stability can only be assured by the use of a tail.

As already mentioned, the drift or resistance is increased by reason of the framing and other parts of the machine. It is desirable, therefore, to make all stays, struts, etc., with a minimum frontal area, or if it be not possible to greatly reduce same, they should be enclosed in a light casing of stream-line form (sine-curve or cigar shape). Petrol tanks, motor-casing, aëronaut's cab (if possible), etc., can in this way be reduced in resistance, provided, of course, the means employed does not materially increase the weight.

As regards steering (both horizontal, vertical, and lateral), small planes or parts of the large ones should be capable of turning or twisting in the three directions. Further details as to this are discussed later.

When there is a system of planes they should be so arranged that each interferes as little as possible with the supply of air to the others. Superposed planes should be separated vertically by a distance at least equal to the width planes behind one another should have an interval equal to upward of one and a half times this dimension.

The spread divided by the width of the surfaces ("aspect ratio") should be as much as possible. The higher the aspect ratio the greater is the ratio of lift-to-drift and consequently the more efficient is the machine.

CHAPTER III.

WEIGHT AND POWER.

It is of course obvious that the most important consideration in connection with any flying-machine is the weight to be lifted. Supposing that soaring (i.e., weight just lifted) is only aimed at, then the rules already given supply a relation between the weight, angle, area, and speed of the plane.

$$\text{Weight} = .0017 \times \text{area of plane} \times \text{velocity}^2 \times \sin\theta . \cos\theta \times 2.5,$$

i.e.,

$$\text{Area} = \frac{\text{weight}}{.0017 \times \text{velocity}^2 \times \sin\theta . \cos\theta}$$

and (for small angle)

$$\sin\theta = \frac{\text{weight}}{.0017 \times \text{velocity}^2 \times \text{area} \times 2.5.}$$

NOTE.—These rules will be greatly simplified if 6° is substituted for θ, but occasionally less efficient angles are used. If combined surfaces are used ($\frac{1}{12}$ camber) the constant 4 can be substituted for 2.5 in the expression for the lift, but 2.5 is retained for the *drift*.

The weight that can be lifted therefore

increases with area;

increases with square of velocity;

increases as $\sin \theta . \cos \theta$ (or $\sin \theta$ for small angles).

The best combination of area and weight has been found to be about 2 lbs. of weight per square foot of aëroplane, which leads to the rule:

$$2.5 \times .0017 \times \text{velocity}^2 \times \sin \theta . \cos \theta = .5$$

For practical purposes the weight may be divided as follows:

(1) Weight of aëroplane.

(2) Weight of framing.

(3) Weight of machinery and propeller.

(4) Weight of aëronaut.

By using silk or calico on bamboo or pine the framing and plane may be kept within one pound per square foot of area. The machinery (if petrol motor is used) need not exceed 10 lbs. per effective horse-power. The weight of aëronaut will vary from 150 to 200 lbs. Experience seems to indicate that a man-lifting machine cannot be built much under 500 lbs. weight, which corresponds to an area of aëroplane equalling 250 ft. super as a minimum. The area can be increased up to as much as 1,000 square feet, but of course the greater the area the greater must be the power, although by using a flatter angle the resistance need not be increased in the same proportion as the area.

As regards the power required we have the following mechanical rules to bear in mind:

Resistance (lbs.) × Velocity (ft. per sec.) = Power (in foot lbs. per sec.)

or

$2.5 \times .0017 \times \text{area} \times \text{velocity}^3 \times \sin^2 \theta =$ power in foot lbs. per sec. to drive plane alone.

If there are (this is always the case in practice) additional resistances we must put the rule in the following form:

$[(2.5 \times .0017 \times \text{area of plane} \times \sin^2 \theta) + (2.5 \times .0017 \times \text{area of other surfaces})] \times \text{velocity}^3 = \text{power}.$

The other surfaces will include the propeller. This expression divided by 550 = effective horse-power required to drive the machine. It will be noticed that there are two features which may be varied, the angle and the velocity.

After flight has commenced the velocity may be increased by (1) increasing the power or (2) decreasing the angle. The latter is, of course, more economical but cannot be carried on indefinitely because of the other resistances and also because when the angle is very small the stability is not great.

Experimenters differ greatly as to the power required. Mr. Henry Farman in his early record flight at Issy-les-Moulineaux used 50 H.P., whereas Mr. Roe's machine succeeded with 9 H.P. Supposing in each case that the efficiency is 60 per cent., this means that Mr. Farman drives with 25 H.P. and Mr. Roe with 6 H.P. The difference lies with the area and angle of the plane. Mr. Roe gets a great initial velocity before soaring, using a very flat angle. Mr. H. Farman used a greater relative area and a larger angle, so that the initial velocity for soaring is much smaller.* The latter, of course, is more practicable, but is less economical of power. M. Santos-Dumont used a very large area (2 ft. per lb. about) and large power to his machine, "14 bis," which made the first flight in Europe. The disposition of the weight is another very

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* In my book "The Problem of Flight" I have shown that the minimum soaring velocity can be obtained with an angle between 20° and 30°.—*H. C.*

important matter. The question of balancing will be further considered later on, but initial balance depends, of course, on the positions of the weights.

The master rule for balancing is simply this: the resultant pressure must always pass through the centre of gravity of the machine. In other words, the pressures on the planes must balance about the centre of weight.

In order to satisfy this condition the weight must be so disposed that the centre of gravity lies in the centre of the width and as nearly as possible at the point in the length about which the pressures on the planes will balance.

We must also have the centre of pressure to advance if the angle of attack decreases and recede if it advances.

Before making a flight it would be well to suspend the machine, so finding the exact position of the centre of gravity and also the actual weight. These will serve as data for computing the stability in the manner described later.

It is the usual practice to put the motor and attachments aft the centre and the aëronaut's car forward, but the reverse arrangement is safer.

A balance weight may be used, which will of course have to be included in the total weight.

The following table of weights will probably be useful:

Aluminium,	.09 lb. per cubic inch
Wrought Iron or Steel,	.28 lb. " "
Bamboo,	25 lbs. per cubic foot
Pear,	23 lbs. " "
Willow,	30 lbs. " "
Calico,	.04 lb. per square foot
Dressed cotton,	.17 lb. " "
Pegamoid,	.10 lb. " "
Silk (dressed),	.05 lb. " "

The *breaking* stresses of some of these materials are as follow:

	(Tensile)
Aluminium, sheet,	12 tons per sq. in. of cross-section.
Wrought Iron,	25 tons, " "
Steel,	30 tons, " "
Soft timber (pine),	4 to 5 tons " "

Also:

Hemp rope	(1 in. girth),	.04 ton	(working	load)
Iron wire rope,	"	.3 ton	"	"
Steel wire rope,	"	.45 ton	"	"

The breaking stresses (given in all but the last three cases) should be divided by a factor of safety not less than 5 to find the working strength.

It should be noticed that snow, rain, or dew deposited on the whole of the surfaces will cause an increase of several pounds in the weight, and also, of course, any stores carried must be included, including petrol, water, provisions, etc.

It must also be noticed that the propelling machinery when more perfect machines are employed will include:

Friction clutch,
Cooling water tank,
Pipes and radiator,
Change-speed gear,
Thrust-block,
Controlling levers,
Lubrication cups and pipes.

At present, of course, the small motors employed comprise only the engine, carbureter, and petrol tank, as no change of speed (beyond that produced by varying the air and petrol supplies) is desired, but this must of course only be the first stage. Further details as to this are given in the next chapter.

SIMPLE RULES AS TO WEIGHT, AREA AND POWER.

$$\frac{\text{Velocity}}{\text{(feet per sec.)}} = 30 \text{ to } 50 \sqrt{\frac{\text{wt. lbs.}}{\text{per sq. ft.}}}$$

30 for curved surfaces; 50 for planes.

Resistance = $\frac{1}{5}$ to $\frac{1}{8}$ of the weight.

$$\frac{\text{Power necessary}}{\text{(B.H.P.)}} = \frac{\text{weight(lbs.)} \times \text{velocity}}{2000}.$$

On *planes* the centre of gravity should be $\frac{1}{4}$ the width of the plane in front of its centre.

On *curves* the centre of gravity should be $\frac{1}{8}$ the width of the surface in front of its centre.

CHAPTER IV.

Motor and Propeller.

The desideratum in respect of a motor is of course a minimum of weight for a maximum of power. In other words, the ratio

$$\frac{\text{weight of motor}}{\text{power}}$$

should be as small as possible. The record values are as follow:

	Per H.P.	
Dufaux,	1.5 lbs.	Petrol
Antoinette Co.,	2.2 lbs.	
Wright Bros.,	2.2 lbs.	
Maxim,	2.0 lbs.	Steam.

These values are, as far as is known, found as follows:

weight in lbs. ÷ B.H.P. = ratio.

There will, however, be a certain loss in the transmission mechanism. In the light machines at present employed this will only be small, but in all cases the loss at the propeller is serious. Professor Langley obtained an efficiency of 50 per cent. for a common type of aërial propeller, and his value is frequently ap-

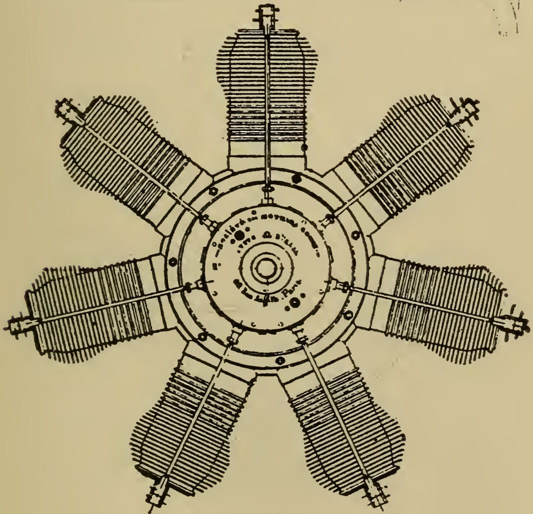
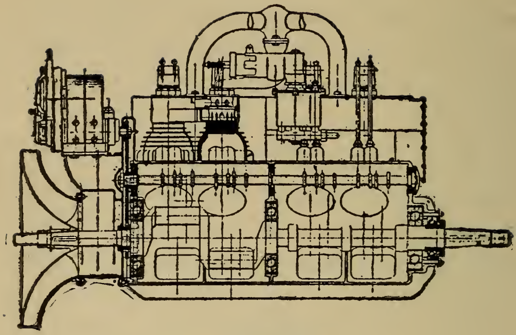
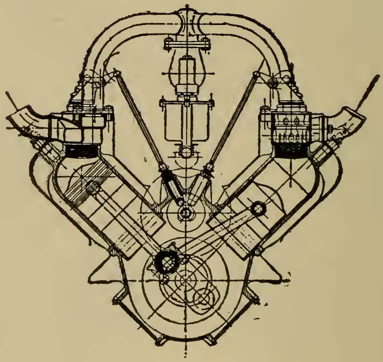


Fig. 2. AERONAUTICAL MOTOR.
The Gnome Rotary Engine.



Longitudinal Section



Cross-section

Fig. 3. THE "PIPE" MOTOR

proximated to. The late M. Froude has shown that in marine practice the maximum possible efficiency is 77 per cent., and there seems to be good reason for supposing the case to be, if anything, less satisfactory in air. 70 per cent seems to be the probable maximum.

Taking the value of 50 per cent., this means that the horse-power actually performable by the propeller in moving the aëroplane will be only half the brake H.P. of the motor.

It is scarcely necessary in these days of motor-cars to describe the petrol motor, but the following features may usefully be noted.

The source of power is petroleum spirit chemically combining with air. The spirit is fed from a tank to a "carbureter," where by passing through a nozzle under a slight pressure, and at the same time mixing with air drawn through a pipe passing over the exhaust-pipe of the engine, it becomes a highly combustible vapor.

The engine works on the "four-cycle" principle, i.e., there are four strokes on each of which a different process is performed. In the first (forward) stroke "admission" occurs—i.e., by atmospheric pressure the petrol vapor and air are pushed into the cylinder through a valve which is opened by a cam driven by a shaft geared to the main shaft. In the second (backward) stroke the gas is compressed into a small space. When the stroke is completed an electric spark is produced across a gap between the terminals of a "sparking plug" screwed into the wall of the cylinder. This fires the mixture and forces the piston forward (the third or ignition stroke). The last stroke pushes the burnt gas out of the cylinder through an exhaust-valve operated by a second cam on the aforesaid small shaft. Another cam on the same "half-speed" shaft makes the electrical connection for firing the mixture.

There are thus three ways of controlling the working of the engine:

(1) By "throttling," i.e., varying the supply of petrol to the carbureter.

(2) By varying the air-supply to the carbureter.

(3) By slightly altering the moment of ignition.

To start the engine hand gearing is generally used (i.e., to make the first and second strokes). In a small motor this may be directly applied to the shaft, but in a large motor chain gearing is necessary.

The motor-shaft is generally directly coupled to the propeller-shaft, but in large motors there should be a friction-clutch and change-speed gear to vary the propeller-thrust.

As regards the power of the motor the following mechanical rules are useful:

$$\text{Indicated horse-power} = \frac{\underset{\text{in lbs. per sq. in.}}{\text{average pressure}} \times \underset{\text{in feet}}{\text{stroke}} \times \underset{\text{in sq. in.}}{\text{area of piston}} \times \underset{\text{per min.}}{\text{revs.}}}{2 \times 33000}$$

The average pressure is generally about 80 lbs., but can be increased a little by enriching the mixture (i.e., admitting more petrol to the carbureter) or decreased by increasing the air-supply. When the motor is running well, by slightly advancing the moment of ignition the power is economized and shock reduced. The brake H.P. is generally from 5 to 10 per cent. less than the indicated H.P. by reason of friction, etc., in the engine.

The twisting moment on the shaft (i.e., force in pounds, at one foot distant from shaft) $= \frac{\text{Brake H.P.} \times 550 \times 7}{44 \times \text{revs. per second}}$,

or

$$\text{B.H.P.} = \frac{\underset{\text{(lbs. feet)}}{\text{Twisting moment}} \times \frac{44}{7} \times \underset{\text{per sec.}}{\text{revs.}}}{550}$$

Thus, by increasing the speed we reduce the twisting moment, and vice versa, but it should be observed that the B.H.P. varies with the speed.

The sources of troubles with a petrol motor are generally as follows:

Firing. Accumulators and induction-coil operate the spark. All connections should be good and clean.

Carburation. The carbureter should be in good working order, with neither too much nor too little petrol, all parts free to move, pipes and nozzles clear.

Compression. There should be no leakage in valves, cylinder, or piston-rings, valves must not stick on seatings. Cylinder-walls lubricated, piston-rings tight. Back-firing is due to hot cylinder or advanced sparking. (If sparking gear is advanced it must be put back before restarting.)

Lubrication. This should be sufficient but not excessive. Over-lubrication of cylinder causes smoky exhaust.

Cooling Water. A large engine will have to have radiator and circulating pipes feeding cool water to jackets around cylinders. Small motors have gills cast on to outside of cylinders. In aëroplanes the air-current will help to cool cylinders, especially if latter are exposed. Stop directly cylinders become overheated.

Mechanism. If any part of the engine or gearing rattles or sticks it should be *at once* examined, lubricated, and adjusted. Valves require periodical grinding in, but this should only be done when surfaces are irregularly worn. Valve-springs need careful attention and spares must be carried in case of stiffness or fracture.

For lightness all parts should be hollow, if possible, as, bulk for bulk, hollow rods, shafts, etc., are much stronger.

The propeller-shaft should bear with one or more collars in a thrust-block before reaching the engine, and should be supported at fairly close intervals to prevent vibration.

The Propeller.

It is well known that a screw propeller is similar in principle to the solid screw used in mechanism and for fixing.

When a screw is used for moving a piece (as in the leading screws of lathes and plane tables) the piece moves by the distance from centre to centre of the same thread ("pitch") for one revolution of the screw. Fixing-screws advance by the same distance for one revolution.

A screw-propeller consists of a surface or surfaces which form part of a screw, and either the fluid is displaced backward from the revolving screw or the screw moves forward from the fluid. The speed at which the motion takes place would in a solid screw be, advance (ft. per sec.) = pitch in ft. × revs. per sec., but generally the actual advance in the fluid is less. Supposing the fluid to be still as regards the earth, the screw tends to get this given velocity backward or forward according to the direction of the pitch and revolution; but since it cannot move faster than the vessel it is attached to it as it were slips backward, the value,

$$\frac{(\text{Pitch} \times \text{revs.}) - \text{speed of vessel}}{(\text{Pitch} \times \text{revs.})}$$

being called the "slip ratio." The screw works more efficiently as the slip ratio is less up to a certain limit. In marine practice this limit is about 12 per cent.

The parts of the screw act in the same manner as a small aëroplane pushing backward and tangentially to the direction of rotation. The backward effect is balanced against the resistance of the machine and its forward acceleration. The tangential effect is balanced against the twisting moment in the shaft. Taking, as before, the efficiency of the propeller as 50 per cent., we can arrive at a notion of the pitch and revolutions from the following rule:

Thrust × velocity of advance = work done on vessel,

i.e.,

$$\frac{\text{Thrust in lbs.} \times \text{velocity of advance (feet per second)}}{550} = \tfrac{1}{2}\ \text{B.H.P.}$$

The velocity of advance = speed of ship = (pitch in ft. × rev. per sec.) − (slip in ft. per sec.)

By assuming a slip ratio it is thus possible to find the revolutions or pitch required, thus:

Speed of ship + slip ratio (speed of ship) = pitch in ft. × revs. per second.

Thus, if slip ratio is taken at 20%, and speed of vessel 66 ft. per second (45 miles an hour),

$66 + \frac{1}{5}(66) =$ say $79 =$ pitch × revs. per sec.

If revolutions are 10 per sec. (600 per minute), this gives a pitch of about 8 feet. From 600 to 1500 is common.

It is a common practice to make the pitch and diameter of the propeller equal to one another.

As regards the form of propeller, since the centre of a rotating mass is only moving with a small velocity, it is best to have blades which do not reach to the centre.

Fan-shaped blades seem to give the best practical results, and it is fairly easy to compute the turning effect required to drive a propeller of this type, as follows:

Turning effect (lbs. feet) = area of one blade (sq. feet) × mean radius of blade (feet) × .002 × sine^2 of mean pitch angle × velocity^2 (ft. per sec.) × number of blades × 2.5.

The pitch angle is found as follows:

$$\text{tangent of pitch angle} = \frac{\text{pitch}}{\frac{22}{7} \times \text{mean diameter of propeller}}$$

(If blades are short it is sufficient to take twice the distance from the centre of the blade to the centre of the shaft.)

The velocity (ft. per sec.) of the blade $= 2 \times \frac{22}{7} \times$ mean radius (feet) × revs. per sec.

Three or four-bladed propellers are in

general preferable to two-bladed. With the latter there is a very considerable vibration. More blades than four should not be used on account of the forward resistance. Complete screw surfaces are not of any use for driving purposes.

Screws may be placed in front ("tractors") if desired, but they interrupt the supply of air to the planes.

On account of the constructional difficulty of fixing a single rear screw to a monoplane, that type of machine usually has a tractor, but biplanes almost always employ propellers.

Lifting-screws will be referred to in the last chapter.

SIMPLE RULES.

Maximum thrust per H.P. =

$$\frac{350}{\text{velocity of machine (f.p.s.)}} \text{ pounds.}$$

Maximum thrust of propeller =

$$0.0012 \times \underset{\text{(ft.)}}{\text{diameter}^2} \times \underset{\text{(ft.)}}{\text{pitch}} \times \text{revs. per sec.} \times \text{slip velocity}$$

CHAPTER V.

BALANCING.

The principle on which balances depend has already been given. It is frequently expressed as "The turning moment about the centre of gravity must be zero."

In order to assure the permanence of this condition it is necessary to know the effect of arranging planes in various manners. In the first chapter it was mentioned that the centre of pressure (i.e., the point at which we may regard the whole air pressure as acting) is not central but nearer to the windward edge. The exact position depends on two things, one constant and one variable, viz., the shape of the plane and the angle of inclination between the plane and the air-stream. For square planes we have Joëssel's law: The centre of pressure is distant from the centre of area 0.3 — (0.3 sin θ) times the width of plane in direction of motion. For narrow planes not greatly inclined the distance is less than this, and for broad ones it is more. If we attach the plane to the frame at the centre of pressure there is of course no turning moment on the plane itself until it alters its angle with the air-stream. If the natural direction of the air-stream or the inclination of the plane decreases in elevation, the centre of pressure goes forward and the plane tends to be tilted backward. If there are planes fore and aft the centre of gravity of the machine, the net turning effect is the sum of the total pressures on each multiplied by the distance of the centre of pressure from the place of suspension. In order to neutralize this some resisting moment must be applied. If we have a small plane or box kite fore or aft the machine to which the air has easy access, by tilting this forward or backward such a moment can be obtained, the moment being the product of the pressure on the said small plane multiplied by the least distance between the line of direction of such pressure and the centre of gravity of the machine. This is the means most commonly employed.*

The same plane may be used for upward or downward steering, although this object would be much more steadily obtained by rotating the main planes. Other means of balancing available are:

(1) *The jockey weight.* A heavy weight slides fore or aft by levers or screws, producing a turning moment about the centre of gravity.

(2) *The gyrostat.* This appliance consists of one or more fly-wheels of fairly considerable inertia, which are rotated very rapidly by a small electric motor. When the vessel tends to incline there is a resistance set up by the mo-

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* On curved surfaces the c.p. varies in the reverse manner with the angle unless the convexity is towards the wind, so that a tail is necessary to obtain stability.

mentum of the fly-wheels (whose angular momentum would thereby be changed) and their spindles tend to swing round (this motion is called "precession"). The motion of the spindles can be employed to operate steering-planes, or by an ingenious arrangement of friction-rollers invented by Mr. Brennan of torpedo fame is accelerated, the result being a righting moment which by using a sufficiently high velocity can meet all emergencies. This method is certainly the most automatic and reliable possible, its only present disadvantage being weight, i.e., for aëroplanes as now made.

(3) *The pendulum.* The deviation of the plane may cause a pendulum to have motion relative to the framework, this motion being employed to operate (with or without relay motors) steering-planes or screws to produce righting. Its disadvantage lies in the time which will elapse before the planes or screws come into action.

In connection with balancing it has to be noticed that there are six directions in which the machine may move or, as it is technically spoken of, three out the six possible degrees of freedom:

a. Vertical rotation:
Forward up = backward down.
Backward up = forward down.

b. Horizontal rotation:
Forward left = backward right.
Backward left = forward right.

c. Horizontal motion:
Forward.
(Backward.)

d. Transverse rotation, vertical and lateral motion are not usually desirable and should only be producible indirectly.

Each of these should be, of course, under control.

Vertical rotation is dealt with above.

Horizontal rotation, which may be required to steer the machine or to resist lateral air pressure, can be produced in three ways:

(1) By a rudder or vertical steering-plane which can be rotated.

(2) By a box kite which can be rotated about a vertical axis. This is often the same kite as is used for vertical rotation. Compare Santos-Dumont's machine.

(3) By twisting one of the planes so that the backward edge goes upward on one side of the centre and downward on the other. This is done by Mr. Roe in his "avroplane" and in the Wright machine.

Horizontal motion is of course controlled by the speed of the propeller. By inclining the main planes upward or downward the speed may be decreased or increased, but this will also cause ascent or (if the flattening be sufficient or the existing speed small) descent.

This is generally achieved by steering surfaces or by shifting the weight, for constructional reasons.

The thrust from the propeller will also be a source of disturbance if the shaft be not placed in the correct position. If the planes balance one another about the centre of gravity the propeller-thrust should pass through the centre of gravity. In some cases the propeller is used to assist the balance of the planes, but since it may not always be used (as in gliding), and certainly will not produce a constant thrust, this does not seem desirable.

If the aëronaut is able to move about in the car this will also lead to alteration of the balance. Thus a man weighing 150 pounds moving backward only two feet produces a turning moment of 300 pounds-feet.

Lateral wind will of course tend to carry the machine with it. The inertia of the machine will at first resist this force, and the smaller the area presented laterally the less will be the disturbing force. This can be imagined perhaps better if we say that the plane will cut into the air-stream obliquely with little effort if its area in the direction of motion be small. Some steering, however, will be necessary if a constant direction *relative to the earth* is desired, the steering plane serving as sail to a yacht. The latter analogy must, however, not be pushed too far, since the resistance of a yacht in water to the force of the wind entirely alters the condition of things. Relatively the steering in the air will require much more effort, since the air is the medium as well as the agent of motion. As regards the mechanism for controlling the planes, wires passing over small pulleys and operated from small levers or hand wheels give the lightest arrangement. Possibly with larger machines levers with notched sectors and spring catches will be used.

In cases where it may not be possible to use tension wires, strut-levers may be built with small rods trussed on four sides with a central cross of rods from the apices of which guy-wires are stretched to the ends of the main rod. Some means of tightening all such wires is indispensable.

If the jockey-weight method is used I should recommend that a deep pitched leading be used on which the weight will run easily between guides, the screws being rotated to either hand by a step-up gear, so that the weight can be rapidly brought into position.

Inventors using the gyrostat would do well to adopt Mr. Brennan's method in toto. Doubtless a specially light form could easily be designed for airships.

SIMPLE RULES.

1. Length of tail must exceed

$$\frac{\text{width of main surfaces}}{4} \times \frac{\text{area of main surfaces}}{\text{area of tail}}.$$

2. Angle of oscillation must not exceed angle of attack.
3. Moment of inertia (*i.e.*, mass × square of distance from centre of gravity) must be a minimum.

CHAPTER VI.

CONSTRUCTION.

The method adopted for the construction of an aëroplane will of course intimately depend on the type of machine and the proportions adopted. Many successful machines have been arranged with two pairs of transverse planes (with or without cell partitions, as in the Hargrave box-kite). Each pair is framed with rectangular panels, the two pairs being connected with a longitudinal frame or girder.

This type seems to have been first developed by Mr. Chanute, and therefore termed the "Chanute biplane." The following sketch and dimensions of the frame of the old Farman machine will indicate the general proportions:

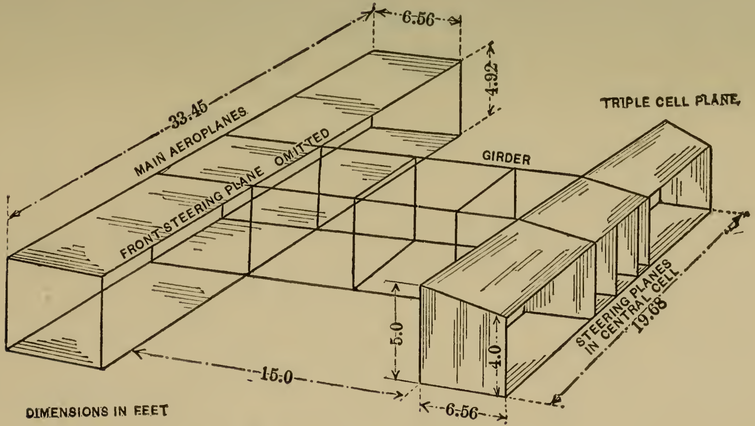


Fig. 4. Diagram of the old Farman Aëroplane

The frames are at present generally constructed of timber or stout bamboo, but steel tube is used in some cases.

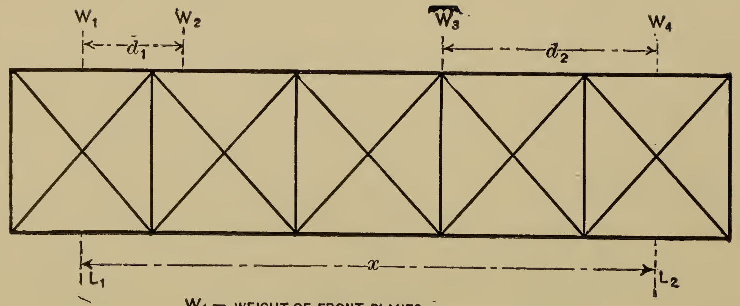
In considering the strength of the frame we have three main parts:

(1) Longitudinal girder, sometimes triangular and sometimes rectangular.

(2) The fore girder, rectangular in section.

(3) The aft girder, rectangular in section.

The latter is generally smaller than the fore girder. To find the forces acting in the parts of the frame we calculate on the same principles as in bridge construction. Taking the longitudinal girder, we have the following arrangement:



W_1 = WEIGHT OF FRONT PLANES
W_2 = " " AERONAUT
W_3 = " " MOTOR
W_4 = " " REAR PLANES

L_1 FORE LIFT
L_2 AFT LIFT

$$W_1 + W_2 + W_3 + W_4 = L_1 + L_2$$

Fig. 5. Longitudinal Girder

We can for finding strength neglect the weight of the longitudinal girder.

The greatest bending moment will be either

$$\left\{(L_1 - w_1) \times (x - d_2)\right\} - \left\{w_2 \times [x - (d_1 + d_2)]\right\}$$

or

$$\left\{(L_2 - w_4) \times (x - d_1)\right\} - \left\{w_3 \times [x - (d_1 + d_2)]\right\}$$

Use feet and pounds for measurements, and the result will be in foot-pounds turning or "bending moment."

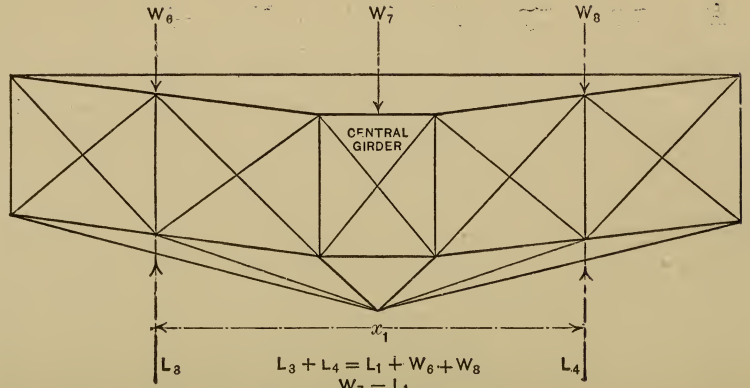
The resisting moment of the frame will be as follows (rectangular frame):

2 × pull or push in one bar (lbs.) × depth of frame (feet) = bending moment.

Using the greatest bending moment, we have then:

$$\text{Greatest}\left\{\begin{matrix}\text{pull in bottom bars}\\ \text{or, push in top bars}\end{matrix}\right\} = \frac{\text{greatest bending moment}}{2 \times \text{depth of frame}}.$$

If the frame is triangular,



$$L_3 + L_4 = L_1 + W_6 + W_8$$
$$W_7 = L_1$$

W_6 = WEIGHT OF LEFT PLANES
W_8 = WEIGHT OF RIGHT PLANES
L_3 = LIFT OF LEFT PLANES
L_4 = LIFT OF RIGHT PLANES

Fig. 6. Transverse Girder

(Push in top bar × $\frac{2}{3}$ depth) + 2 (pull in each bottom bar × $\frac{1}{3}$ depth) = bending moment.

This leads to the following simple rule:

$$\left.\begin{array}{l}\text{Pull or push}\\ \quad\text{in rods}\end{array}\right\} = \frac{3 \times \text{bending moment}}{4 \times \text{depth}}.$$

For the transverse frame we have:

Greatest bending moment =

$$(L_3 - W_6) \times \frac{x}{2}, \text{ or } (L_4 - W_8) \times \frac{x}{2}.$$

The monoplane type of machine devised by Professor Langley is also adopted by some experimenters, but not with surfaces in tandem as he had them. In this there is a central girder, and the transverse planes (which are not superposed in pairs) have framings which are jointed with tee-pieces into the central shaft. The frames are stiffened by cross-struts and stay-wires fixed to the ends like the trussed beams used in travelling cranes. Steel is preferable for this type of frame. Aluminum is of no great advantage, as strength for strength it is very little lighter, and much more expensive and difficult to procure.

As regards the joints of framework it is perhaps best to have specially cast junction-pieces, although for small experiments Messrs. Voisin (the builders of Mr. Farman's aëroplane) recommend pieces of sheet metal cut into an "H" form which will fold over and join three pieces meeting at right angles. Lashed connections should only be temporary.

Mr. Walker recommends the use of an alloy of aluminum, copper, and zinc (Al. 6%, Cu. 60%, Zn. 30%), which he says has a tensile strength of 8500 pounds per square inch.

All planes or other parts not framed should be stayed or stiffened to the main framing. Planes which are to be revolvable should have a main rib passing through the usual centre of *pressure,* sheathed with metal at the point of crossing the frame and passing through trunnions. Rotation should be produced by wires attached to the plane at some point distant from the main rib, the said wires being balanced by compensating weights or wires, so that the plane can be turned in either direction without any wire slackening. A screw gearing can be used.

The motor should be placed within the longitudinal girder, the transverse frames of which will carry the thrust-block and bearings of the propeller-shaft.

The petrol tank can be carried at the top bars of the longitudinal girder, so as to have a gravity feed to the carbureter, which should be attached to the motor-casing or some part of the framing adjacent thereto. The space about the motor should be as clear as possible.

The aviator's seat is generally toward the front of the vehicle, and should be so arranged that, while access and egress are easy, it is possible for him to enclose himself so as not to be thrown out in any position of the aëroplane, but there is some danger in having the motor at his rear.

There must be easy control from the aëronaut's seat of the following devices:

1. Wheel for rotating rising plane for ascent or descent.

2. Lever or wheel for rotating or twisting steering-plane.

3. Lever operating friction-clutch on propeller-shaft.

4. Lever operating brake on propeller-shaft.

(The two latter will not be required on a small machine.)

5. Throttling lever.

6. Lever controlling air-feed to carbureter.

7. Lever advancing spark.

8. Switch for ignition.

9. Wheel or lever controlling balance weight.

It is obvious that in larger machines these will have to be divided between two pilots, but at present all have to be operated by one man. On this point there are some remarks in the following chapter.

It is necessary to have wheels for starting and springs to take the shock of impact with the ground at descent.

Small rubber-tired wheels (about 9 inches or 12 inches diameter) are used at present, the spindles sliding in a square axle-box between horn plates. Providing the plane descends squarely, these will take the shock. At present nothing can be definitely said as to the best way of fitting springs to the framing. The aggregate stiffness of the springs should at least equal twice the weight, or the springs will be liable to fracture.

The framing should be constructed with large curved runners or skids to protect the planes when landing.

Every rectangular bay of framing should be cross-braced with diagonal wires, such wires being fitted with adjustable coupling-nuts. The longitudinal girder should also be well stiffened and cross-braced, as it has to transmit the thrust and also withstand shearing forces from the loads and plane-reaction.

As to the construction of the propellers, simple fan-bladed screws can be made, with two straight rods for each blade adjusted so as to give the correct pitch-angle at the different points in the length, the outer ends having the fabric (generally silk, but sheet aluminum may be used) stretched across to form the blade, but properly shaped wooden and steel blades are preferable.

Professor Pettigrew has recommended a flexible propeller, which could be made with a rib of telescopically jointed tube, winding to give the correct bevel, transverse ribs being tee-jointed to it. Over the latter and to the main rib the blades could be fixed with eyelets and clips or rivets. It is very essential that the propeller frame should be sufficiently strong, as a serious accident might result from a broken blade flying off.

If curved planes are used the framing should of course be curved to fit, with guy-wires stretched across the chord of the curve if necessary.

CHAPTER VII.

DIFFICULTIES.

Although in the previous chapters the subject has seemed fairly straightforward, yet it must not be overlooked that there are many points which are not thoroughly understood. Rule-of-thumb methods prevail in this as in all other subjects, and such methods are not always reliable.

Some of the critical difficulties are the following:

1. Gustiness of wind.
2. Rapid change of balance.
3. Simultaneous manipulation of planes, balancing, and propulsion gear.
4. Descent.
5. Ascent.
6. Change of speed.
7. Lateral motion against air-current.

1. *The Gustiness of Wind* has received attention at the hands of several eminent scientists, particularly the late Professor Langley. In his work the "Internal Work of the Wind" he has given the results of a large number of experiments made with very delicate and continuously recording anemometers. These results show that the variations in the wind pressure are much greater than is commonly supposed. The Forth Bridge anemometer records also indicate this fact, and Lord Rayleigh has shown how this variation is probably utilized by birds in economizing muscular power. As far as aëroplanes are concerned there is no apparent means by which they could respond to the fluctuations in pressure so as to do this, but they will tend to oscillate.

This oscillation will, if the natural period of vibration of the machine about its centre of gravity be about the same as the period of the gust, increase and terminate in collapse. Professor Bryan, assisted by Mr. Williams, B.Sc., has made a number of experiments with simple planes gliding, and finds that there are two kinds of oscillation, one of short period and one of long period, but these results may not exactly apply to a large complex and weighty aëroplane.

The periodic time increases as the square root of the weight and as the distance of any part of the weight from the centre of gravity. It decreases as the square root of the turning moment which is righting the machine.

2. *Rapid Righting of Balance.*—If the aëroplane is subject to a sudden turning moment by a gust or motion of a weight in the vehicle, it would of course be desirable to be able to immediately supply an equal and opposite moment to maintain balance. This is not, however, generally possible, since the means employed for balancing are of such a kind that a large turning moment needs a little time to develop. While this is

increasing, the excess from the deviating moment will give kinetic energy to the vehicle and so it will heel over to a greater degree than would occur if the moment was balanced at once. When this point has been reached the righting moment should be more than the deviating moment and the vessel will swing back. This oscillation will continue until the damping action of the air on the planes extinguishes it. It will be obvious from this that it is desirable to bring the righting moment into action as soon as possible, whether planes or jockey-weights are used, particularly as in most cases there are limits beyond which the righting moments decrease.

3. *Simultaneous Operation of Balance, Steering and Propulsion.*—Referring back to the chapter on construction it will be observed how many different levers, wheels, etc., need attention. In cases of emergency this will undoubtedly lead to trouble, and as far as possible the system should be simplified. Thus the

steering-gear can be reduced to one wheel if the shaft is pivoted close to the pulley or lever rotated by the wheel. The rotation of the wheel can then operate the balance-plane (for motion vertically up or down), and the motion of the wheel-shaft used as a lever can be employed to operate the steering-planes.

If a jockey-weight is used, a single wheel with bevel gearing driving the leading-screw (which must be of deep pitch) should be used, with free motion in either direction.

Steering (or even balancing) may be assisted in a small machine by the aëronaut leaning to either side or forward (providing, of course, his accommodations will allow him to do so).

The propelling machinery needs considerable attention. After switching on the ignition and opening the throttle the motor is started and will need to be controlled by varying the throttle of the air-supply. Should the motor stop, the balance-plane should be rotated until inclined slightly downward in front, when the plane will glide downward. It will be preferable to slope all the planes slightly downward for free gliding.

4. *Descent.*—In descending it is necessary that the planes should be so inclined that there is a sufficient vertical component pressure to support the plane and a sufficient resistance in the direction of motion to prevent a very high velocity being maintained.

Theoretically the best arrangement will be for the planes to be inclined at an angle from the horizontal downward in front about one-third the angle of descent from the horizontal. It is very important to notice that the effective angle between the plane and the stream is in this case *not* the angle with the horizontal but the angle with the line of motion.

Descent on to a fairly level surface is of course a *sine qua non,* and springs to take the shock of impact. If there are wheels and the descent is at a flat angle, the shock will be considerably lessened if the vehicle can run along the ground.

5. *Ascent.*—It has already been mentioned that the minimum soaring velocity is obtained with an angle of about 30°. This, however, involves of course a considerable resistance as compared with smaller angles, so that many experimenters, to save power, use a flatter angle. A higher initial velocity is of course required, and the travel of the plane on the ground will be more. It will often be difficult to secure a suitable site for commencing a flight, the only alternatives to a flat run being a long slope or an escarpment. The latter is of course dangerous, since if sufficient velocity is not reached before the machine has reached the base of the escarpment a bad accident will occur. On the whole the level course is far preferable.

The usual practice is to develop speed with planes flat, and when soaring speed for any angle is reached throw up the planes to that angle. Difficulty is generally experienced with the turning moment thus suddenly brought into play, the centre of pressure receding so that the machine tends to dip forward, or if the planes are pointed at a forward position, the machine dips backward. This must of course be corrected by the steering-plane.

6. Acceleration needs a reserve of power and a change of attacking angle so that little seems to have been done in this direction as yet.

7. *Lateral Motion against a Current.*—As already mentioned, this is rather a serious difficulty. Save for its inertia the machine tends to drift with all currents, so that unless there is any means of steering laterally the actual motion (as compared with the earth) will be compounded of its motion through the air and the motion of the air as compared with the earth.

A vertical plane acting like the rudder of a ship will serve to deviate the vessel from this course, but since it depends for its action on the relative motion of the air itself, it will often be far less efficient than the marine rudder, since the latter rarely has to encounter cross-currents of great relative magnitude.

To illustrate this point, let us suppose the machine is proceeding northward relative to the air, which air is at the same time blowing eastward with the same velocity. The machine will then proceed to the northeast (relative to the earth) with a velocity compounded of the said two velocities. If the rudder be now set at an angle of 45° to the axis of the vessel in the manner which would be employed in steering a boat or ship to bring it round to the *north,* after the first response to the helm, owing to the fact that the air-stream is now relatively moving against the rudder from the northwest, it will act very strongly. If, on the other hand, we desire to go farther northeast and rotate the rudder 45° to the left, it will *not* *act at all,* shortly after the vessel responds to the helm.

On this matter it is of course only possible to give general ideas which practical experience must supplement, but sufficient has been said to show that the problems of balancing, steering, and controlling an aërial machine are many and serious.

CHAPTER VIII.

FUTURE DEVELOPMENTS.

The art of prophecy has been so much practiced in connection with aërial navigation that it is scarcely necessary to repeat the oft-recurring description of its possibilities. Personally, I think at first we must not expect very much. Whether it will eventually produce a reconstruction of methods and ideas like that which railways have achieved it is as yet impossible to say. It depends very largely on those practical limitations of aëronautics, which up to the present we have not been able to exactly define.

Regarding the matter from a more optimistic point of view, we can say definitely that mechanical flight has been achieved and doubtless will continue to be in the future, so that the problem now is, In what way can the flying-machine be developed to give a more efficient result? All prototypes are inefficient and clumsy. The "Rocket" compared with a modern express locomotive shows scarcely any resemblance; in fact, the identity is almost one of principle only. So we may expect it to be with aëroplanes.

As regards the size of the aëroplane, by using more power without increase of weight (which of course involves an even lighter type of motor than we at present have) it will be possible to reduce the bearing surface. Probably six or seven pounds per square foot will eventually be carried, the conditions being a larger angle of inclination or a greater speed, either of which is necessarily accompanied by a greater resistance.

As regards balancing I venture to think that a perfectly automatic gyrostatic apparatus must displace all rivals.

Small planes will only need to be used for steering.

There seems more scope for improvement in the form and arrangement of the planes than in anything else at present. The system introduced by Mr. Chanute of a longitudinal girder crossed by two transverse frames supporting the planes is rather fragile when the weight is limited as at present, and the monoplane is even weaker.

Most of the machines at present are a maze of fine stay-wires interlacing one another in all directions to truss the various ribs and frames. It would seem desirable that the joints of the frames should be formed with strong brazed angle-pieces, the stay-wires being dispensed with. The objection to this at present is the weight of the angle-pieces and extra thickness of frame-tubes.

These machines seem particularly weak at the outer ends of the planes. If a plane touches any obstacle when landing there is almost certain destruction of the whole machine. For this reason it seems desirable to reduce the spread of the planes, although of course the surfaces must be kept relatively narrow in the direction of motion. Mr. Chanute designed a tiered machine consisting of several narrow planes above one another, and Mr. Phillips has a very similar arrangement of curved blades fixed in a frame. Developments in this direction seem to be promising.

Further improvements will probably appear in the control of the planes. It is probably desirable that every bearing surface should be revolvable about its axis, as is the case with the wings of birds. This will of course involve the pivoting of each plane frame through its usual centre of pressure, and attachment to the frame of levers or wheels capable of motion relative to the main girder. Toothed sectors operated by pinions would seem to be the best arrangement when the lifting force will allow of the weight involved.* Unless these rotary motions can be automatically controlled, however, this improvement will have to wait until the machines can carry two engineers to look after the mechanism.

As already mentioned, several features necessary in the propelling machinery of ships will be indispensable when the aëroplanes are built for larger loads: clutches, brakes, reversing and change-speed gears, auxiliary machines for starting, and possibly for steering and balancing.

The use of sheet metal (probably aluminum) for the bearing surfaces is not likely to be long delayed. Cochrane's corrugated aluminum seems a good idea, but of course needs to be tried on a large scale.

Various instruments will also be needed when voyages of any length are made, including:

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* This is shown in the diagram which forms the frontispiece, but most machines as yet rely on the action of the steering surfaces.

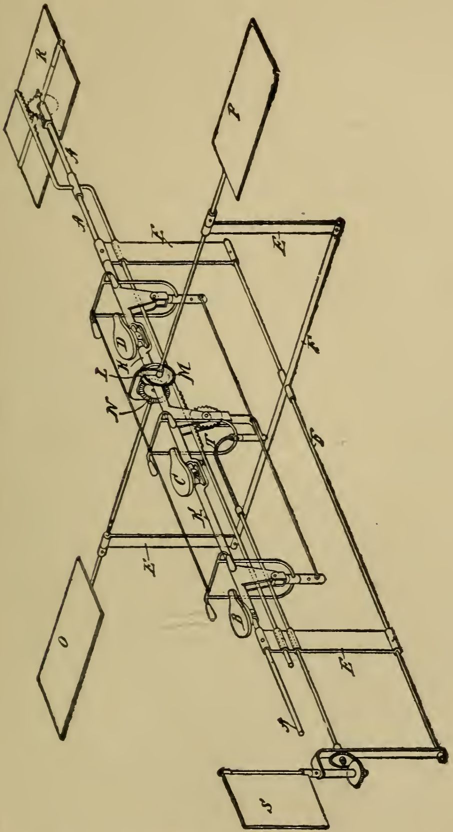

Fig. 7. The Means Control Mechanism

Aneroid barometer. (This will probably be seriously affected by the air-current and disturbance about the planes, but a correction for this may perhaps be found by experiment.)

Thermometer and apparatus for boiling water.

Compass on gimbals.

Sextant or other angle-measuring instrument.

Anemometer to find relative velocity.

Another feature which would be desirable in larger machines would be a casing for the car, of stream-line form, so that the resistance to the air would be minimized as much as possible. This could be constructed of sheet aluminum on a light steel framing. A fish, torpedo, or sinuous form would be preferably adopted, but a cylindrical form with spherical or conoidal ends would be nearly as efficient and more commodious. Transparent lookout panels fore and aft would of course be necessary, as well as openings for access and repairs.

One of the chief disadvantages with the aëroplane is the necessity of a space to commence flight from; and if aërial flight on this system becomes common, special spaces or stages will have to be arranged. The length of these would need to be upward of fifty yards, with no great obstacle at either end, and the width at least half as wide again as the largest machine to be accommodated. A gentle slope would be preferable.

Much has been said for and against the military utility of aëroplanes. That the authorities consider the matter of importance is now certain.

The following applications of aërial flight would seem to be possible:

1. *Reconnoitring.*—An enemy's movements would be discernible from a great height. The speed of the machine and liability to be struck would be the chief disadvantages. Neither of these constitute insuperable difficulties. Observations could be obtained, with allowance for the displacement of the point of

view, and the danger to an aëroplane from artillery is not nearly so great as with a balloon, since moving more rapidly it would be more difficult to hit, and, if hit, unless the machinery is touched, only a small hole would be made in the bearing surfaces.

2. *Despatch work.*—When the machines are thoroughly controllable the aëroplane would give a ready means of quickly crossing a country occupied by hostile troops, or into or from a beleaguered city. For even routine work when speed was essential and the distance great, aëroplanes could also be used.

3. *Bombardment.*—This is the novelist's favorite theme, but is open to many difficulties. The recoil from even light guns (supposing weight can be carried) would seriously affect the stability, and many difficulties would occur in getting the range, since a projectile would have a resultant velocity composed from the velocity of the aëroplane, the initial

velocity from the gun, the gravitationally acquired velocity during the descent, and the motion of the air through which it falls. This may not be an insurmountable difficulty but is certainly a serious one.

Explosives dropped from any aërial machine will be subject to the same difficulties.

4. *Fighting.*—Aëroplanes to attack other aërial vessels (balloons or aëroplanes) have been projected, and the officers of the department dealing with this matter in England are understood to have this idea in view.

Rifles might possibly be used from an aëroplane, although there are many difficulties in connection with marksmanship.

Ramming would almost certainly bring catastrophe to both vessels, and hence would only be permissible in extremis.

Balloons would be able to rise above aëroplanes.

It is rather interesting to note in connection with this subject that Mr. Jane, the inventor of the naval "War Game," has stated that manœuvres of aërial vessels have already been schemed by his system.

5. *Military surveying.*— Topographical work of a rough but effective character could well be performed from aëroplanes, more particularly on account of the increased elevation and range of view.

Other developments in connection with exploration, surveying, meteorology, transit, etc., may be expected.

CHAPTER IX.

COST.

The expense involved in building and experimenting with aëroplanes is undoubtedly a serious item. Both Professor Langley and Sir Hiram Maxim spent many thousands of dollars and after all failed to construct entirely satisfactory machines. Their work has, however, cheapened the work of their successors. A small man-carrying machine may now be built for less than the cost of a motor-car.

The main item is of course the motor. The cost of this is roughly $50 per H.P. when the power is above 20 H.P. and less than 80 H.P. For economy it is of course best to have small power, but this involves a lack of control and a high initial speed, both of which are objectionable.

If we classify the parts in the following manner we can get a general idea of the cost:

Say 1 H.P. lifts 16 lbs. (angle about 12°, speed 35 ft. per sec.).
Power plant, x H.P. wt. $6x$ lbs.
$\$(x) \times (30)$
Framing, say $5x$ lbs. say $8x$
Surface, say 750 sq. ft.
Load (pilot, etc.), say $6x$ lbs.

Thus an aëroplane taking 50 H.P. will weigh and cost as follows:

	Weight.	Cost.
Power plant, 50 H.P.	300 lbs.	$1500
Framing,	250 lbs.	400
Surface, 750 sq. ft.	50 lbs.	50
Load	300 lbs.	$1950

Total, 900 lbs.

Labor would probably work out at $200, making in all $2150.

Again, take a lower power:

1 H.P. lifts 50 lbs (angle 7°, speed 45 ft. per sec.).

		Cost.
Power Plant, 10 H.P.,	wt. $10x = 100$ lbs.	$30x =$ $300
Framing,	wt. $10x = 100$ lbs.	$10x =$ 100
Surface, say, 200 sq. ft.,	15 lbs.	15
Load (aëronaut)	150 lbs.	
	Total wt. $50x = 375$ lbs.	$415
	Labor at about	200
		$625

Note the proportions are different in this case. It will be obvious from this that the cost of a man-carrying machine will vary from about $300 to $4500. I do not think the most enthusiastic and skilled amateur could do much with less than five hundred dollars to spend.

A variety of amusing and instructive experiments may, however, be made with small gliders. These may be constructed of bamboo or cane with cotton fabric for a trifling cost, and can vary in size from that of a child's kite to that of a man-carrying aëroplane.

The larger varieties of say 100 super feet and upward bearing surface can be tried on a slope, when if the slope is long enough or there is a favorable wind up the slope a man will be able to soar through the air some distance. Even comparatively great heights can be obtained in this way, but the experiment carried to this extent is dangerous. Otto Lilienthal and Percy Pilcher both lost their lives in practising soaring, even though both men had much previous experience. A glide near the ground is, however, quite safe.

Generally speaking, no true motor at present known is light and powerful enough to drive small aëroplanes. Bands of rubber fixed at one end to the frame and at the other end to a propeller boss, and twisted many times by revolving the propeller-shaft, will store sufficient energy to drive a plane several hundred feet. Special clockwork springs, if made extra heavy and fully wound, will carry a well-designed model a short distance, but on account of the reducing gear necessary are generally too heavy.

Rubber will safely store about 100 inch-pounds per cubic inch.

Hardened steel springs will store about 10 inch-pounds per cubic inch.

Some useful information concerning the construction of kites is given in Mr. Fred Walker's little book on "Kites" (Simpkin, Marshall & Co.).

As to the cost of upkeep of an aëroplane, particulars are of course not yet available, but considerable information can be obtained by comparing the cost of motor-cars, excluding tire repairs. Particulars of this are given in most of the motoring journals from time to time. The cost per H.P. is the essential item.

Generally the cost of a machine per unit time is of the following form:

$$(\text{Constant} \times \text{H.P.}) + \text{constant}.$$

The first constant includes consumption of fuel, lubricant, etc. The second includes depreciation, repairs, and accessories.

CHAPTER X.

OTHER TYPES.

So much has been said about the aëroplane that the possible importance of other types has been to a great extent overlooked. Many men who are considered experts have pronounced in favor of the helicoptere, and still more have pinned their faith on the birdlike machine, or ornithoptere.

Before dogmatizing on the subject a very careful consideration of the pros and cons is necessary.

Let us take the *ornithoptere* first. Its disadvantages are:

1. Complexity of mechanism.
2. Downthrust on the back stroke of the wings, unless their plane coincides with the direction of relative motion.
3. Balancing difficulties.
4. Paucity of thrust at low speeds.

5. Periodic variation in the lift and thrust, which reduces the average value of both and may tend to cause oscillation.

It is only recently that the flight of birds has been at all well understood, and its success is now seen to depend on a far closer correspondence to environment than was previously suspected. Professor Marey has shown by photography and electrical apparatus that, during one up-and-down beat of the wing, the wing is twisted from an upward slope (at commencement of downstroke) to a downward slope (at end of downstroke) and again to an upward slope during the upstroke (the slope increasing to a maximum at the middle of the upstroke). The wing is only horizontal near the lowest point of the stroke.

There are thus the following motions of the wing planes during one period:

1. Forward motion with body.

2. Revolution of tip of wing in a roughly circular path (i.e., as compared

with the body, or cycloidal as compared with the air).

3. Torsion of the wing plane, amounting to about 60° on the downstroke and 45° on the upstroke. The upstroke is generally performed in less time than the downstroke, and is more nearly vertical than the downstroke.

The period of one complete up-and-down stroke varies from 350 to 9 in insects, and from 13 to 3 (per second) in birds.

The area of the wings varies from 50 sq. ft. per pound (gnat) to $\frac{1}{2}$ sq. ft. per pound (Australian crane). The heavier the bird the smaller are the wings and *generally the better does it fly.*

Professor Pettigrew was firmly of opinion that the efficiency of bird and insect flight depended very largely on elasticity of the wing. He also showed that the body rises during the downstroke and falls during the upstroke, and that the wings are twisted into a screwlike form during the stroke.

Yet another important point is that all flying animals are provided with a universal joint between the wing and the body, the wings being attached just near the centre of gravity of the body, the balance being maintained by the alteration of the body and head and by the rudderlike action of the tail plane.

From a mechanical point of view it is evident that the wings act in just the manner of an aëroplane, the action being, however, complicated by the reciprocating motion. During the downstroke there is lifting and propulsion, and during the upstroke probably no dynamic action. The air-currents induced seem to be very intricate in character, and it is also practically certain that birds habitually employ the periodic variations in the wind velocity to diminish the muscular effort.

Many machines have been constructed which profess to imitate bird flight, and there are inventors who claim to have made successful flights with such machines. Whether they have done so or not I cannot say, but in any case the mechanism will need to be of great complexity and consequent uncertainty as compared with the simple aëroplane.

The advantages of the ornithoptere are as follows:

1. Flight from rest without preliminary surface glide.

2. More independence in regard to variations of the air-currents.

3. Propulsion without propellers.

The Helicoptere.—Admirers of Jules Verne and George Griffiths will be familiar with the vertical-screw machines by which (on paper) those novelists have "conquered the air."

As a matter of fact the vertical-screw machine has been regarded by many students of flight as extremely promising. Sir G. Cayley, Penaud, and more recently Kress, Breguet, and others, have made many experiments. The advantages are as follow:

1. Direct lift from rest.

2. Lift independent of horizontal velocity.

3. Less exposed surface and consequent better dirigibility.

4. Balance obtained by differential motion of screws.

The disadvantages are:

1. Absolute dependence on motors. Breakdown means catastrophe.

2. Separate motors required for driving and lifting.

3. Smaller mechanical efficiency of screw as compared with aëroplane.

4. Greater strength, and consequently weight, of framing.

5. Greater thrust required.

It has been suggested that a combination of the aëroplane and helicoptere would get over the first difficulty, but this would accentuate the remaining three objections.

Edison made some experiments on lifting-screws, with unsatisfactory results, but more recent work by Walker, Kress, and Breguet have shown that lifts amounting to from 10 to as much as 40 lbs. per H.P. are possible (85 lbs. is claimed in one case but the figure is doubtful), so that there can be no great mechanical difficulty in constructing machines which will lift themselves. So long, however, as we have petrol motors which will stop upon (comparatively) slight provocation this form will not be safe.

As to the form of propeller, if the lifting speed is not to be great, I am of opinion that types somewhat resembling ventilating-fans would be preferable. By the courtesy of Mr. Hattersley Pickard, of Leeds, I have had some particulars of a fan which seems to give very good results (50 or 60% efficiency). The blades are turned axially at the tips so as to limit the escape of air by centrifugal force, and at the centre a torpedo-shaped boss fills the space which otherwise would be filled with inert air. The pitch must be very fine so that the pitch angle does not exceed 6° at the tip of the blades.

In a previous chapter I have given rules for calculating the thrust from a propeller. This same thrust will serve as lifting force. The aggregate lift for all the propellers used must of course always exceed the weight carried.

For purpose of balance four vertically acting screws at least are necessary (paired laterally and longitudinally). Any multiple of two (more than four can be used), but, generally speaking, four propellers of the same total effective area as six or eight others will give better results.

In this type of machine it is desirable to encase the whole car in a stream-line form (torpedo, cigar, or hull-shape) to minimize the horizontal resistance. This can be of sheet aluminum.

It also seems desirable to surround the propellers with light casings to form tunnels for access and egress of air. These must clear the tips of the blades by a good distance (say the radius of the fan), or there will be loss by friction.

The car in this type of machine will need lateral and longitudinal frames (these should be continuous), as in a ship. Thrust-blocks will be needed for each of the lifting and tractive propellers. As regards the latter they may be fore or aft, or both.

Rudders will be necessary, and vertical steering can be controlled by planes capable of rotation about a horizontal axis or by varying the speed of the lifting-screws. If a large lifting speed is desired, the lifting-screws must be of the open type, not the ventilating type.

We have now scanned practically the whole field of aërial navigation (excluding balloons), and a few words as to further sources of information will perhaps be useful.

It may be said that a student of this subject needs to give attention to the following branches of science:

1. Meteorology.

2. Thermodynamics.
3. Hydraulics (of compressible fluids).
4. General applied mechanics of machines and structures.
5. Practical construction.

It is very surprising how wide an area of knowledge aëronautics touches. Almost every branch of physical science must give its quota, and when all is done the information obtained is barely sufficient.

The literature of the subject is now fairly extensive. There are works in English, French, German, Italian, and Russian dealing with it. The beginner cannot have a better book to start with than the late Professor Langley's "Experiments in Aërodynamics" (2d edition), published at Washington by the Smithsonian Institution. It is *the* classic work, *not* on flying-machines but on the mechanics of the atmospheric conditions concerned in flight.

As regards bird flight, Professor Marey's "Animal Mechanism" (International Science Series, Kegan Paul, London) is excellent, but does not deal with the mathematical question. The articles "Aëronautics" and "Flight" in the "Encyclopædia Britannica," Edition IX, are good, and there are some good illustrations in the "Harmsworth Encyclopædia" (article "Flight"). Herr Moedebeck's "Pocket Book of Aëronautics" (Whittaker, London) contains much information, and possibly my own "Problem of Flight" (Griffin & Co., London) may prove of use. Mr. Lanchester's recent volumes contain some very important matter.

As regards construction and design of frames, engines, etc., any of the textbooks on "Applied Mechanics" (Perry, Goodman, or Cotterill) will be of service.

Important original papers are:

1. Lord Rayleigh, "The Mechanical Principles of Flight," Memoirs of the Manchester Lit. and Philosoph. Soc., 1899. One shilling.

2. Proceeding of the Aëronautical So-

ciety of Great Britain, published in the "Aëronautical Journal," quarterly. One shilling.

3. Transactions of the Institute of Naval Architects (paper on Propellers, Resistance, etc.) and the Transactions of the Royal Meteorological Society (papers on Resistance of Air, etc.).

4. Professor Langley, "The Internal Work of the Wind," Smithsonian Institution, Washington.

The next few years will doubtless see the adoption of aërial navigation among the regular means of locomotion, and its sociological effect cannot be predicted safely. There is no doubt by now that it has come to stay, and that it cannot be neglected by any man, and especially the engineer, who has an eye to the future. Many well known and learned scientists are now dealing with the subject. To mention the names of Lord Rayleigh, perhaps the most brilliant mathematician living, Professor Hele-Shaw, Professor W. H. Dines, Professor

Bryan, Major Baden Powell, Colonel Templer, and Colonel Capper, will be sufficient to show that the constructor of a flying-machine need no longer be a "crank."

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