HOW TO BUILD AN AEROPLANE

ROBERT PETIT

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BY

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Preface

Books on the subject of aeronautics are numerous, but, with few exceptions, they have neglected the technical aspects of the subject, and none, as yet, have dealt with actual aeroplane construction. The present work, however, treats this question fully for the first time. M. Petit is an eminent French engineer who, during the past few years, has made a personal study of the methods of construction adopted by the great French firms. It is universally recognised that France, at the present time, has no rival in aeroplane building, and in this book the experience gained from close association with the best methods of what is now a large and flourishing industry is set out in simple language. Designers of British aeroplanes, it is true, will probably follow their own ideas in construction, but a great deal is to be gained from a general knowledge of the methods adopted by constructors in other countries as the result of long experience and patient experiment. The following pages, from this standpoint, undoubtedly provide a full review of a new department of engineering, whose growing importance it is difficult to overestimate.

Already great strides have been made in the industry by British firms, and Great Britain is evidently about to regain her lost lead in aviation. It is hoped that this book may contribute in some small measure to the desired end.

T. O'B. HUBBARD
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[*The translators desire to express their indebtedness to Mr F. Handley Page for the elucidation of several difficult points.*]

Author's Introduction

ONLY yesterday aviation was born ; to-day it has already called into being a vast representative industry whose future is definitely assured. Two years have passed since that great day when we stood on the manœuvring ground of Issy-les-Moulineaux, waiting anxiously to see the Voisin aeroplane, piloted by Farman, rise and fly. Although the flights of previous days had made us confident, our expectation was not unmingled with quiet scepticism. For at this period, which has already passed into the realms of history, one could not implicitly rely on the proper working of the motor, and severe criticism had been launched against the design of the aeroplane itself. Farman flew a kilometre and returned to his starting-point. Aviation had taken its first step ; aviation was established. Since then we have seen Blériot flying in his monoplane across the water from Calais to Dover. In the presence of these exploits, one's thoughts travel back with pleasure to the heroic age of aviation, to the years when a few solitary "madmen," named Voisin, Blériot, and Esnault-Pelterie, sought to free themselves from the fetters of gravity. In those days there was not a single manufacturer of aeroplanes, but those who then sacrificed a dark corner of their workshops to putting together, with the help of one or two of their workmen, a flying machine of their own design, have to-day become aeroplane constructors at the head of vast workshops, turning out new machines every week, with whose performances not even the technical reviews can keep pace.

In this new industry, the same phases are evident that characterised the history of the motor car. The pioneers of aviation have passed for good the stage when the principle of the thing required demonstration. They are now confining their attention to the perfection of the construction and to the lowering of prices.

Many people, even the firmest adherents of the new locomotion, refuse to credit the actual existence of an aeronautical industry, believing rather that aeroplanes are only constructed to order in general engineering or motor works ; they even scout the idea of a separate industry as visionary. Let those doubters pay a visit to the works of Voisin, Blériot, or Esnault-Pelterie,[1] and they will soon realise their mistake. The workshops resound with the murmur of incessant living activity ; lathes and machine-tools, driven by powerful dynamos and motors, hum from morning to evening, splitting, sawing, cutting, shaping and fashioning the special varieties of rare wood brought over from America and Africa. Chips and shavings fly from the pinewood, and the raw material becomes smooth and polished, so that the air may slip easily around it. The workmen move hither and thither under the supervision of skilled engineers. In a corner of the works, near the tall double doors, a framework is set together ; flashing steel wires are drawn taut by wire strainers ; the motor, with its rows of cylinders, is built in ; the sharp blades of the screw are riveted, ready for cutting their way through the fluid air. The aeroplane stands complete.

[1] Or, let us add, to the works of our British constructors.—Eds.

Against the dark background of the workshop it spreads its broad white wings, trembling, longing for flight and space. The doors are opened ; the straining machine emerges into the sunshine. The doors close again ; in the space left vacant workmen are laying down the keel of a fresh aeroplane.

The industry of aviation is a living reality.

In the belief that a description of the construction of an aeroplane in its successive stages would prove interesting, we have sought in the following pages to present the knowledge and experience gained by many extensive visits to the various aeroplane works. In order that the reader may have a complete grasp of the subject, it has been thought advisable to give, in a preliminary chapter, some technical information regarding the theoretical calculations on which the design is founded, such as the determination of the surface required, necessary horsepower, etc. Only fundamental technical principles will be touched upon in this part, so as not to exceed the limits of this work, which is primarily intended to present a general, and above all practical, account of the building of an aeroplane.

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CHAPTER I

GENERAL PRINCIPLES OF AEROPLANE DESIGN—THEORY AND CALCULATION

EVERY calculation relating to aeroplane design is based on the expression of the resistance offered by the air to a surface moving through it under given conditions. For this reason it is impossible to obtain rigorously accurate numerical results. The basis, the starting-point, of every calculation, is in fact a subject on which the most eminent theorists are of divided opinions.

I.—*Resistance of the air to a plane moving through it*

The formula giving the resistance of the air cannot be stated in invariable terms even to-day, and it is this fact which is the cause of so much hesitation on the part of the constructor in calculating the design of an aeroplane.

The uncertainty of this formula should be ascribed to the presence of the famous—or infamous—coefficient K, which has formed the subject of so much controversy. The mysterious figure K assumes the most unexpected values, nor can the law of its variations be determined. We cannot say whether this coefficient hides an unknown law, or whether it has a separate value for each different machine. The solution of this problem has been attempted by many engineers, but hitherto without success. Only recently M. Rateau, an engineer well known for his work on turbines, has undertaken the task of laying down a fresh set of values for aerodynamics, but his researches have not yet reached anything like finality.

Two young engineers, MM. Tariel,[1] published a treatise a short while ago, in which, by applying the principles of mechanics, they prove very clearly that the study of the motion of surfaces through the air may be based on the conception that they press downward in a vertical direction a definite quantity of the fluid. This interesting work cannot as yet be applied to practical purposes, but undoubtedly contains some excellent ideas. In any case, researches of this nature deserve every encouragement.

We will, however, leave this controversy; and in our calculations we will take the resistance of the air as being proportional to the surface, and to the square of the velocity of motion. These laws, which can be easily verified, have never been refuted, and will, in all probability, remain good. We will adopt the value of the coefficient $K = 0.08$ as determined by M. Eiffel as a result of his extensive experiments from the Eiffel Tower. This figure has usually given good results, relatively speaking, and seems to approach nearest to the truth. We can therefore adopt the following formula to express the resistance of the air to a surface moving through it orthogonally, that is, perpendicularly to the direction of motion:

$$R = KSV^2 = 0.08\ SV^2, \tag{1}$$

where S is the surface in square metres and V the velocity in metres per second. The power required to drive a surface in these conditions will, consequently, be equal in kilogrammetre-seconds to $0.08\ SV^2$, or, expressed in horse-power,

$$p = \frac{0.08\ SV^3}{75}\text{HP}.$$

[1] *Études sur les surfaces portantes en aéroplanie* (1909).

This formula shows us the limits within which we must avoid plane surfaces, perpendicular to the direction of movement, in an aeroplane.

But formula (1) only applies to orthogonal motion, which has no interest for the study of sustentation. The only way to sustain a certain weight by means of carrying-surfaces is to place the latter in such a position that the air gives up some of its energy in the course of its flow past the surface. In the case considered above, the impact of the air on the plane is the sole force that produces R; but as the surface is in motion, a certain quantity of air is thrown back in front. But, in order to produce continuous work, it is necessary for the air to *flow away*; it must be met at the forward edge of the surface, led to its rear, and only abandoned when the whole, or the greater part, of its energy has been absorbed. It follows directly from this that the *inclined position* is the only one that can fulfil this condition. In the case of the inclined plane the fluid must not collide with the surface so as to lose its velocity suddenly, and to assume a velocity in the opposite direction. On the contrary, it must preserve a velocity in the same direction as the relative velocity it possessed at first, and must only retain a sufficient part thereof to enable it to *leave the plane without interfering with the following masses of air*. The inclined plane is therefore employed in the aeroplane. Hence it is essential to know the variation of the lift as a function of the angle of incidence. Here, again, opinions unfortunately differ. It is impossible to represent numerically the variations caused by decreasing or increasing the angle of incidence. The most we can say is that an increase in the angle brings about an increase of the resistance R. As in the previous case, therefore, we must employ such formulæ as seem to approximate the most nearly to reality.

Let AB (fig. 1) be a longitudinal section of a surface moving through the air in the direction of the arrow at a velocity V. Although the case can never arise in practice, we will consider the air as arriving beneath the surface and yielding its energy, due to the relative velocity V, in two parts: the first, R_a, resisting forward motion, the second, R_s, producing sustentation. Of these two we need only consider the latter; for since, in practice, the main object aimed at is to decrease the resistance to forward motion, we may, in theory, consider it to have been attained, and

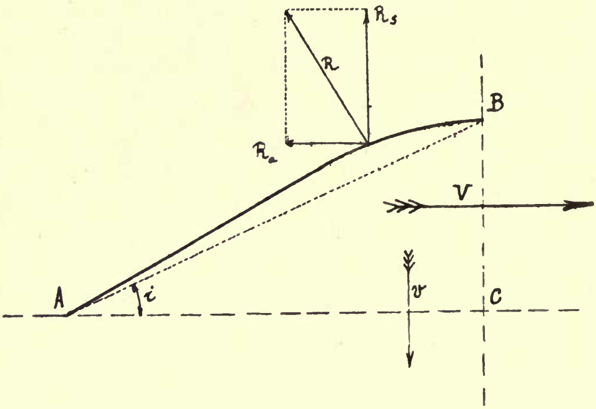

FIG. I.

assume that the sum-total of the energy of the air is utilised for sustentation.

In consequence, the results we shall obtain are theoretical in the full meaning of the word, since they will finally give us the power necessary for sustentation alone.

II.—*Lift of a surface* S *at a velocity* V *meeting the air at an angle of incidence* i

By the *lift* of an aeroplane surface of area S, meeting the air at an angle *i*, with a velocity V, we denote the vertical component of the resistance of the air to the surface. In other words, the lift is the weight that can be lifted by the surface. If we take the velocity as unity, *i.e.* 1 metre per second, and if we give the surface an area of 1 square metre, we shall obtain a lift in terms of unity. We can now work out our forces.

Turning to the preceding figure, *i* denotes the angle of incidence. It has already been stated that we shall consider the air as being pressed downwards. Since this air possesses, initially, relative velocity only in a horizontal direction, it will by its inertia resist this motion imparted to it and will produce sustentation.

Let us now consider a molecule of air at the moment of its striking the under side of the surface at B. It will be impelled in a vertical sense with a certain velocity V during a space of time that will depend on the actual width AB of the surface and will equal $\frac{AC}{V}$ where AC represents the horizontal projection of AB. The molecule forced downwards in this manner will resist this motion by developing a force proportional to its mass and to the vertical velocity which it is given by the surface.

Let v denote the velocity of the motion imparted to the air along BC. If this velocity were constant, the molecule of air would produce no further energy after its contact at B, and we would have the case of an orthogonal translation of AB. But the air must flow from A to B. Consequently, the velocity v must not disappear in spite of the amount of the energy it has given up to the surface. To attain this the air must possess, in addition to v, a uniform vertical acceleration γ, which will give it a continuous value. In this way the molecule will exert against AB a vertical force in an upward direction $m\gamma$ throughout the time that the surface and the air retain similar relative positions. It follows that the most efficient surface will be so shaped that a molecule of air will continue to exert its force throughout the distance from A to B. We shall examine the necessary conditions to be fulfilled in this respect later on when considering curvature.

The relative horizontal velocity of the air being V, a mass of air M will meet the surface every second. This mass M will be equal to $m\,\frac{AC}{V}$, and consequently the lift of the surface will be expressed in the formula

(2) $$F_s = \left(\frac{m.AC}{V}\right)\gamma.$$

The German physicist Wegner von Dallwitz has deduced from this point a complete theory for the calculation of the lift. After proving that the acceleration γ is represented by

$$\gamma = \frac{2\,.\,BC\,.\,V^2}{AC},$$

he obtains, by utilising a formula analogous to that we have laid down above for F_s, the expression of the lift as a function of the angle of incidence,

(3) $$F_s = 0.26\,.\,\cos i\,.\,tg^2 i\,.\,S\,.\,V^2.$$

Although we should have liked to show the steps by which he obtains this result, lack of space only allows us to seek to turn it to practical account.

Let us take S as being 1 square metre. The lift per square metre will be

(4) $$F_s' = 0.26\,.\,\cos i\,.\,tg^2 i\,.V^2.$$

III.—*Power required for sustentation*

We have seen above the method of calculating the lift of any given aeroplane surface when its □ area, its velocity of motion, and angle of incidence are known. For practical purposes, the most important consideration is the power required to maintain the velocity V at the level necessary to fulfil the conditions of flight. In section II. we saw that the lift is produced by the reaction of the air which the surface tends to press downwards. The energy by which the air is then impelled will obviously be furnished by the motor of the aeroplane. The expression will therefore denote the *theoretical power* required for the given sustentation, the latter being known *a priori* from the weight of the machine and its pilot.

Every second a certain mass of air will therefore be impelled towards the lower edge with an acceleration γ. If h represents the difference in level between the forward and rear edges, it is evident that this mass of air, striking the surface at B, will gradually be impelled downwards to A; that is, it is forced to descend a distance h with an acceleration γ.

The energy required to produce this movement is $M\gamma h$ kilogrammetres. (It must be remembered that the air possessed no vertical velocity before coming into contact with the surface.) The requisite power will be

$$(5) \qquad P = \frac{M\gamma h}{75} = \left(\frac{0.26 \sin i . tg^2 i}{75}\right) SV^3 \text{ HP}.$$

This gives us the power required to sustain the aeroplane. Whatever hypothesis we may have assumed at the outset of our calculations, it is obvious that the above result will attain our object. Our solution was to determine the conditions required for the aeroplane to leave the ground. We now know the motive power necessary to achieve this purpose. Practical considerations will allow us to amplify the figures obtained in the correct degree.

IV.—*Resistance to forward motion*

Consideration of the power P provides the means to determine the *theoretical resistance to forward motion* of the surface. It is evident (fig. 2) that the power of the propeller is utilised entirely in overcoming the component N of the resistance R. We already know the power from formula (4). Let us assume the efficiency of the propeller as 80%. The actual power will be 0.80 P, that is

$$(6) \qquad \frac{0.80 \text{ SV}^3}{75} . \ 0.26 \sin i . tg^2 i \text{ HP}.$$

The resistance to forward motion being N, the velocity of translation of the point O being V, we can write

$$0.80\ P = NV; \qquad \text{hence} \qquad N = \frac{0.80\ P}{V}.$$

With the help of this formula we shall later be able to estimate the resistance to forward motion of any aeroplane

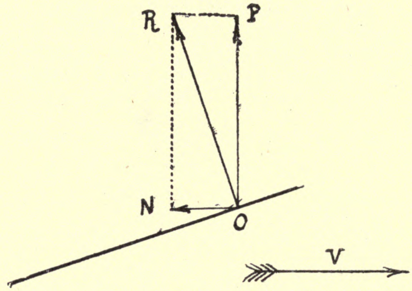

FIG. 2.

from the velocity obtained during flight and from the power developed by its motor.

V.—*Effect of unit power on the sustaining surface*

On the other hand, knowing from formula (3) the lift of a surface S moving at a velocity V at an angle of incidence *i*, and, on the other hand, knowing the power necessary for sustentation, we can determine the work done by 1 HP by dividing the lift by the power.

$$(7) \qquad \frac{F_s}{P} = \frac{0.26 \cos i \,.\, tg^2 i\ SV^2 \,.\, 75}{0.26 \sin i \,.\, tg^2 i\ SV^3} = \frac{75}{V tgi}.$$

VI.—*Superiority of the aeroplane over every other type of flying machine in respect of lift*

In the foregoing calculations we have always considered the downward impulse imparted to a certain mass of air, for which a certain power was required. We have further seen that the work to be done was greatly inferior to the force of gravity. Practice confirms the conclusion. To take an instance: Santos-Dumont's aeroplane, weighing, including the pilot, 150 kilogrammes (330 lbs.), rose from the ground when the screw-propeller gave a pull of 60 kilos (132 lbs.).

Again, the Wright biplane sustains 500 kilos (1100 lbs.), while the thrust of the screw is about 103 kilogrammes, or 51.5 kilos (113½ lbs.) by each screw.

But if we turn now to a helicopter or flapping-wing machine, we see immediately that the propelling organs must produce first of all a vertical force, neutralising that of gravity, and this without reckoning the power lost in consequence of the extreme fluidity of the air. The aeroplane therefore provides the only economical solution to the problem of mechanical flight, nor can machines of a different type that may be utilised in future ever deprive it of this advantage.

VII.—*Elementary calculations for the design of an aeroplane fulfilling certain given conditions*

We now possess a knowledge of every element entering into the calculation of the general features of an aeroplane. In practice, constructional requirements will enter into these calculations, but only in so far as the strength of the materials is affected by the factor of safety and the modulus of the metals used. An example will demonstrate more clearly than any amount of explanations the exact method of procedure in designing an aeroplane.

The problem may be approached in different ways. It may be necessary to calculate the sustaining surface from the given horse-power of a motor which is available and which one wishes to employ. Or the requirement may be that a surface of a given area should carry a certain number of passengers, in which case we should first have to calculate the speed required, and thence deduce the necessary power. As a general rule, the only conditions imposed are the weight of the aeroplane and the speed that can be attained without danger according to the dimensions of the manœuvring ground. Nowadays the speed at which an aeroplane should leave the ground is usually taken as between 60 and 90 km. per hour ; that is, between 16 and 25 metres per second. The starting grounds utilised, such as Issy, Châlons, Buc, Juvisy, etc., render higher speeds dangerous.[1] Before we can increase the figures given above, we should be able to foresee with absolute accuracy at which precise spot the aeroplane would leave the ground, which is not yet the case.

The piloting of an aeroplane is subject to so much uncertainty that the minimum velocity forecasted is sometimes attained only after considerable delay ; and it is evident that in these circumstances a relatively restricted starting ground would give rise to serious dangers.

The weight of the aeroplane is one of the factors known by the builder *a priori*. He starts, in fact, with the knowledge of the number of passengers he wishes to carry, of the approximate weight of motor, framework, etc.

Having made these preliminary remarks, we can now set ourselves the following problem, which will serve as an example of the method of applying the formula given above :—

An aeroplane designed to carry two people weighs in all 500 kilos (1100 lbs.). The starting ground limits the speed to 60 km. p.h. What are the characteristic features of the aeroplane ?

Our solution will be divided into several parts.

(1) *Surface*

The means of construction at our disposal to-day do not admit of a greater load than 15 kilos (33 lbs.) per square

[1] The same applies to our English grounds such as Blackpool, Brooklands, Shellbeach, Barking, etc.—Eds.

metre, but within these limits we can depend on obtaining a large margin of safety. The carrying surface will therefore be $\frac{500}{15} = 33$ square metres. This figure, however, is not final, since it will have to be slightly increased afterwards to compensate any variations due to the designed angle of incidence and to any departure, adopted to increase stability, from the normal position of the planes, as in the case where they are placed at a dihedral angle ; in other cases the wing-tips of an aeroplane, seen from the front, are turned up, in imitation of the curved extremities of a bird's wing.[1] The efficient surface in such a case no longer coincides with the actual surface, but to the horizontal projection of the latter which varies with the cosine of the above angles. But these observations need not be taken into consideration until we proceed to the arrangement of our carrying surfaces according to the special methods adopted by different constructors.

(2) *Power*

There are many ways of calculating the power needed to raise from the ground an aeroplane whose weight, surface, and speed are known ; but every method is to a certain extent based on practical experience, and its accuracy remains more or less open to doubt. The laws of aerodynamics are not precise enough as yet to be followed without discussion. The calculation of the power of an aeroplane motor is usually unreliable, and the figures arrived at for a given machine, which has not at the time been built, are often shown to be insufficient when it comes to a practical test. But this does not apply to a well-tried type of machine. All Blériot machines, for instance, possess a certain similarity of character which makes it possible to apply the observations made on any one of

[1] M. Tatin's aeroplane is an instance.

them to every one of the remaining machines of the type. Unfortunately the limits of this work do not allow us to explain some of the theoretical methods employed.

We will therefore confine ourselves to giving some figures obtained from certain existing types of aeroplanes, and giving an approximate estimate of the power they require :—

Aeroplane.	Type.	Speed k.p.h.	Weight in Working Order.		Surface (sq. m.).	HP
			Kilos.	lbs.		
Voisin . .	Biplane	60	500	1100	55	50
Wright . .	,,	65	550	1200	50	25
Ferber . .	,,	40	400	880	40	50
Blériot XI. .	Monoplane	70	350	770	15	24
,, XII.	,,	?	400	880	22	35

From this it is evident that in the aeroplane we are considering the motor must develop about 45 HP.

As this experimental method of calculating the power required may, however, be deemed too crude, and find little favour in the eyes of the technical man, we will, in order not to omit all calculation of the motive power, state the method adopted by the distinguished physicist Wegner von Dallwitz. This method is, in our opinion, the simplest yet devised, and—most important consideration of all—when applied to existing aeroplanes, it has given figures that come very near to reality.

This method is based on the formulæ (4), (5), and (7) given above. The aeroplane we are designing already possesses the following known features :—

$$P = 500 \text{ kg. } (1100 \text{ lbs.}).$$
$$S = 33 \text{ sq. m.}$$
$$V = 16.6 \text{ m.p.s.}$$
$$\text{Load per sq. m.} = 15 \text{ kg. } (33 \text{ lbs.}).$$

We now proceed as follows :—

In the formula giving the lift, we make $S = 1$ and $V = 1$. There remains :

$$F_s' = 0.26 \cos i . tg^2 i.$$

If now we work out every value of F_s' for every value of i from 1° to 70°, we shall know what angle of incidence must be adopted for a surface of 1 sq. m. moving at a velocity of 1 m.p.s. to lift our chosen weight of 15 kg. But in order that the machine may leave the ground we must have

$$\frac{P}{S} = V^2 F_s' ; \text{ or } 15 = (16.6)^2 F_s' ; \text{ hence } F_s' = 0.054545.$$

From the table of values we have just previously calculated, we find that 26° is the value of i, corresponding to 0.054545.

According to formula (7)

$$P = V tgi \frac{F_s}{75}.$$

A knowledge of F_s' will give us the value of F_s. But, as a rule, according to Wegner von Dallwitz himself, it is more convenient in regard to F_s and to the corresponding angles i to calculate the value of

$$P' = tgi \frac{F_s'}{75} \text{HP}$$

obtained by making $V = 1$ and $F_s' = F_s$ in the formula which gives P. We thus get to know the power needed per unit of speed. The total power P is consequently obtained by multiplying P' by SV^3. In our case $P' = 0.000317$, hence

$$P = SV^3 P' \text{ HP},$$

whence

$$P = 33(16.6)^3 0.000317$$
$$P = 47 \text{ HP}.$$

The power required to raise our aeroplane from the ground therefore works out at 47 HP. A 50 HP motor will amply suffice, since the method of calculation followed allows for the simultaneous variation of the angle of incidence and the speed without affecting the result. In practice, as is almost invariably the case, the angle of incidence will probably be smaller and the speed greater.

To sum up, the chief features of our machine are :—

Weight	500 kg. (1100 lbs.).
Carrying surfaces . . .	33 sq. m.
Motor	50 HP.
Probable speed . . .	70 k.p.h.
Load per sq. m. . . .	15 kg. (33 lbs.).

VIII.—*Application of the motive-power—Calculation of the propeller*

To turn to practical use the power of our 50 HP motor, the power developed must be transformed into a tractive effort acting on the surfaces, compelling the latter to move forwards, this forward motion resulting in sustentation. These transformers will have to find their point of support on the air, a fluid and unstable medium. The only device employed in aeronautics to fulfil this purpose is the *screw-propeller*, which consists of surfaces arranged in a special manner about an axis to which they are fixed ; the rotation of the axis causes the surfaces to rotate likewise and to drive back the air to the rear, thus tending to move forwards. This tendency to advance is utilised to drive the aeroplane. It follows that the design of an efficient propeller is a matter of extreme delicacy.

The whole question of propellers is very little understood at the present day, and it is difficult to find a complete theory for their calculation. Many theorists have examined the question, but among them only very few indeed have evolved a comprehensive and connected theory. Among the remainder there are some — Sir Hiram Maxim and William Froude, for instance—who have emitted correct views and made valuable observations, but without explaining them with sufficient clearness.

Practical experiment still remains master of the situation, and the majority of constructors follow their own special method of design. But, as a rule, their chief error lies in fixing *a priori* the diameter of the propeller.

Nothing could well be more illogical. The diameter, the principal dimension of the propeller, is the very first that ought to vary according to the power. Their next mistake, usually, is to base the other dimensions of the propeller on that of its diameter. One builder, for instance, favours a pitch = $1\frac{1}{2}$ diameters, the width of the blades being made = $\frac{1}{5}$ diameter. These methods, to say the least, lack the mathematical accuracy that ought to be the first consideration in propeller-design ; and low efficiency can usually be ascribed to these causes.

The most complete theory of the screw-propeller in existence is the one published last year by the Russian engineer, M. Drzewiecki, whose remarkable works on fluids are widely known.[1]

Drzewiecki's theory is worth following, principally on account of the strict reasoning on which it is founded. Moreover, even if it should prove not to be absolutely accurate, it has the further advantage of resulting in a method of construction which can be immediately applied in practice. (Further reference to this point will be made in the chapter on the Construction of Propellers.) Consequently, in his case, errors, which cannot be eliminated from any theory, are, at any rate, not increased by faults in the construction. We will, therefore, in the next paragraph follow Drzewiecki's method of calculating the design of a propeller driven by a 50 HP motor, revolving at 600 r.p.m., or 10 r.p.s.

Number of blades—On this point Drzewiecki's theory is not explicit enough. In consequence, we will adopt the usual number of blades, two, without going into the

[1] Drzewiecki, *Des hélices aériennes*, 1909.

theoretical question. At the same time, we may point out that three blades might be preferable.

Diameter of propeller—To arrive at the diameter we must first calculate the *modulus*[1] of the propeller :

$$M = \frac{V}{2\pi n}; \quad \text{that is} \quad M = \frac{16}{2\pi 10} = 0.26.$$

The diameter D is given by

$$D = M \times 10 = 2.60 \text{ metres.}$$

In reality, the width of the blade is constant ; this is what M. Drzewiecki implies by the term *specific width* of the blade.

It is constant, and, as can be shown mathematically, equal to $\frac{3}{4}$ths of the *modulus* :

$$W = 0.75 \text{ M} = 0.75 \times 0.26 = 0.195 \text{ metres.}$$

From the working drawings given in M. Drzewiecki's book we can now construct the templates for the surface of the blades. But this will be dealt with in the chapter on Construction.

The propeller of our aeroplane will, therefore, have the following dimensions : Diameter 2.60 m. ; specific width 0.195 m. ; r.p.s. 10.

The blades ought not, as is sometimes thought, to start from the boss, but at a certain distance from it, equal to half the modulus M, or in this case = 0.13 metres. We know that any point on the propeller diameter revolves at a speed inversely proportional to its distance from the centre. The tips of the blades move at a velocity $n\pi D$ (n being the number of rev. p. sec. and D the diameter). Consequently, as we approach nearer to the centre the speed will diminish in the proportion given, and the angle of incidence of the blades must be increased to produce the same amount of work. But the

[1] *Modulus* is the term used by M. Drzewiecki to denote the pitch-constant.

effect of this increased angle of incidence disappears after it has reached a certain point.

In a communication to the Academy of Sciences in Paris, the late Captain Ferber laid down the following axiom which bears on the point, but is only of importance in actual practice :

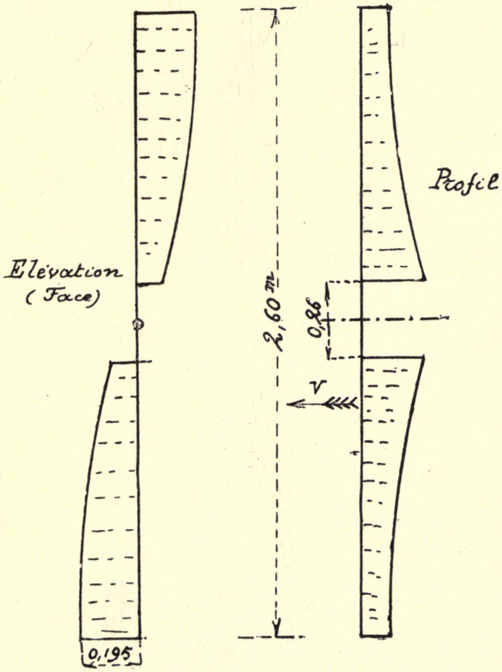

FIG. 3.

" Whether a plane moves through the air in an inclined position or almost at a tangent to its trajectory, the resistance of the air to the gravitating tendency of the total weight remains almost the same."

We therefore reach a point at which it is preferable to cut away the blade, a fact which, as we have seen, is in accord both with theory and with practice. Fig. 3 gives a diagrammatic view of the propeller and its dimensions.

Having explained the method of calculating the principal dimensions of the aeroplane and propeller—every one of these calculations being based on theoretical principles—we can now turn to their practical application. For, as we shall see, it is not sufficient to give the carrying surfaces a certain area; their shape is a matter of equal importance. The efficiency of the carrying surfaces, in fact, varies greatly with their shape, and, above all, with the *form of the perimeter.*

IX.—*Arrangement of the surfaces*

One fact has been noticed during the course of every experiment dealing with resistance of the air to the passage through it of a plane surface, *i.e.* that if the resistance R is proportional to the area of the planes it varies with their perimeter. It has always been a point of capital importance for the development of the aeroplane to determine the causes of these variations.

The first definite results were obtained by M. Le Dantec, who experimented with planes which were suitably ballasted and caused to slide down a wire at a speed of 1 metre per sec. The area of the planes was exactly 1 sq. m. The coefficient K was in this case, therefore, equal to the resistance. It was proved that the value of K varied with the shape of the planes; thus the resistance to a triangular shape is greater than to a square of the same area, while a circular plane experiences less resistance than the square one. The resistance was therefore proved to increase with the perimeter of the surface, independently of all other factors. M. Canovetti has made similar researches and has given the following table:—

Shape.	Speed.	Area.	Resistance = K.
Circle	9 m.p. sec.	0.79 sq. m.	0.061
Vertical rectangle .	,,	,,	0.066
Horizontal ,,	,,	,,	0.07

This table already shows the influence of the position of the greater side of a rectangle relatively to the direction of motion.

M. Eiffel has obtained the following values :—

Shape.	Dimensions.				
	1/16.	1/8.	1/4.	1/2.	1.
Circle . . .	0.068	0.071	0.074	0.077	0.077
Square . . .	0.070	0.072	0.075	"	0.079
Rectangle *a* .	0.073	0.074	"	"	"
" *b* .	0.070	0.072	"	"	"

The dimensions of the rectangle *a* were 4/1, those of rectangle *b* were 2/1. These figures indicate the effect of the outline of the plane when moving orthogonally, which, however, is of no direct interest. But they are important in that they show that in an aeroplane all useless surfaces (*i.e.* that do not produce lift) situated perpendicularly to the direction of motion ought to be given a circular shape.

For the *inclined plane* the only conclusion that can be made from these experiments is that a rectangle meeting the air with its larger side experiences far greater resistance than a rectangle meeting the air with its lesser side. Among the formulæ which bear on this point we need only mention that of M. Soreau, who takes into account the factors of the length and width of the rectangle.

In almost every formula hitherto enunciated are included values of a more or less fantastic nature, which rob them of practical value. We must therefore be guided almost entirely by experimental data, such as the observation of the outstretched wing of a bird, on which to model the shape of our surfaces. The works of Mouillard, Pettigrew, Marey, and Lilienthal are the best to consult on this point ; and of these, Lilienthal is to be preferred to the others by reason of the accurate measurements he gives, and to which he always attached the greatest importance. We will therefore turn to his book[1] for a model on which to base the shape of the surfaces of our monoplane.

It may incidentally be pointed out that the majority of existing monoplanes indirectly proceed from the same ideas. The Blériot, Esnault-Pelterie, Antoinette machines

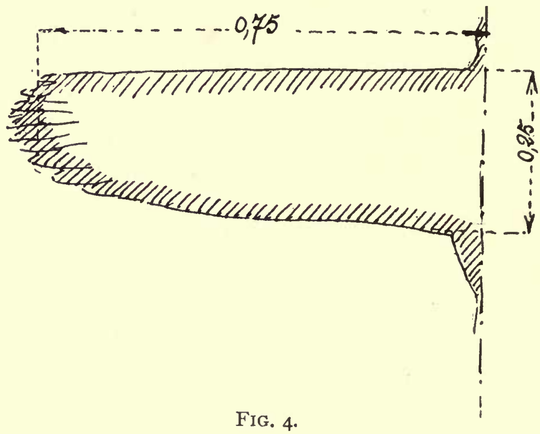

FIG. 4.

and others have surfaces shaped on the lines followed by nature in designing a bird's wing.

Let us take the wing of a stork. Lilienthal gives it the following dimensions, $\frac{0.75 \text{ m.}}{0.25 \text{ m.}}$ (fig. 4). It should be noted that the tips of the primary feathers are not included in the total length. The entire span of a stork's wings is therefore equal to six times their width.

But these dimensions cannot be followed with absolute fidelity, since the stork belongs to the class of sailing-birds, whose wings are relatively longer at the base than those

[1] *Der Vogelflug als Grundlage der Fliegekunst.*

of the soaring-birds, as is shown perfectly clearly in Mouillard's *Empire de l'Air*. In the wings of an aeroplane, therefore, the maximum width ought not to be less than $\frac{1}{6}$th of the total span. This proportion is the one adopted by M. Tatin in his aeroplane, which has a ratio of 5 to 1.

It must, however, be acknowledged that in arriving at these dimensions constructional requirements have

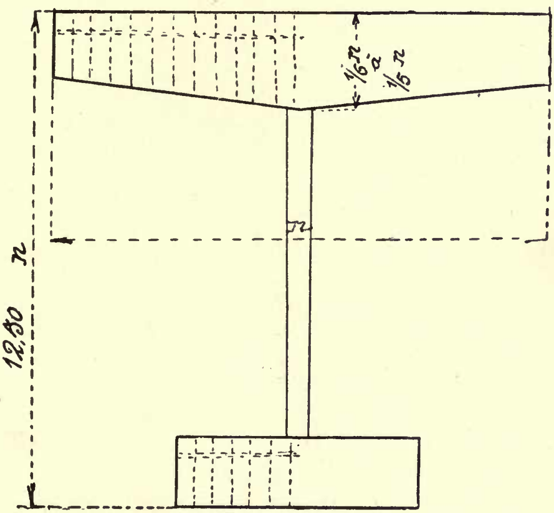

FIG. 5.

been taken into consideration; for an aeroplane must not be given too large a span, since this would necessitate the construction of immensely broad sheds, and would seriously affect the solidity of construction of the machine. In preserving the area of the surfaces it becomes in consequence necessary to increase the width relatively.

In accordance with the above remarks, we now proceed to arrange the carrying surface of our projected aeroplane according to fig. 5. The span of 13 metres will not appear too great if it is remembered that the aeroplane is to lift 500 to 570 kilos. (1100 to 1250 lbs.).

The Wright machine, which lifted a similar weight, has approximately the same dimensions *for each of its planes.*

The length, fore and aft, of the machine will be roughly equal to the span. Here, again, we are guided by nature and by existing machines. It is clear that where stability is obtained by means of a tail, the greater the distance of the latter from the carrying surface, the greater will be its effect on the longitudinal balance, on account of its leverage. But since an increase in this distance entails difficulties of construction and makes the machine unwieldy, the length is not allowed to exceed the dimension of the span. This arrangement has the further advantage that the tail plane acts in the same part of the air as the machine itself, so that the danger of currents of different directions acting on different parts of the machine is decreased.

X.—*Lateral stability—Position of the centre of gravity*

Before adopting any specific means for ensuring the lateral stability of an aeroplane, the latter must be considered in every position it may be caused to assume during flight, and in each case the sum-total of the forces acting upon it must be taken into account. In this way the aeroplane is considered first during normal flight, *i.e.* when its trajectory lies in a straight line, and later in any departures from the normal, such as when turning. Before adopting a particular method of preserving the stability of an aeroplane during its flight in a straight line, it will therefore be necessary to see whether the method is efficient when the forces acting during a turn are taken into consideration. Before we proceed to examine the effect of the centre of gravity, it is necessary to state that we need only consider the resultant of the forces and its effect, and that no attention must be paid to the misleading effect of the individual components.

(a) *Flight in a horizontal straight line*—In this case the aeroplane is only subjected to two forces—weight and lift. Under their combined action the aeroplane is in equilibrium in calm air. The only feature inherent in the design, which will avoid the upsetting of the aeroplane if it is struck by a current of air, is to place the centre of gravity below the centre of resistance. This is an essential

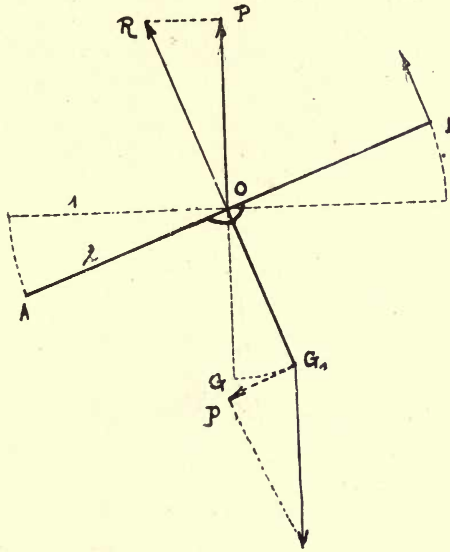

FIG. 6.

condition of lateral stability in an aeroplane. When the weight is thus disposed, as soon as the aeroplane tilts to one side, the component G_1P, through its lever arm OG, tends to restore the aeroplane to a position of equilibrium.

This lever arm is in any case constant, but since G_1P increases with the tilt, the action of the weight will increase in like degree, with excellent results. This application of the centre of gravity is shown in elementary physics by the pendulum. In proportion as the centre of gravity is situated closer to O, the "sensitiveness" of the pendulum increases ; that is, its tendency to restore equilibrium grows less.

A dihedral angle of the planes (*i.e.* each wing being turned upwards laterally) brings about great stability, but this method also is only effective when the centre of gravity is low. Since it has the disadvantages of entailing an increase in the sustaining surface and of behaving very badly in side-winds, it is preferable to employ wings with

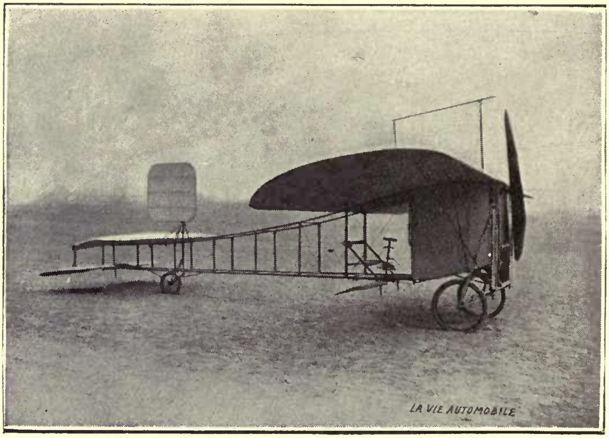

Fig. 7.

a continuous forward edge mounted above the plane containing the motor. The monoplane Blériot XII. (fig. 7) is excellently designed in this respect, and has proved the correctness of this system of construction in practice.

(b) *Turning*—Some few constructors, such as Esnault-Pelterie in France and Grade in Germany, have, on the contrary, placed their centre of gravity above the centre of resistance, with the object of rendering turning movements more easy to execute. Let us see what will happen during the turning movement of an aeroplane with the centre of gravity situated at different points.

Let us take an aeroplane (fig. 8) whose centre of gravity is situated at G, and which is turning in the direction of the arrow. Let ρ be the radius of the curve described around the centre O, m the mass of the aeroplane ; during its rotation round the centre of the curve the aeroplane will be subjected to a new force, which will tend to drive

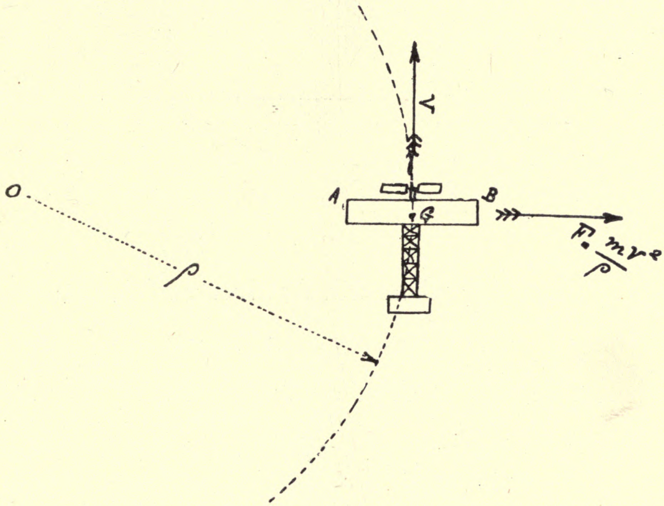

FIG. 8.

it away from the centre—centrifugal force. This latter force must be reckoned with, and is equal to

$$\frac{mV^2}{\rho}.$$

It will therefore tend to force the aeroplane to the outer side of the curve. Three different cases may arise according to the position of the centre of gravity relatively to the planes AB.

(1) *The centre of gravity is on a level with the plane*

Let AB be the aeroplane (fig. 9) seen from the front, turning round O, in a direction towards the reader. Owing to its rotation round O, the aeroplane will be forced towards the outside by reason of the force $\frac{mV^2}{\rho}$ applied to the centre of gravity G. It is manifest that if the plane AB remains

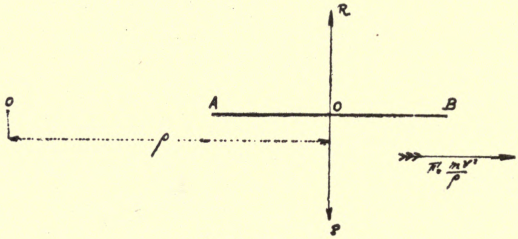

FIG. 9.

horizontal, the aeroplane will be diverted from its course, since only the side B will oppose the force $\frac{mV^2}{\rho}$. In order to neutralise this force it becomes necessary to resort to

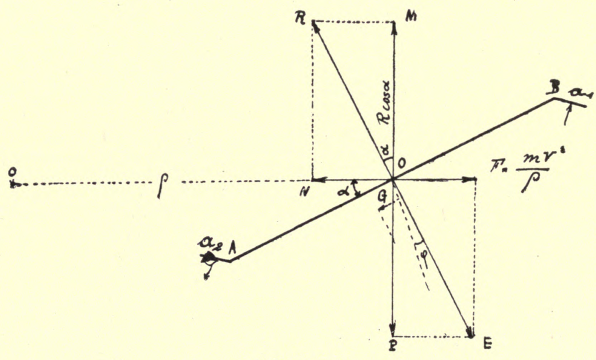

FIG. 10.

another method, which consists in tilting the aeroplane laterally, as in fig. 10, so as to create an antagonistic force. Since the resistance R remains perpendicular to AB, it will be tilted with the plane. It can then be resolved into two forces, GM and GN, the former vertical, the latter horizontal. The angle α will be regulated either automatically or by the pilot until GN = GF.

This action may be obtained by many different methods, every one of which, however, really amounts to a warping of the surfaces. The "aileron"[1] a_1 being lowered, the air is confined in a pocket and tends to raise GB around the axis G, whilst the aileron a_2 is raised. A tends to descend.

It will be noticed that in this first case, in which the centre of gravity is situated on a level with the planes, the weight has no effect on the evolution, since it only acts as the centre of rotation. The force GN, which is equal and directly opposed to centrifugal force, will simply neutralise the latter without exerting any other effect on the aeroplane, for the simple reason that in this case there exists no lever arm allowing the forces that are called into play to upset transverse equilibrium.

The tilting of the aeroplane, and consequently that of the air-resistance, has the inevitable result of decreasing the lift, which before the turning movement began was equal to R, but during the turn is only equal to R $\cos \alpha$. The aeroplane, therefore, will descend during the turn. And this actually occurs, so that the pilot must, before tilting his aeroplane for the turn, ascertain that his height above the ground is sufficient to allow him to clear any obstacles during turning.

The decrease in the lift brings about a difference between the resultant of the forces acting on the planes and of those acting on the centre of gravity.

The latter is slightly stronger than the former, and the force E forms with the force R an angle ϕ, which is very small, but nevertheless appreciable. The result is a component which, in case the aeroplane is tilted too far, will cause it to drift to the inner side of the curve. But if, on the other hand, the aeroplane is not tilted at a sufficient angle, the force resulting from GN and F will

[1] Movable wing-tip or auxiliary plane.

be superior to E, and the aeroplane will be diverted to the outer side of the curve.

It will be noticed that the fall in the path of flight of an aeroplane during turning cannot be avoided by varying the speed, since if the latter is increased so as to increase OM, the result is to amplify in proportion the centrifugal force, and, consequently, the tilt of the aeroplane required to overcome it. It must not be forgotten that the resistance of the air and centrifugal force are both proportional to the square of the linear velocity.

(2) *The centre of gravity is situated below the planes*

In this case the effect of the weight P acts detrimentally during a turning movement. We have seen that the essential condition preventing the aeroplane from being diverted from its course was to tilt it towards the centre of the curve. This tilt can be regulated by the pilot. Let us examine the action of the weight P during this manœuvre in the present case.

Rigidity of construction (as in the Blériot XII.) prevents any alteration of the relative positions of the two straight lines AB and OG.

Let us consider the aeroplane when tilted at an angle α for turning (fig. 11). Since the planes AB are rigidly connected to OG, which remains perpendicular to them, they will cause the latter to assume the same angle of inclination. The centre of gravity G will be displaced to G_1, where the weight P acts. If we take the sum of the forces acting on O, we obtain the product F_s. At G_1 we have a force G_1E, forming with F_s an angle ϕ on the side towards P. We have already seen that the tilt of the planes causes the lift and weight to become unequal. The force G_1E and the angle ϕ produce a component G_1D, which, acting at the extremity of the lever OG_1, tends to restore the aeroplane to a horizontal position.

If the centre of gravity lies below the planes it therefore hinders turning movements to a certain extent. Every-body who witnessed the flights during the Rheims meeting last summer must remember the tendency of the aeroplane Blériot XII. to be diverted from its course when attempting to turn.

It is therefore evident that the first effect of a low position of the centre of gravity is good, but that as soon

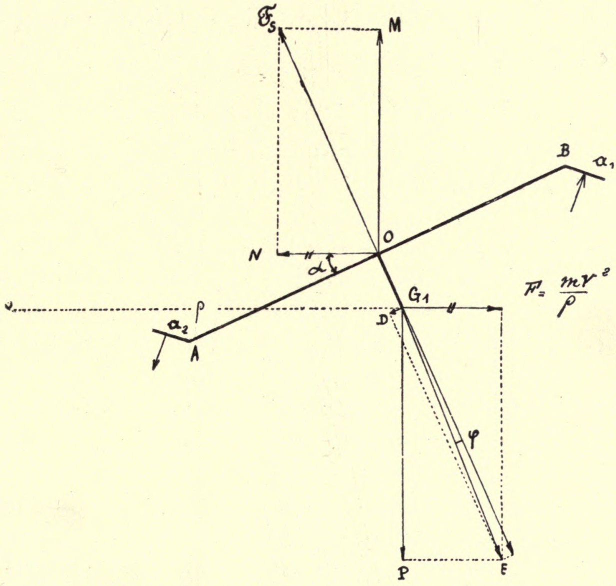

FIG. 11.

as this effect becomes appreciable, the force G_1D appears and neutralises it.

On the whole, then, a low centre of gravity is bad for turning movements. But the turning movement only forms a small incident in flight. Too great attention should not, therefore, be paid to it so long as the velocity of flight of an aeroplane remains what it is to-day ; flight in a straight line must be chiefly considered, and this favours the position we have just discussed.

What is the best way to obtain a low centre of gravity ?

The oldest method was to arrange the planes so that they formed an obtuse or *dihedral* angle. Unfortunately this method is bad, for the reason that it renders the aeroplane more likely to capsize in a side-wind. In our opinion it is greatly preferable to build the planes as one continuous surface above the frame containing motor, tanks, and pilot, after the method adopted by Blériot in his monoplane No. XII., which caught fire and was destroyed at Rheims on August 29, 1909.

(3) *Centre of gravity above the planes*

This is the position adopted by Esnault-Pelterie in France for his monoplanes, and in the German biplanes of Grade.

Referring to fig. 12, it will be seen that, for the same reasons stated in the preceding section, the inequality between the lift during a turning movement and the weight P tends to accentuate the inward tilt of the aeroplane, thus preventing its diversion from its course. This position of the centre of gravity is therefore excellent for a turning movement, which by its aid can be accomplished at a very high rate of speed, but for maintaining stability during straight flight it is most deficient: any departure from equilibrium is immediately increased by the high position of the centre of gravity, and it is exceedingly difficult to check this tendency to upset. The dangers of the system have been practically illustrated by the accidents that have occurred to the Esnault-Pelterie monoplane at Buc.[1]

On the whole, the problem of the stability of an aeroplane may be said to be in complete accord with the laws of the pendulum. The three cases we have considered follow the laws exactly. From this we may conclude that the best method for ensuring stability is, at any rate at the present day, to place the centre of gravity below the planes.

[1] On more than one occasion the machine turned turtle.—EDS.

As soon as the speed of the aeroplane reaches a sufficiently high figure, stability during straight flight will no longer need to be considered.

Then we shall only have to concern ourselves with stability during turning movements; and not till then will the principle adopted by Esnault-Pelterie prove practicable. For its high speed will render the aeroplane indifferent to any atmospheric currents, thus ensuring stability during straight flight; and the centre of gravity,

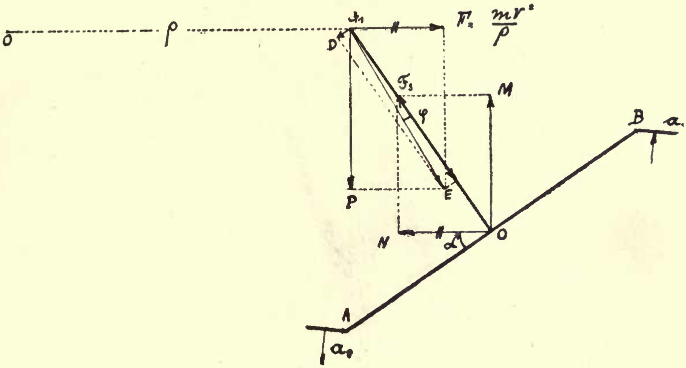

FIG. 12.

then situated above the planes, will allow it to execute the sharpest turn in safety.

But at the present time, when the speed of flight is relatively slow, we dare not adopt this system, but must rather concern ourselves mainly with the stability of the aeroplane during its flight in a straight line. The centre of gravity, therefore, must be placed below the planes. The future will see its position altered to above the planes, thus vindicating M. Esnault-Pelterie's contention.

XI.—*Longitudinal stability*

The longitudinal stability of an aeroplane offers few difficulties. It is automatic, provided always that the

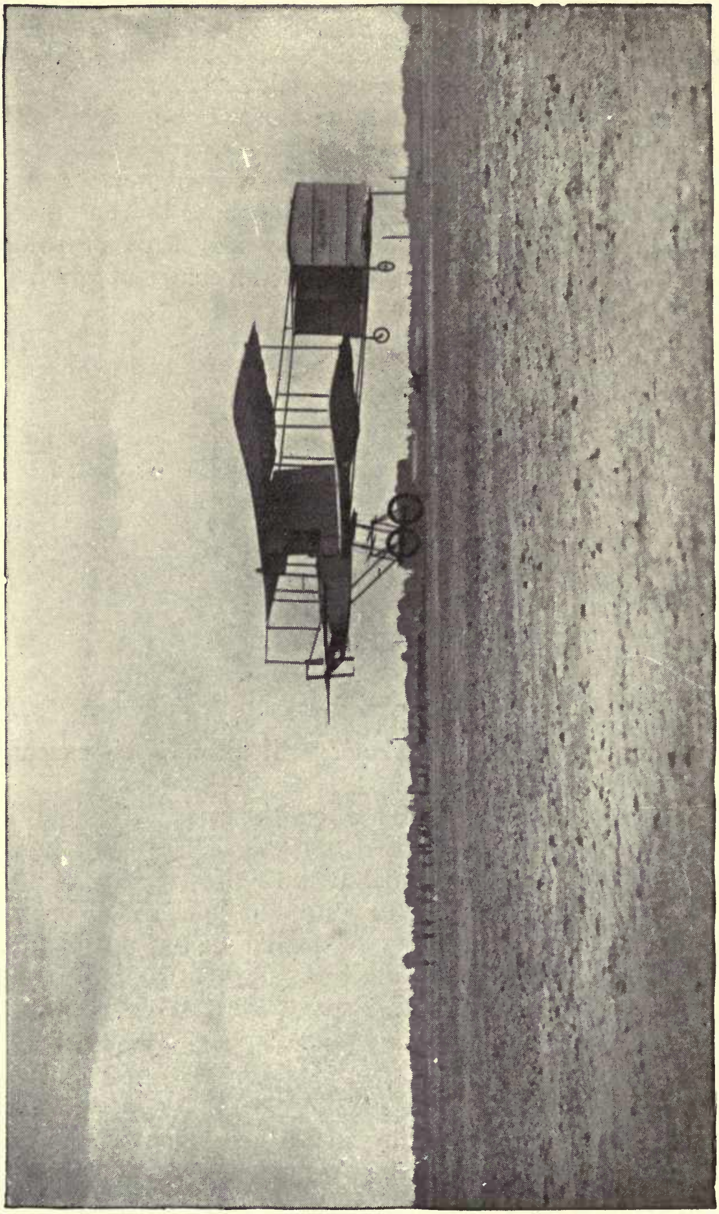

Fig. 13.

surface of the elevator be sufficiently great. Two distinct systems of obtaining stability may be employed: in the first, the horizontal rudder is placed in the rear; in the second, it is in front of the carrying planes.

To the former type belong the Voisin machines, to the latter the Wright aeroplane. The majority of machines to-day, as a matter of fact, belong to the former type. The second is mainly favoured by the American school—the Wrights, Herring, Curtiss, etc. (figs. 13 and 14).

FIG. 14.

We will now consider the action of the horizontal rudder in these machines during ascent and descent.

Let us take the aeroplane with a carrying plane AB (fig. 15) moving in the direction of the arrow at a velocity V. The air exerts a vertical resistance F_s applied to the point M. Let us assume that the centre of gravity lies at the point G on the vertical line Δ. The weight P of the aeroplane, equal but opposite to the lift, acts on this point. A couple will therefore arise tending to turn the whole of the plane AB around a horizontal axis passing through the point K at the centre of the line joining the points where the two forces are applied. The surface AB will assume the position A′B′, and this must be avoided. In order to counteract this couple, a surface CD is placed in the rear of AB. The surface CD receives from the air a vertical force F_g which counteracts the effect of the couple owing to its lever arm OE. In order to overcome the couple we can also, within limits, bring the vertical line Δ nearer to the point M.

From the foregoing argument it is evident that if the centre of gravity lies to the rear of the centre of pressure, the surfaces which produce longitudinal stability must be placed behind the main planes, but that they must be situated in front whenever the weight is applied forward

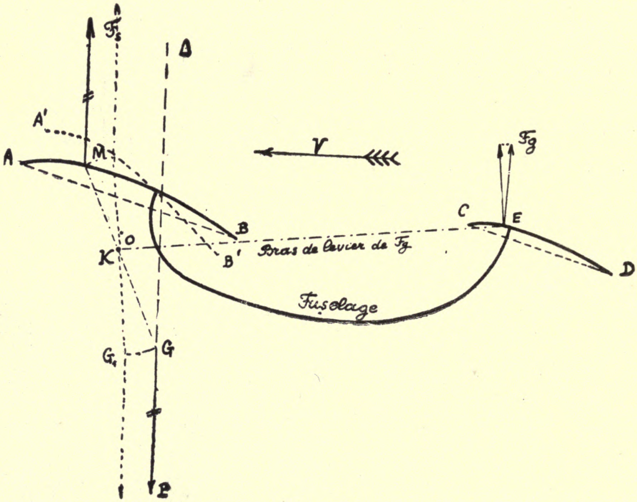

FIG. 15.

of the centre of pressure. For this reason the stability surfaces are situated aft in the Voisin aeroplane, in which the motor and pilot are placed near the rear edge of the carrying planes, whereas in the Wright machine, in which the passengers are seated near the forward edge of the planes—*i.e.* in front of the centre of pressure—the stability surfaces are placed in front. Figs. 15 and 16 show the distribution of the forces in the Voisin and Wright aeroplanes respectively.

XII.—*Variations in altitude*

The aeroplane is caused to rise or descend by methods which differ according to the various builders.

The majority utilise for this purpose the stabilising surfaces of the aeroplane, irrespective of their position, by raising its angle of incidence α, and consequently the force F_g. The foregoing diagrams clearly show that in this case the angle of incidence of the main carrying planes will be altered, thus causing the machine to move in an

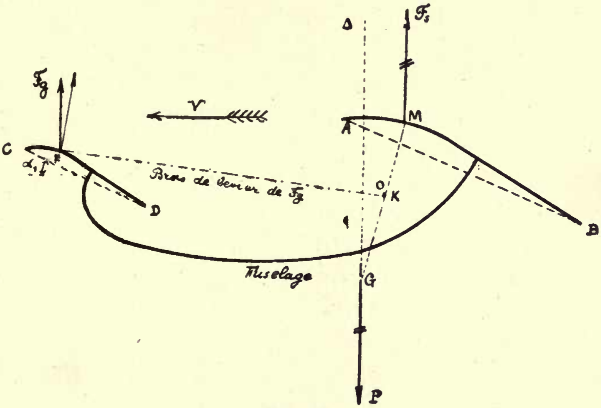

FIG. 16.

ascending or descending direction. Another class of constructors, among them the Voisins, use a horizontal rudder situated in front, independently of the stabilising surfaces. The action of the elevator is easily understood: if we increase its angle of incidence, it will obtain greater lift, thus increasing the incidence of the main planes in like measure; its action is therefore the same for ascending or descending as in maintaining stability. The aeroplane of the brothers Wright possesses the great advantage of enabling the machine to ascend or descend very rapidly: the position of the elevator in front renders it very powerful and, consequently, rapid in its action; and this unquestionably forms one of the best features of this machine. Among those who have adopted the same system are Blériot, Esnault-Pelterie, Tatin, Santos-Dumont, Antoinette, Pischoff-Koechlin, etc. The number of builders who have adopted a joint elevator and stabilising surface is small, and includes Voisin, Bonnet-Labranche, and Farman.

XIII.—*Direction*

It would be unnecessary to devote an entire section to the question of direction, since it possesses little special interest. The solution simply consists in utilising vertical planes turning round a vertical axis.

This concludes our study of the first principles and the general technique of aeroplane construction. Perhaps the briefness of our summary of the calculations and method of designing an aeroplane demands an apology : within the limits of the present work it was, however, impossible to enter into lengthy technical discussions.

The effect of the curvature of the surfaces will be dealt with when the construction of the framework of the planes is considered. Further, in the chapter on the Construction of Propellers will be found a review of the general methods hitherto adopted.

CHAPTER II

MATERIALS USED IN AEROPLANE CONSTRUCTION

I.—*General principles of construction*

By reason of its being required to fulfil so many conditions simultaneously, aerial construction is one of the most difficult tasks to which man has ever set his hand. The apparent contradictions which constantly occur make it a fecund source for researches for the engineer who is a specialist in the strength of materials, while the metallurgist will find a new occupation in the search for suitable metals. The skilled mechanic will evolve his own special structural designs. Briefly, almost every branch of industry is called upon to perform its separate part in aerial construction.

The first essential requirement of a flying-machine is that it should be strong; the second, that it should be light. In addition, the structure must have enough rigidity to prevent it from being deformed in flight by the normal action of the air: it should, however, be rigid only as a whole; that is to say, if, instead of being supported by the uniform action of the air on every part of the carrying surface, the machine were, so to speak, suspended from one single point, this point must possess some freedom of movement. Flexibility, therefore, is another essential feature of construction, but only within definite limits.

To embody all these qualities in a single structure is a task of manifest difficulty, and requires first-class materials of construction, which must present a maximum of resistance to every kind of stress and strain.

II.—*Materials used in construction*

(1) *Metals*

Contrary to expectation, the advent of aerial locomotion has not brought about an aluminium age. Notwithstanding its extreme lightness, this metal does not, as a matter of fact, possess sufficient strength, whatever its method of utilisation. It cannot be used in the form of wires: its tensile strength never exceeds 25 kilogrammes per square millimetre. Its bending strength is even worse. It is not very cohesive, a fault which is aggravated by vibration. It can only be used for parts which are constantly subjected to compression, as for instance in the sockets for the uprights in the Voisin biplanes. The motor industry is gradually banning aluminium, and the day is near when not a particle will be included in an aeroplane.

Steel becomes more important every day. It is without question the best metal available at the present time; weight for weight, its strength is much greater than that of aluminium. Moreover, it is one of those rare metals that work as well under tension as when subjected to bending or torsional strain.

The development of the steel industry is of comparatively recent date; for long the speed of machinery was not designed to exceed some 50 revolutions per minute. The construction of hydraulic turbines, followed by that of the explosion motor, and, lastly, by the steam turbine, created a demand for a new metal capable of withstanding enormous velocities of rotation. Then arose, by the side of the great metal industry, that of special steel. The latter attracted a large number of distinguished metallurgists who have succeeded in producing steel alloys of extreme strength. The famous Krupp Works in Germany produce a nickel-steel which, in the form of wires, can withstand a strain of 165 kilos (364 lbs.) per sq. mm.; a fact which shows that steel, with a specific gravity treble that of aluminium, has a tensile strength six or seven times greater.

The proportion of carbon in steel is an important factor of strength. Hardened steel is much stronger than ordinary steel. Thus, the nickel-steel referred to, before being hardened, only withstands a strain of 80.4 kilos (177 lbs.) per sq. mm.

Many varieties of steel may be employed in aerial construction. Their quality varies according to the proportion of other metals contained in the alloy, such as nickel, chromium, vanadium, silicium, etc.

Steel is chiefly used in the form of wires in the building of an aeroplane; for the latter really contains no metallic portions, save, of course, the motor chassis, and occasionally the framework.

The following table gives the breaking-strains of different wires having a section of 1 sq. mm.:—

Iron wire, drawn . .	56–70 kg.	123–150 lbs.
" tempered .	40 "	88 "
"Höper" metal . .	140 "	310 "
"Delta" " . .	98 "	216 "
Bessemer Steel, drawn .	65 "	143 "
" " tempered	40–60 "	88–132 "
Zinc	19 "	42 "
Lead	2.2 "	4.8 "
Silicium Bronze . .	65–85 "	143–187 "
Aluminium . . .	23–27 "	50–60 "
Copper . . .	40 "	88 "

The above figures show that silicium bronze is fairly solid. There would be no advantage, in point of weight, in employing this metal were it not that it possesses one most valuable quality: it can be turned perfectly, and, with a steel screw-tap, gives very smooth threads in which the screw has no play. In addition, the threads will be found as solid as possible, having regard to their section. This bronze is therefore used in the manufacture of the wire-strainers, which must be able to stand the same strains as the wire they keep taut, otherwise the strength of the latter would be useless.

A wire-strainer simply consists of a bronze screw-nut with two threads, one at either end, into which enter two screws provided with eyelets, to which are attached the ends of the wire to be stretched; the wire is strained by means of a gudgeon in the nut. There are, of course, a good many types of strainers, but their only point of difference is in the manner of threading. Figs. 17 and 18 show two different types of strainers. In order to attach the wire as firmly as possible, it is first threaded

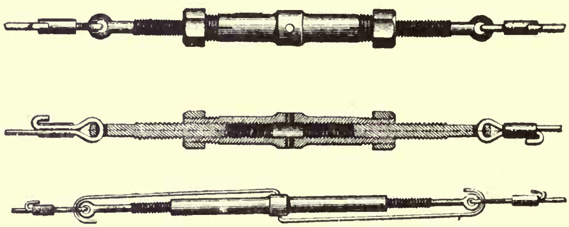

FIG. 17.

through a small piece of copper tubing *t* (fig. 19); the wire is then passed through the eyelet, bent, and the end passed back through the tube *t*; the wire is then bent back and cut. This method of fixing withstands the greatest strains. In order to prevent the strainer from becoming unscrewed, it is as well to thread a strong piece of steel wire through the hole *b* and to pass it through one of the eyelets.

(2) *Wood*

Wood is the most important material used in building an aeroplane. The framework of the planes is usually made of American pine, although, as will be shown later, the planes are occasionally stretched over a frame built entirely of metal. The varieties of wood used are few in number, and need not be described at length. Pine is the most generally used, since it offers a good resistance to bending strains ; unfortunately it is apt to break.

In the early days bamboo was often employed, but to-day it has been definitely abandoned, since a bamboo structure never possesses very great strength. Whatever its claims on the score of lightness, this wood cannot be recommended, since by its shape it offers great resistance to the air.

At times it may be useful to employ poplar. This wood is very light and very flexible, but unfortunately it warps very readily under strains and under the action of atmospheric changes.

Hard woods, such as oak, hickory, ash, are only used in short lengths for the body itself and for the supporting framework of the motor. Some builders favour ash for the ribs of the planes ; when carefully steamed it certainly can be bent to an accurate curve. In such a case it can be given the exact curvature of the plane by means of an ordinary template.

FIG. 18.

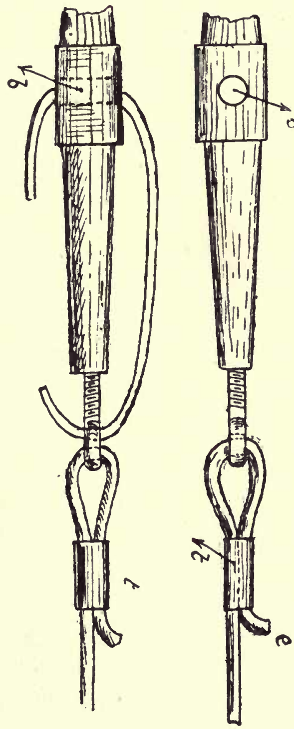

FIG. 19.

Once it has been bent, it remains set for an indefinite period of time.

But if the study of the wood itself need not detain us long, this is not the case when we come to consider the means adopted to utilise its strength to the full. The whole question of strength, in fact, rests on the shape and arrangement of the material. Acting on this principle, M. Ader, the great pioneer who built the famous "Avion III.,"[1] invented, with the help of MM. Espinoza and Vallier, a process of producing hollow spaces, comparing favourably, in point of strength, with the majority of metals, and greatly superior to every metal in point of lightness. Ader's "Avion," which was exhibited at the Aviation Salon in Paris in 1908, completely justified his claims. The huge wings of this machine could, in fact, bear the entire weight without bending, and this in spite of the fact that the entire structure did not contain a single strainer, and that the wings could be folded back for transport. These hollow spaces are of varying section (fig. 20),

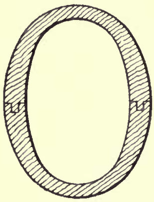

FIG. 20.

and are only built up of carefully selected lengths of wood and glued together in the sense of their length by means of a special product, of which the inventor has kept the secret. They are used for the construction of the framework. To form a frame, the spars are joined together by a process also invented by Ader and his collaborators. It is obvious that no section of the spar could be pierced, as would have been necessary if they had been bolted or screwed together, without destroying the strength of the remaining length of spar. Consequently the various lengths are assembled in the positions they are to occupy, and a long strip of strong fabric, impregnated with a special kind of glue, is tightly

[1] This aeroplane made the first flight, with a man on board, in history, at Satory, on October 17, 1897. It flew a distance of 300 metres.

rolled round the joints. By this method it is possible to produce fully as strong and rigid a framework as by means of bolts or screws.

It frequently occurs that the wood for the construction of the planes is not available in sufficient lengths ; in this case several lengths have to be joined together. This is accomplished by gluing several strips one over the other and alternating the joints. The strips are then fixed with a special insoluble glue and bound round with fabric.

A much simpler process, but by no means so strong, consists in bevelling the extremities of the length down

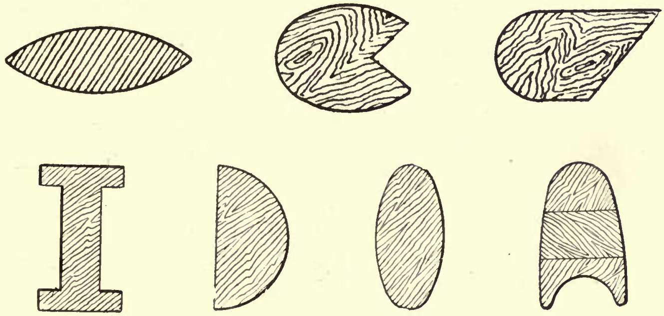

FIG. 21.

to a very fine edge and sheathing them in a small aluminium sleeve, which is fixed in place by two small bolts. But this method cannot be recommended, since the aluminium sleeve is very apt to crack when the plane is subjected to a shock.

In every case the sections used are specially designed to decrease the resistance of the air (fig. 21). These special sections are produced by a machine known as a moulding-machine, which consists of a revolving head provided with several cutting blades, forming in profile the shape of the section required. The spar is fed into the machine, and the cutting blades, revolving at high speed, remove all projecting portions.

(3) *Fabric*

The surface of the planes is constituted by specially prepared fabric of extreme lightness. Some builders, such as MM. Zens, at one time attempted to cover their planes with Chinese parchment,[1] but, apart from the fact that it is easily torn, this material is easily affected by atmospheric moisture, which renders it unserviceable. Rubbered cloth is practically the only fabric employed at the present time. It is vulcanised at a high temperature, which renders it unaffected by moisture. In Europe it is manufactured by the Continental Company, by Michelin, by the Gutta-Percha Co. of Hanover, by Hutchinson & Co., the North British Rubber Company, Messrs Dunlop, and Messrs Spencer & Sons. A gas-tight and waterproof British fabric, into whose composition, however, india-rubber does not enter, is manufactured by Messrs Hart. It should not exceed in weight 150 grammes ($5\frac{1}{4}$ oz.) per sq. m.

[1] In England, Mr A. V. Roe has used muslin-backed paper with satisfactory results.—Eds.

CHAPTER III

THE CONSTRUCTION OF PROPELLERS

I.—*Preliminary remarks*

PROPELLER theories are nowadays very numerous, and all have good points ; but unfortunately they do not agree in their most important features, and should always be looked upon with suspicion.

The best and only way to form any idea of the value of a theory is to build a propeller in accordance therewith and to try it. The result will be conclusive. However, even this method of procedure is open to argument, for it is possible in nearly every instance to point out some constructional error. It is therefore necessary, in choosing a *modus operandi*, to take one which follows most closely the theory from which it is deduced.

II.—*Procedure based on M. Drzewiecki's theory*

As we have said, when calculating the dimensions of a propeller for our imaginary aeroplane,[1] it is for these reasons that M. Drzewiecki's theory appears preferable. We have always used it in making propellers, and we have always had good results.

It has been shown how the general dimensions of a propeller should be calculated, and it only remains, before examining other ways of doing so, to show how the formula obtained should be applied.

M. Drzewiecki explains in his book how the necessary

[1] See p. 15.

templates may be obtained by means of a working drawing similar to that in fig. 22.

On a horizontal axis O Δ the pitch constant M is laid off, which gives the point B. On an axis perpendicular to O, starting from this point, lengths equal to $\frac{1}{2}$M, M, 2M, 3M, 5M are marked, which give the points 1, 2, 3, 4, 5, 6, which are then joined to the point B. In this way are obtained lines drawn at varying angles to the vertical axis.

From these points 1, 2, 3, etc., with a radius equal to $\frac{1}{4}$ of the specific width of the blade, calculated as explained in Chapter I., arcs are drawn on the same side of the vertical axis as the point B, which cut the lines 1B, 2B, etc., and horizontal lines are drawn from the points of intersection.

The same procedure is carried out on the other side of the axis with the same centres, but

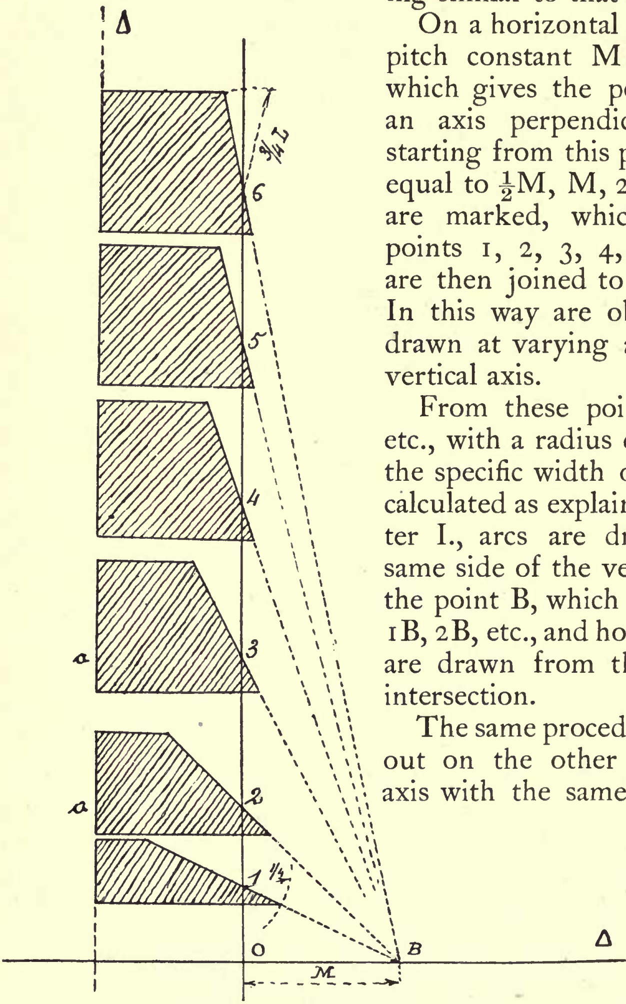

FIG. 22.

with a radius equal to $\frac{3}{4}$ of the specific width, and horizontal lines are again drawn from the points of intersection.

The fourth side of the templates, which are shown as the shaded portions in the figure, is bounded by the vertical line Δ.

The templates thus obtained are cut out in thin pieces of wood, and the points *a* are marked upon them at a dis-

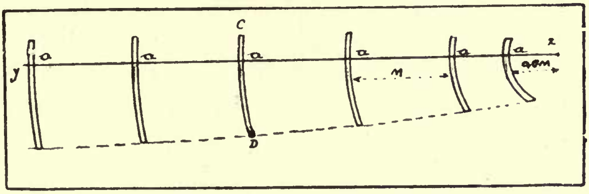

FIG. 23.

tance of $\frac{1}{4}$ of their width. They are numbered as on the working plan, and fixed securely on the board P with their plane perpendicular to that of P, and to the axis *xy*, which is the projection of the arm of the blade.

All the points *a* mentioned above are placed on the axis *xy* at the distances $\frac{1}{2}$M, M, 2M, etc., starting from

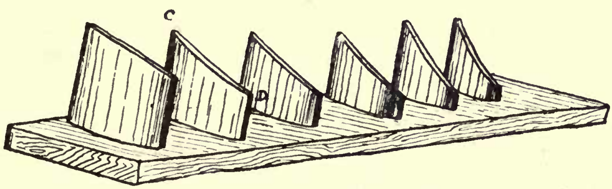

FIG. 24.

the point O, which thus becomes the centre of rotation (fig. 23).

The templates, of course, must have been previously curved to form segments of the circles obtained by taking O for the centre and the distances previously mentioned as radii.

It will be seen that the edges CD of the templates form a "table," which determines the shape of the propeller-blade ; and after they have been trimmed down where necessary, its construction can begin (fig. 24).

From this description it will be readily understood why we have said that Drzewiecki's theory, even if it contains errors, is still preferable to the others ; and how it is possible to make templates by exactly following his working drawings.

The above method does not give any curvature to the blade. If it should be asked if the blades ought to be curved like aeroplane surfaces, the answer is certainly in the affirmative, because in both cases the surfaces act in the same way and with the same object.

Tatin and Wegner von Dallwitz both say—and we agree with them—that the blade should have a slight concavity, which is easily made, even in a completed screw, if it is of wood, but where it is built up on a metal framework the cross members should be given the designed curvature from the beginning.

III.—*Other ways of designing propellers—The Colliex process*

M. Colliex, the engineer of the Voisin Works, follows an empirical method in designing his propellers, and the reader already knows what confidence to place in results so obtained.

His method is as follows :—The diameter and pitch of the propeller are determined by previously known examples, and the first step is taken by finding the inclination of the blades at any distance R from the centre. A horizontal line OC is then drawn equal to the circumference of the circle described by the tip of the blade and the dimension of the pitch drawn perpendicularly at C. In this way the point D is obtained, from which the horizontal line DG can be drawn. Now if it is required to know the inclination of the blade at its extremity, join DO, and the angle a_1 formed by DO, OC gives the answer.

If it is wished to find the inclination at a distance R_1 from the centre, this distance is marked on OC, which gives the point A. From A a horizontal line is drawn to DC, meeting it at E, and the angle α_n formed by EO, OC gives the answer.

In practice, the angles thus obtained must be slightly decreased to allow for the forward motion of the aeroplane.

It will be seen that the angle increases towards the boss;

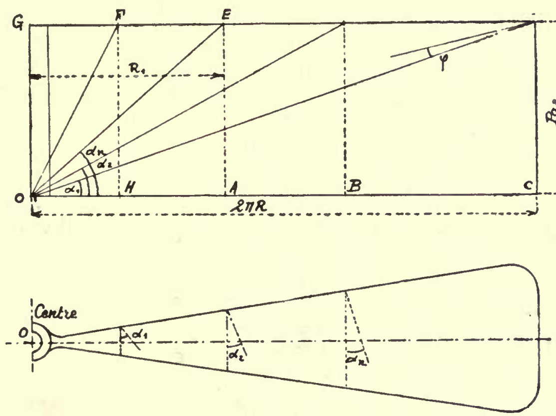

FIG. 25.

and in order to apply the rules given above, the blade should be placed at a distance r from the boss. For this purpose M. Colliex usually makes the length of his blade equal to a third of the diameter, and the width of the blade equal to a one-fifteenth diameter. The angles, α_1, α_2, α_3, being known, as well as the distances of the corresponding points from the centre, it is easy to construct templates to the required shape.

The Tatin process—M. Tatin's process has no special peculiarity. It consists principally in choosing a certain diameter, and deducing from it the values of width and pitch.

The Chauvière method and that of Pischoff and Koechlin might be mentioned, but they are only interesting from a constructional point of view, as we shall see.

IV.—*The manufacture of propellers*

It has been seen that every one of these methods of calculating the design of a propeller leads to the construction of a sort of "table" formed by the edges of the templates on which the blades are shaped. What the surface of the blade will be like can thus be seen at a glance, but there are many more points, chiefly of a constructional nature, to be considered before it is actually made. For example, it has been found advisable to cut off the rear edge from the tip of the blade, and this should be done whenever it is possible. The efficiency of a surface meeting the air reaches its maximum at an angle of incidence of 45° ; and it was this fact, no doubt, which influenced Blériot in giving his flexible propeller-blades a width gradually increasing towards the boss. However, he has now definitely abandoned this type.

The extreme ends of a propeller in motion move at a very high speed and at a very slight angle of incidence, but those parts nearer the boss move at a decreasing rate, and in order that they may give an equal thrust the angle of incidence must be increased. But the speed increases so much faster than the angle of incidence that they cannot always be counterbalanced ; and that portion of the screw near the boss offers a relatively enormous resistance to rotation, which is not in proportion to the work performed.

From this it follows that this portion of the blade should be cut away in every case where it will not affect the strength of the propeller.

Propellers can be manufactured in metal or in wood. The first propellers to be made had iron arms ; they are nowadays very widely used, and there is no reason why they should not continue to be so, as they can easily be improved in many ways. At the present moment they are used by the Voisin Brothers, Esnault-Pelterie, the Antoinette Company, Blériot, and many others.

(a) *Metal propellers*—A flat steel arm is made and pierced with holes corresponding to those in the blade, which has previously been suitably shaped on the templates, and the two are then riveted together with copper rivets. Both blades having been similarly treated, it only remains to fix them in their place, and for this purpose the steel arms have rectangular or triangular ends, which

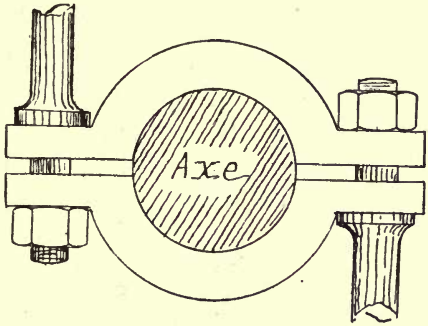

FIG. 26

are fixed in a collar by means of a cotter and nut. The collar can vary considerably in its form, and must be made so as to fit firmly on the motor shaft (fig. 26). In the sketch it should be noticed that the propeller arms are parallel, and not in the same straight line. In many types, however, arms are situated along the same diameter, as in the Esnault-Pelterie and Antoinette propellers (figs. 27 and 28).

In our opinion, the best metal to use for the surface of the blades is sheet aluminium, as it can be used in comparatively great thicknesses on account of its lightness, and this tends to increase the moment of inertia of the section of the blade, and in consequence to preserve its shape. We have seen that the blades are attached to the arms by copper rivets, a great number of which, of course, must be used to form a solid structure. In order partly

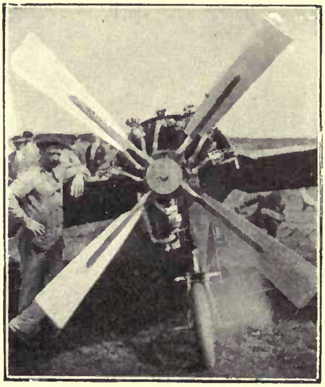

FIG. 27.

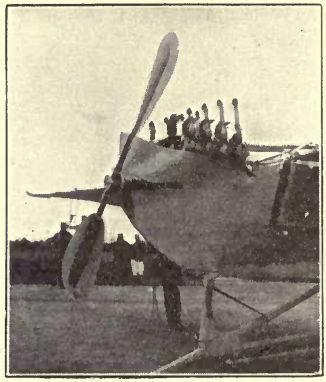

FIG. 28.

to avoid this lengthy operation, M. Rudolph Chillingworth of Nürnberg has patented the device shown in figs. 29 and 30. The propeller-blade is cut out of sheet metal,

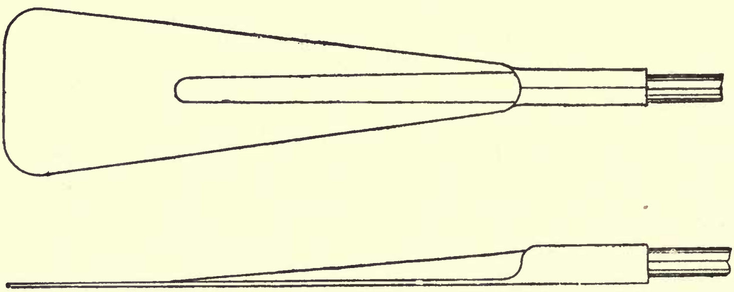

FIG. 29.

with two tongues at its base, which are folded over and welded to the arm. In this way only a few rivets are necessary to attach the arm to the surface of the blade. Often the two blades are cut all in one piece, but this method is open to objection on account of the difficulty in attaching the propeller to the motor shaft. We cannot pass over the name of M. Chillingworth without mentioning another patent of his for making propellers. The blades are fashioned as before out of one sheet of metal, but are reinforced over a part of their

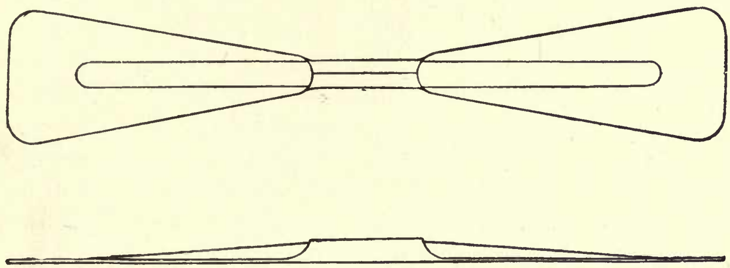

FIG. 30.

surface by a wooden facing, which is attached to the metal by a kind of circular copper rim riveted to the blade. This method makes use of the best quality possessed by wood, which is its resistance to bending stress (fig. 31).

(b) *Wooden propellers*—There are a certain number of

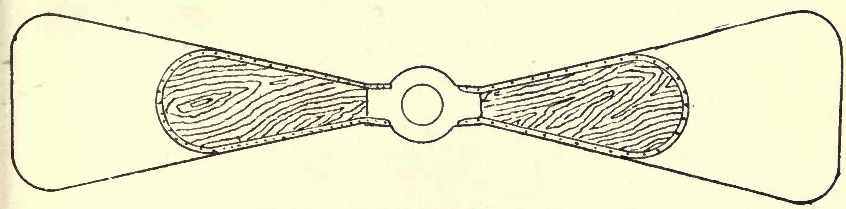

FIG. 31.

drawbacks inherent in metal propellers. They are heavy and easily bent, and because of their great elasticity they vibrate when in use. If they burst under the strain of high velocity, the pieces are a great source of danger. It is a matter of some difficulty to attach the blade to the arm, and the rear face, however well it may be constructed, cannot be made to show an even surface. For this reason it is easier to make wooden propellers, as they have advantages which make them preferable to the others. Wood has greater tensile strength than the best nickel-steel. With the grain running lengthways to the blade, the danger of its flying to pieces under centrifugal force is reduced to a minimum.

Its lightness allows the blade to be very thick through, and to be shaped in such a way as to offer the least possible resistance to motion. There is, moreover, another advantage arising from the fact that the moment of inertia increases as the square of the thickness, so that the propeller will offer a great resistance to flexure and can be run at a very high rate of speed. In the event of its breaking, the pieces, being of no great mass, possess very little force, and are generally harmless.

The only drawback of these propellers is the difficulty of their construction, which makes them very expensive. The best-known makers are Messrs Chauvière, Pischoff, and Koechlin. They can be made in one piece like those of Messrs Wright and of M. Pischoff, or in superposed thicknesses or laminæ like those of M. Chauvière. Both methods require great skill and give good results. On the whole, however, we believe the latter method to be the better, as it allows the choice of the first quality wood without any flaws to impair their strength ; but it necessitates the use of special insoluble glue to unite the pieces securely.

The method of construction is as follows :—On an axis *xy* are threaded thin strips of wood, 1, 2, and 3, cut out according to the dimensions of the propeller. They are superposed as shown in fig. 32 and glued together. The projecting edges are then cut away along the lines *aa*, *bb*, after which the blades have to be shaped in accordance with the templates. Although this method of construction may appear simple, it is in reality extremely difficult, for the smallest irregularity affects the efficiency of the propeller to an enormous degree. When the blades have been shaped, they are polished and varnished.

It is obvious that the best shape of blade is that giving a cross section which combines strength with the least resistance to forward motion.

Sir Hiram Maxim has shown that the section illustrated

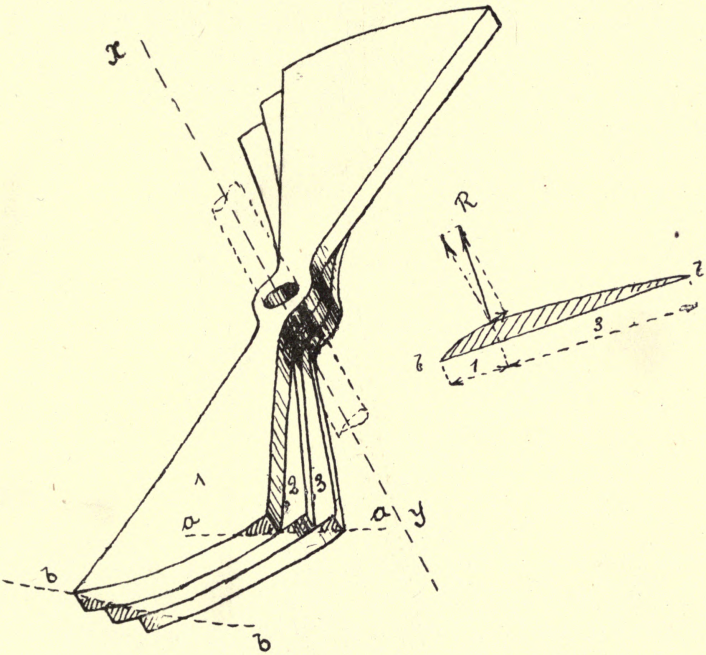

FIG. 32.

in fig. 32 is the best for this purpose. Its greatest thickness lies at about one-fourth of its width from the forward edge, where the greatest pressure is applied. Although we think it desirable to make *bb* slightly concave, several well-known engineers are opposed to this opinion.

(c) *Framework propellers*—In addition to the foregoing, a third class of propellers must be mentioned. In this case the blades are formed by arms and cross-members covered with fabric. The first propellers of this type were made by Colonel Charles Renard in connection with his dirigible balloon experiments.[1] They were formed by two lengths of steel tubing fixed to the axis of rotation at two different points. The cross-members over which the fabric is stretched are given a curve suitable to the helicoidal surface. M. Tatin has designed propellers of this type for existing dirigibles. In some cases the cross-members over which the fabric is stretched are only supported by a single steel tube.

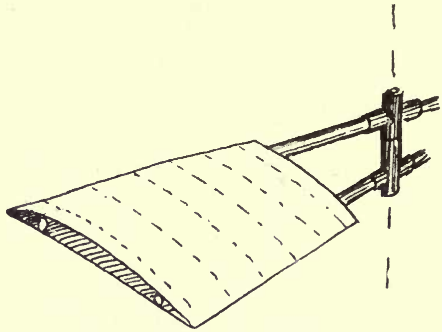

FIG. 33.

(d) *Other types of propellers*—Types of propellers can be multiplied *ad infinitum*, so that we are unable to refer to them all. Mention should, however, be made of the propeller with flaccid blades, which act solely through the action of centrifugal force. The blades consist of strips of fabric, to the extremities of which are attached iron weights. When set in motion the weights, under the action of centrifugal force, cause the blades to assume their proper shape.

Major von Parseval actually uses this type in his dirigibles. It is sometimes thought that these flaccid

[1] This type of propeller for aeroplane experiments was made in England by Stringfellow about thirty years before Renard.—EDS.

propellers possess the advantage of a variable pitch, but, in our opinion, this would not counterbalance the detrimental effect of the pockets which are formed in the

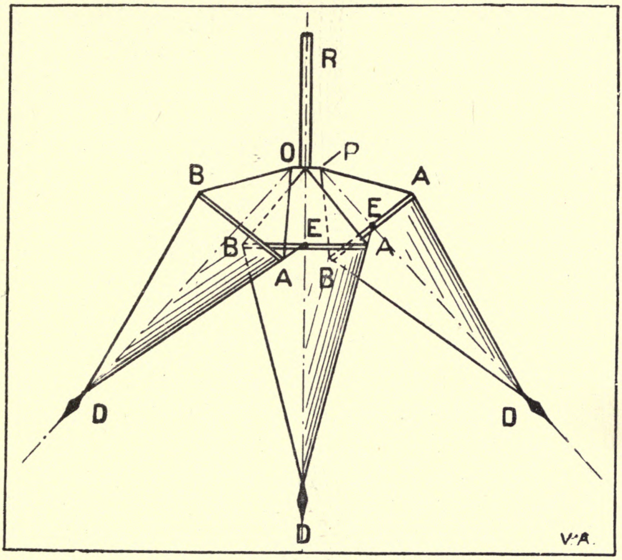

FIG. 34.

fabric during rotation. At any rate, the type is very little used; the firm of August Riedinger of Augsburg has patented a mixed type which, nevertheless, seems to possess good points.

CHAPTER IV

THE ARRANGEMENTS FOR STARTING AND LANDING

I.—*General remarks*

An essential condition in a flying-machine is its ability to leave the ground under its own power; and in order that it may do so quickly, as well as for ease in transportation, it should be able to move easily over the ground up to the moment of rising. Thus it is necessary to provide some means—wheels or skids—on which the machine may be readily moved about. These wheels or skids should be fixed to the chassis, which must be so arranged as to absorb the entire shock of landing. The chassis, moreover, must be flexible and capable of movement in any direction, for an aeroplane when travelling over the ground meets with all sorts of obstacles and is often turned out of its straight course. The wheels should therefore be capable of adapting themselves to circumstances. It is clear, then, that it is not easy to build a good chassis, and that the materials used must be of the first quality, strong and light.

Some few pilots employ a system of a rail and a tower or pylon, and launch their machines by means of a falling weight. In our opinion, however, this method will not survive, and we only mention it in passing.

II.—*Wheeled chassis*

The most general way of mounting chassis is on wheels, set like castors, free to move in all directions. The types

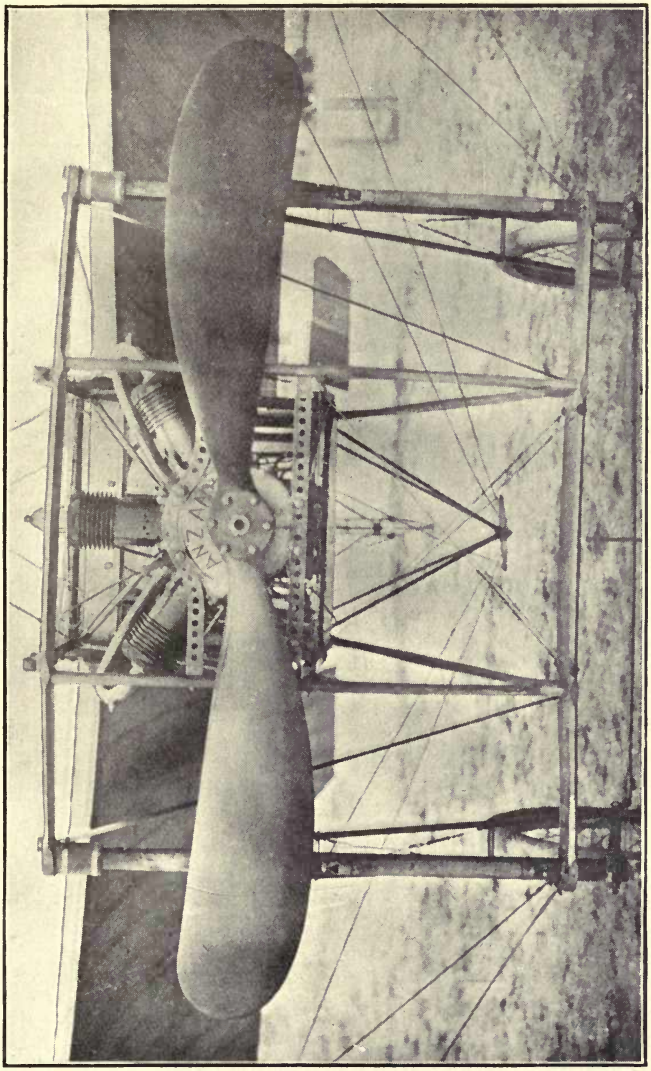

Fig. 35.

of chassis are so numerous that they cannot all be described in detail, so we will only mention those which are most widely used and those fitted to well-known machines.

(a) *The Voisin chassis* (fig. 37)—The Voisin chassis is the oldest now in use, and consists of a rigid rectangular frame of steel tubing. The longer sides of this frame are parallel to the ground, while the others carry the two forks which hold the wheels, and can move freely in every direction. Two steel tubes fixed to the frame unite it firmly to the fuselage, and at the same time act as receptacles for powerful shock-absorbers in the shape of

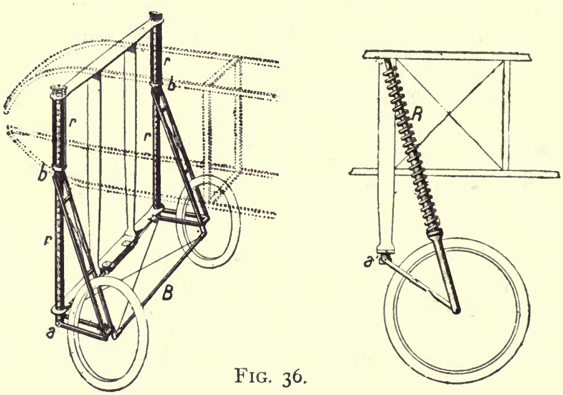

FIG. 36.

helicoidal springs. To ensure rigidity it is trussed with tension-wires. As the wheels would not run parallel if the forks were free to turn independently, the hubs are united by a jointed rod, and tension springs are stretched diagonally from the hubs to the framework.

This chassis has given abundant proof of its reliability, and has been adopted by many of the leading aviators.

(b) *The Blériot chassis* (fig. 36)—Simplicity is the chief feature of the chassis made by the hero of the Channel crossing. The main frame is of hard wood, and carries two steel tubes on which the wheel-forks slide. A jointed rod similar to that described above keeps the wheels

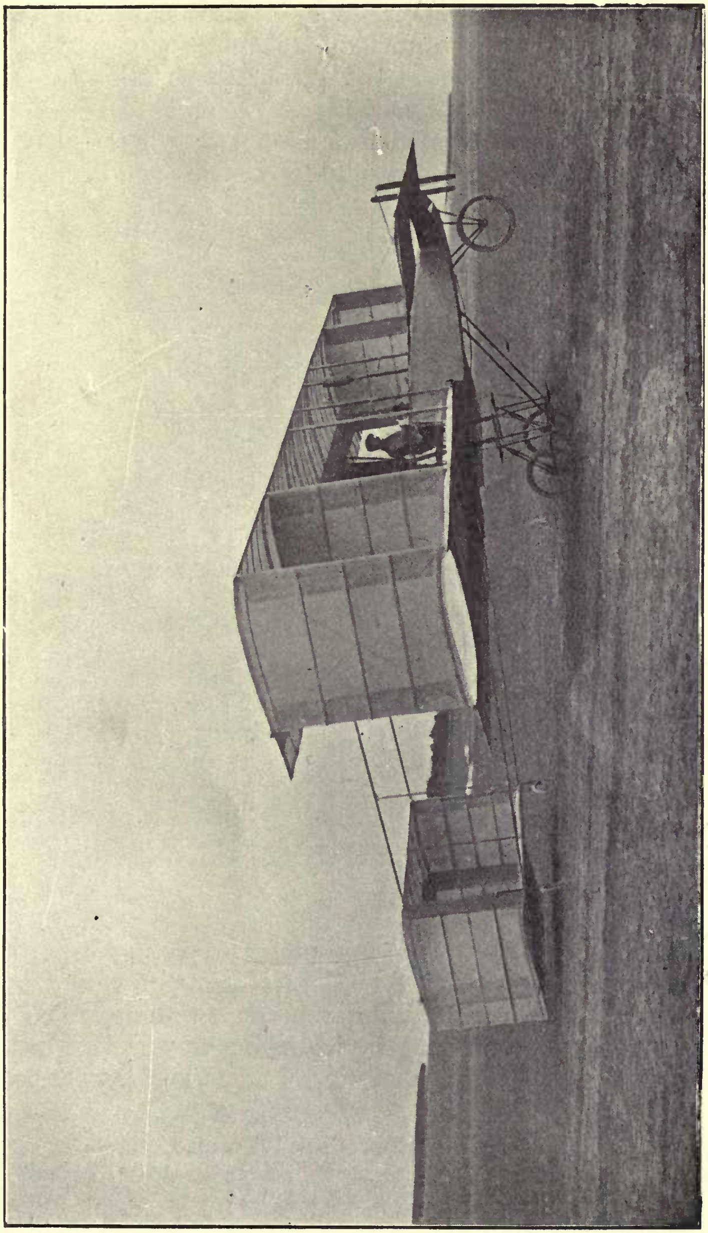

Fig. 37.

running parallel. Another type is also shown in the figure, which, though quite good, is not so often used. Its extreme simplicity does not warrant explanation.

(c) *The Antoinette chassis* (figs. 38 and 39)—The Antoinette aeroplane is mounted on two wheels placed close together and secured rigidly to the framework. Ad-

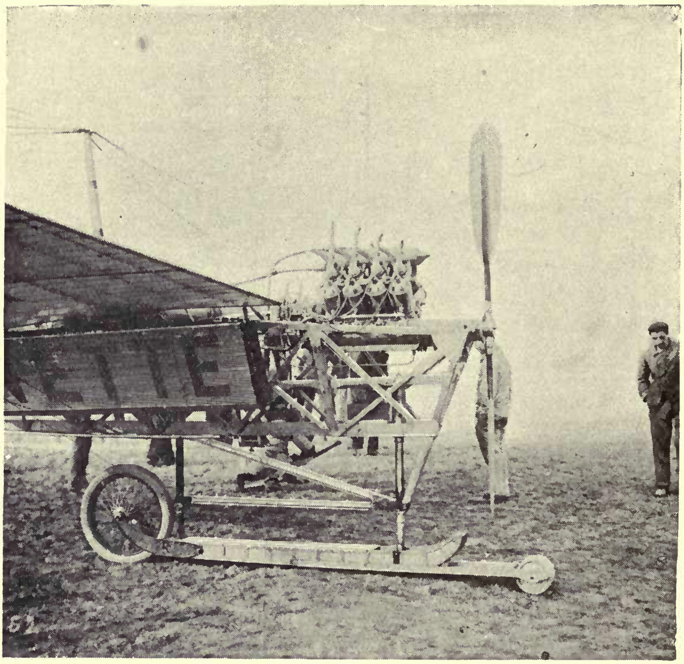

FIG. 38.

ditional support is provided by buffers projecting beneath the wings (see fig. 39). As this arrangement would be too rigid to absorb the shock of landing, two long wooden shock-absorbers are added in front of the wheels, which touch the ground before they do, and ease the descent.[1]

[1] The chassis has undergone considerable alterations since the above was written. The buffers have been discarded, and the wheels placed further apart.—EDS.

Such are the chief types of wheeled chassis. They are always constructed of steel tubing, as that has been found to be the best material for the purpose. Their assembling must, however, be conducted with care, on account of the great strains which they have to undergo. This is done in several ways : either by inserting the ends of the tubes in cast-iron angle brackets and brazing them bicycle-fashion, or by acetylene-welding the tubes together.

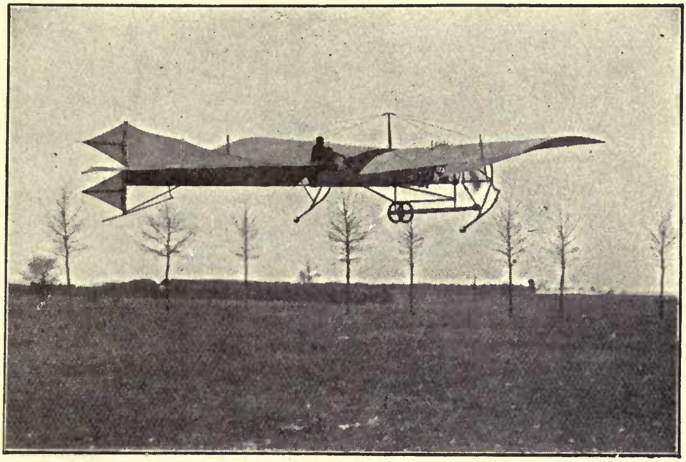

FIG. 39.

In the Esnault-Pelterie workshops the latter method is always used, with the result that R.E.P. monoplanes have a reputation for rigidity. The German Jatho aeroplane is entirely constructed by this process.

Another excellent chassis is that used on M. Karl Hippsich's aeroplane at Bremen. It is composed of two wheels on a common axle, with two rods carrying shock-absorbers, which are both inclined towards the centre of the machine, so that if the landing takes place on one wheel, the shock is taken orthogonally by the spring and sustained equally by the whole machine. If a normal landing on both wheels is made, the same result obtains.

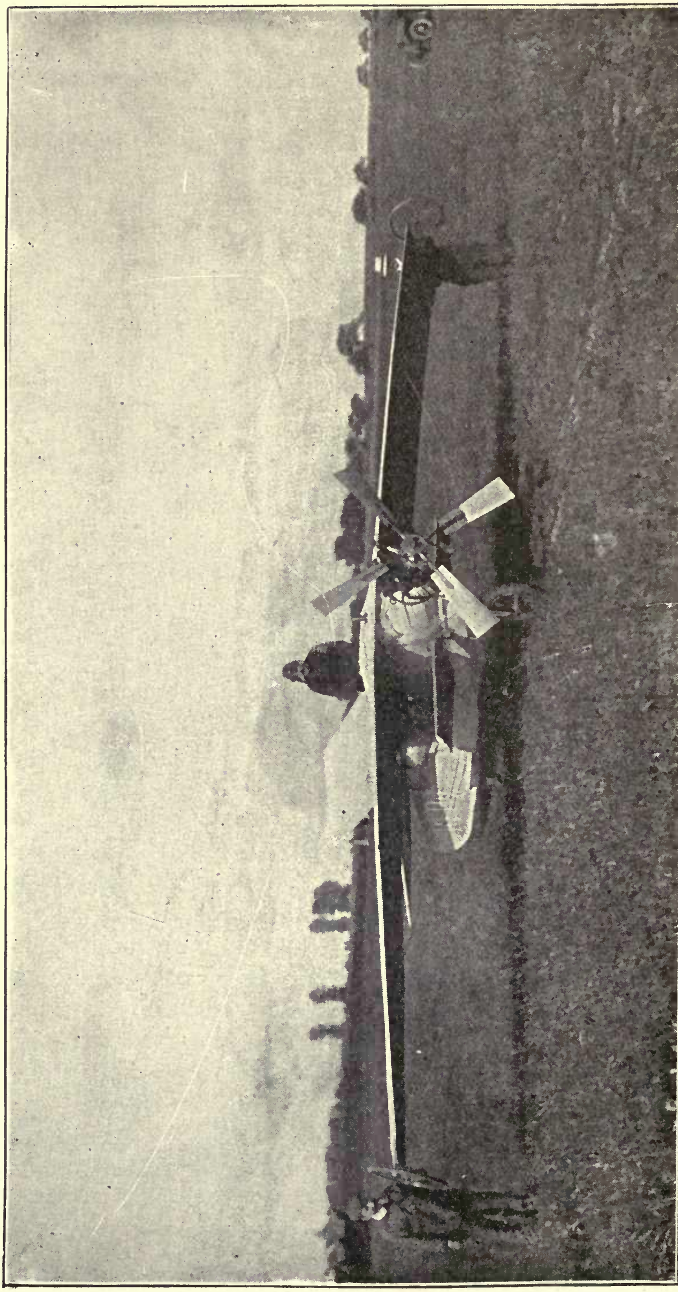

Fig. 40.

The Jatho aeroplane No. IV. is mounted on a chassis constructed of large steel tubes. The two front wheels, furnished with laminated waggon-springs, are under control, but the third wheel at the rear is left free. Every part of the machine is acetylene-welded.

In all the foregoing types the aeroplane, or rather its centre of gravity, is supported on two principal wheels, while the third wheel attached to the fuselage merely supports the tail and keeps it off the ground.

III.—*Chassis with skids*

This is the type employed by the Brothers Wright, and necessitates the use of supplementary means of starting. The Astra Company, who are the sole manufacturers of the Wright machines in France, make the skids out of American pine, the strength and elasticity of which renders it peculiarly adaptable to the purpose. They are shaped by being soaked and keyed on templates, which have a slightly greater curve than the one desired. After remaining soaked for some days they are dried, and the wood gradually springs back into its destined curve. They are then ready for use. The chassis is assembled by means of socket-brackets, and secured by small bolts, and the skids are fixed under the lower sustainer.

The American type of aeroplane is furnished with skids, and does not carry wheels. While inconvenient for starting, they are excellent for landing purposes, and for this reason several aviators have devised means whereby the advantages of wheels and skids may be combined in one system.

IV.—*Combined chassis*

The first of these was built by Henry Farman. It consists of two pairs of wheels, each pair crossing a skid fixed beneath the surface (fig. 42). The wheels are mounted on laminated waggon-springs attached to the

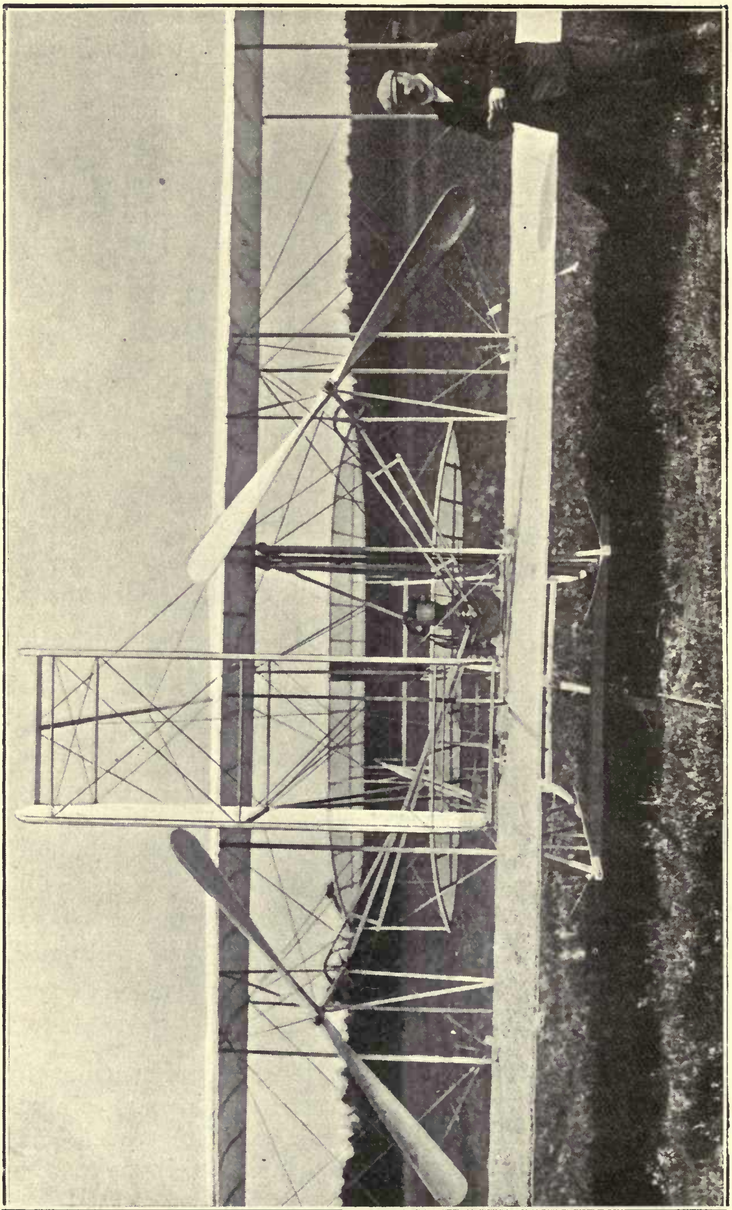

Fig. 41.

skids. If the landing is made with a certain force, the springs give, and bring the skids into contact with the ground, where their friction brings the aeroplane to a standstill. This device proved most satisfactory at

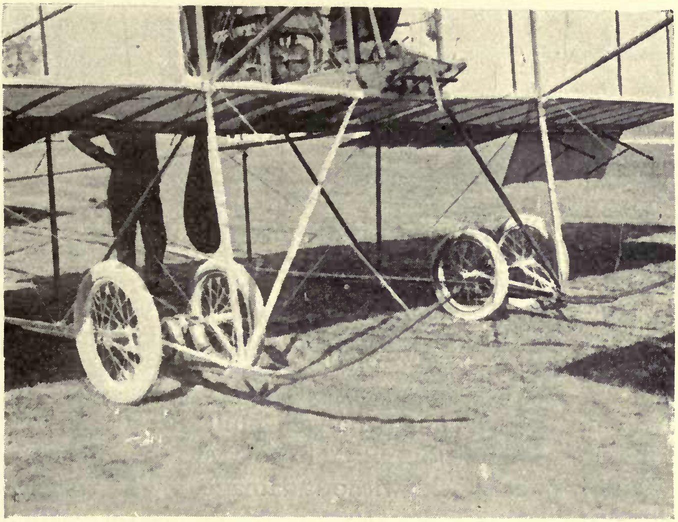

FIG. 42.

Châlons, and, with a little improvement, should become very popular.

The Prini-Bertaut aeroplane, tried at Juvisy, and the Herring-Curtiss biplane, are also fitted with wheels and skids, an arrangement which, in our opinion, will be applied to all machines in the near future.

CHAPTER V

THE FUSELAGE—BUILDING-IN THE MOTOR—THE CONTROLS

I.—*Necessary qualities of the fuselage*

We have now arrived at the most important part of an aeroplane, the fuselage.[1] It is to this part that the chassis, the sustainers, the motor, the control levers, the pilot seat, and the controls are fixed. It ought therefore to be capable of sustaining any strain, for it is the body, so to speak, of the bird.

It is most important that a well-built fuselage should be indifferent to vibration, be able to resist bending strain, and suffer great shocks without damage. The assembling of its constituent parts must be done in the strongest manner possible, for the construction of the fuselage is of as much importance as that of the aeroplane proper.

II.—*Various types of fuselage—Their manufacture*

A fuselage is in fact only a built-up girder, like that used in many other constructional operations. In aviation, however, it must be able to stand an equal strain, and at the same time be very much lighter than when used in other structures. For this reason its construction presents a very nice problem.

Under different manufacturers they assume various shapes, which are influenced by the position of the pro-

[1] Fuselage is the term generally used to denote the body of the aeroplane.—Eds.

peller. If the propeller is in rear of the surfaces, provision must be made for its revolution, as in the Voisin biplanes. The fuselage consists essentially of four members, joined by ties, and trussed by steel wire and strainers. Both wood and steel are used in its manufacture.

A wooden fuselage is lighter and quite as strong as a steel one, but is more expensive, owing to the difficulty of construction.

It is made either in triangular or square section, and in both cases the same methods are employed.

(a) *Wooden fuselage*—The templates, cut according to the plans, are secured temporarily on a very strong spar. Other rods forming the longitudinal members of the fuselage are bent along the templates, fitting in the notches left for this purpose. These rods are then tied with carefully chosen pieces of wood, sectionally and diagonally, to meet every possible strain (fig. 43).

After the ties have been placed in position, the whole frame is assembled in the way invented by Ader and Espinoza, which has been referred to in a previous chapter. This consists of winding fabric coated with glue round the joints. When the whole is dry, the templates are taken out and other ties inserted in such a way as to consolidate the whole structure. Finally, several coats of varnish are applied (fig. 44).

In this way very long fuselages and truncated fuselages are built: the former serve as the main body of the whole machine, while the latter only contain the motor and the control levers.

MM. Pischoff and Koechlin have built their monoplanes with fuselages which may be compared to the hull of a motor boat (fig. 45). It is an excellent type in point of strength, but its weight is often excessive. Some manufacturers build their fuselages in quite a simple way, as follows :—

The four longitudinal members have aluminium sockets attached to them, in which the ends of the lateral members fit. By this means the upper and lower constructions of

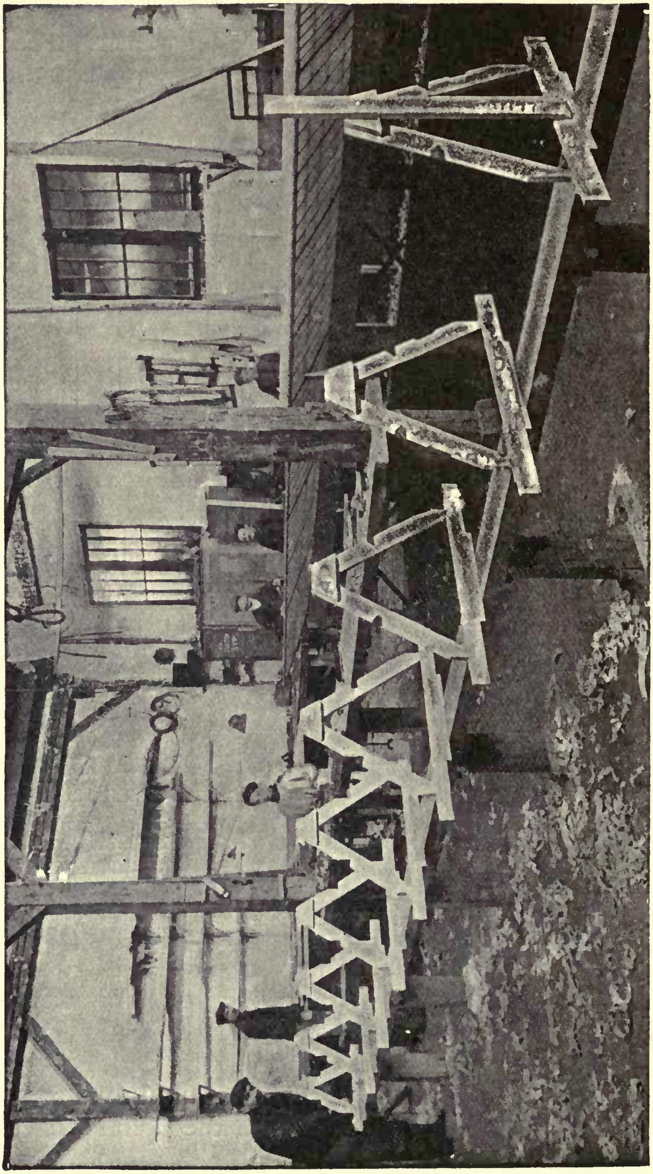

FIG. 43.

the fuselage are built up separately. It is easy enough when they have been completed to place one on the other and to join them. Wire stays are attached to the eye-bolts which fasten the sockets to the main members, and ensure the rigidity of the whole. It may be remarked

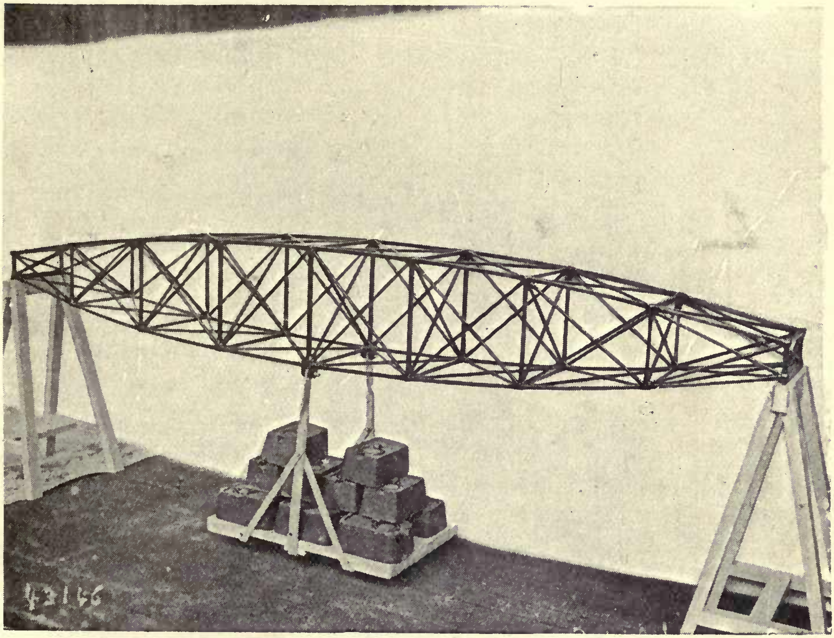

FIG. 44.

that this method is only easily applied to fuselages with not less than four sides.

In constructing a triangular fuselage, particular care must be taken to prevent weakening the sections of the lower member, which is caused by the insertion of a large number of bolts in each of them. In addition, it would be necessary to pierce sockets in some of the types, or otherwise the bolts will not be placed regularly as in the case of a quadrangular fuselage.

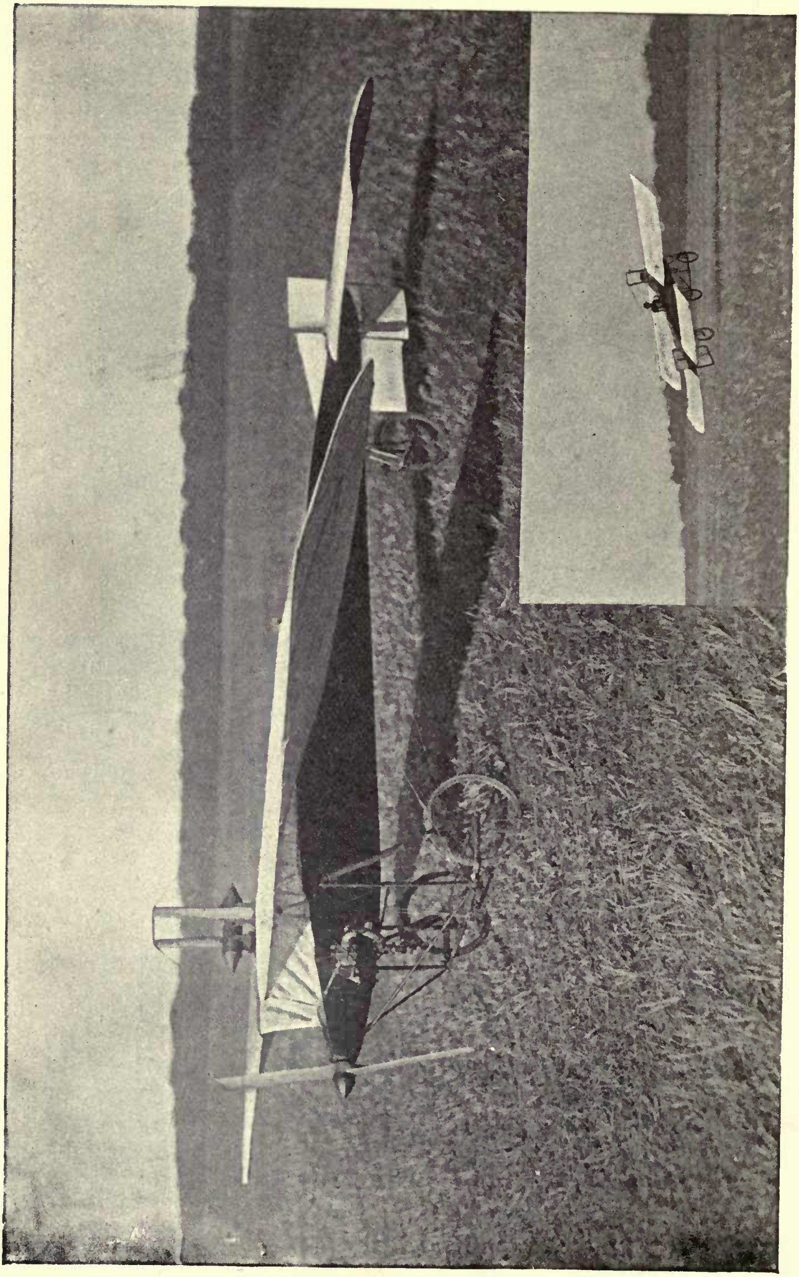

FIG. 45.

(b) *Metal fuselages*—Metal fuselages have the advantage of being rapidly and easily constructed without constant supervision. The Blériot machines are all provided with them. They are made by simply uniting the lengths of steel tubing with corner brackets and joining the longitudinal members together with steel-tube uprights. The whole is then braced with wire and strainers in the usual way (see fig. 46).

These fuselages will support a very heavy load without bending, but in certain cases they have the drawback of being unable to stand torsion ; and while the chassis, the

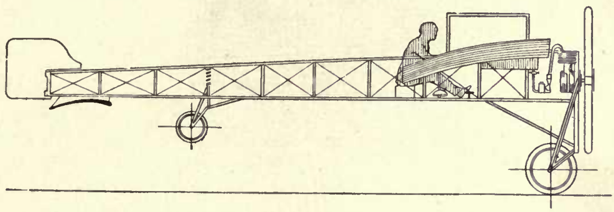

FIG. 46.

sustainers, and the controls are easily supported by them, the addition of the motor requires them to be very strongly reinforced.

III.—*Building-in the motor*

A wooden fuselage, unlike those in metal, is very suitable for carrying motors. It is only necessary to replace some of the parts, which will come into direct contact with the metal parts of the motor, by strong girders of T or V iron. Most aeroplane motors are mounted in this way.

In Voisin biplanes the motor is placed near the rear end of a very strong truncated fuselage made of hickory, above the lower sustainer. This wood framework is reinforced by two side-members and four cross-members of steel pierced with holes to reduce the weight.

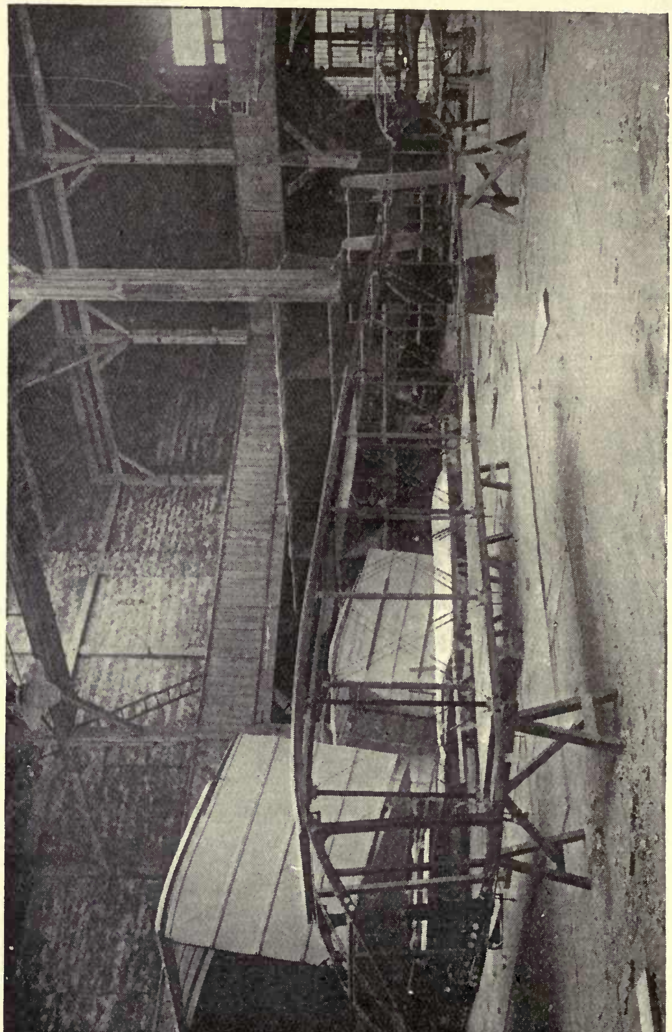

Fig. 47.

The motor is then bolted down on to similar hollow girders placed on each side.

In some cases, to avoid the additional construction, the whole of the fore-part of the fuselage is built of steel, as in the Bolotoff machine (fig. 47).

The mounting of a rotary motor is much easier. It merely consists of passing the motor shaft through the centres of two steel cross-pieces forming the diagonals of the fuselage in two different sections.

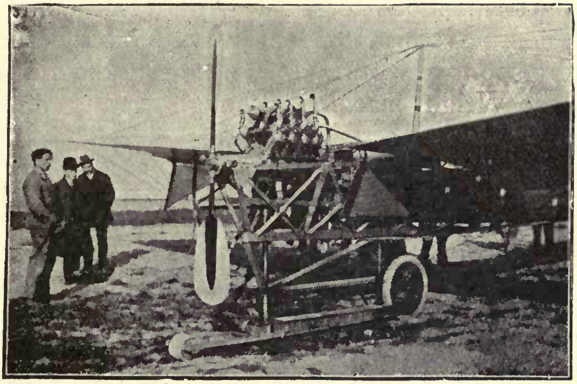

FIG. 48.

Fig. 48 shows the method of mounting an Antoinette motor, and fig. 78 a Gnome rotary motor on a Voisin biplane. In Antoinette and Blériot aeroplanes the motor is mounted in the same way in the fore-end of the fuselage.

The important point to remember in building-in motors is not the method—for all are similar—but the way of carrying it out. Care must be taken that the motor couple is not taken by a weak part of the machine. It should be distributed as far as possible over the whole perimeter of the fuselage. The bolting down of the motor, it need not be said, must be very carefully done, and frequently overhauled. A loose bolt in so fragile a framework may easily cause disaster.

The Wright motor is very simply mounted on two stout pieces of wood attached to the lower sustainer. This arrangement does away with the need for any fuselage, and only requires the sustainer to be strengthened where the motor rests. It must not be forgotten, however, that while it may be quite adequate on a Wright aeroplane, this mounting would not do on all machines. Most aeroplanes are driven by a single propeller, which sets up a tremendous torque with its lever point on the motor bed. If this point is situated on the sustainers they very soon wear out. It is not quite the same in the case of the Wright machine, although even there the contingency exists to a certain extent.

However, this way of mounting motors is not likely to endure in the future, and is only convenient for experimental work.

IV.—*Arrangement of the controls*

The various movements of aeroplanes in the vertical and horizontal plane are brought about by altering the angle of incidence of certain surfaces, which are hinged and moved in the required direction by lever or wheel controls.

The rudder planes are stretched on framework, and are easily controlled by cables led over small pulleys and connected with arms rigidly attached to their surfaces and projecting from each side. By moving them so as to oppose a portion of their surface to the wind, the pilot is able to guide the machine. This movement is accomplished by levers, which are capable of very easy and delicate operating.

Either hand or foot control can be used. The former is generally reserved for warping the surfaces, or for operating the ailerons, upon which the lateral stability depends, and which must be performed with the utmost nicety. The turning and elevating motions, calling for less care, are performed by double-armed levers, which combine both these movements in either direction. It may be remarked that the use of cables to manipulate the controls necessitates a duplicate set, because they

FIG. 49.

cannot be reversed to push back after being pulled forward.

The arms, therefore, fixed to the rudders and ailerons previously referred to, must project on either side, and have cables attached to each end in order to give a positive and negative movement to the surface.

Control levers, which are placed by the pilot's seat, must move easily, but not involuntarily. The use of a fuselage has the great advantage of allowing the pilot's seat, the controls, radiators, etc., to be easily disposed. A sort of platform can then be made on which are mounted steel supports carrying the bearings of the controlling mechanism.

The Voisin fuselage is well arranged in this respect. A

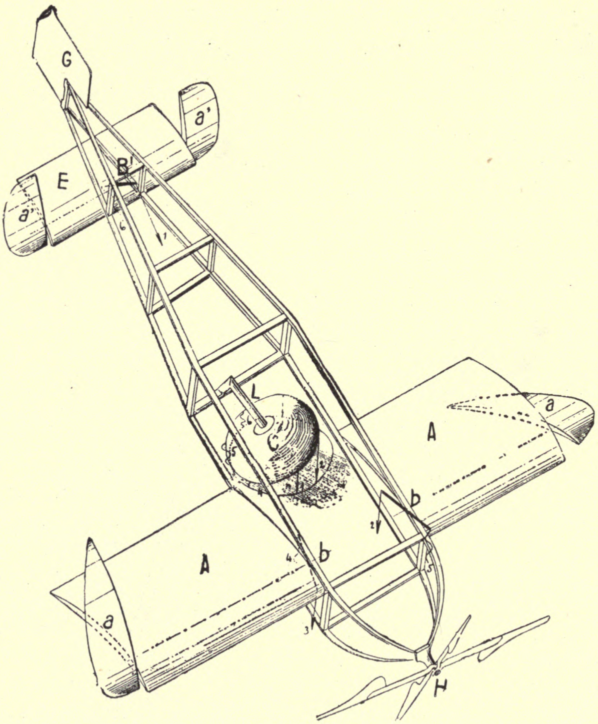

FIG. 50.

single steering-wheel controls the movements of the machine in both the horizontal and vertical planes, the former by being turned to the right or left, the latter by being pushed to and fro.

The elevator is mounted on a prolongation of the fuselage (fig. 37) formed by two plates turned upwards, in which are made two holes giving passage to the axis on which the elevator rocks. A rod rigidly connected to this axis is hinged to the rod actuated by the to-and-fro movements of the steering-pillar.

The Antoinette utilises the whole length of the fuselage, carrying the aluminium-tube radiator, invented by M. Levavasseur, on either side. The steering-wheels are on either side of a comfortable pilot's seat (fig. 49).

In Blériot aeroplanes, the controls are most interesting. A single steering-pillar is used, capable of movement in every direction, and carrying a large inverted cup. To the sides of this cup cables are attached, which pass over small pulleys and are connected to the rudders and ailerons. The inclination of the cup in any direction tightens one of the cables, and consequently affects the desired manœuvre (fig. 50).

Pischoff and Koechlin, assuming that in flight the pilot always tends to maintain his body in a vertical position, have invented a pilot's seat which can oscillate backwards and forwards. The elevator is actuated by these movements, which therefore should ensure automatic equilibrium.

The question of controls is obviously one in which the ingenuity of various constructors has full scope. In fact, many other contrivances have been devised, but the majority of them are impracticable.

CHAPTER VI

THE PLANES

I.—*General remarks*

After the fuselage, the chassis, and the motor have all been assembled, the machine is nearly ready for flight. It only lacks the planes, which are very difficult to manufacture for monoplanes, and only a little less difficult in the case of biplanes.

The planes, though very light and presenting a large surface, have to support the entire weight of the machine ; and while they must be flexible enough to sustain without injury the shock of landing, they must also be strong enough to keep their shape under the pressure of the air.

Wood or steel is used to fulfil these conditions in various machines.

II.—*Biplane surfaces*

The biplane takes the same place in aerial locomotion as the wheelbarrow does in the history of land travel. It was the first form of dynamic flying-machine to carry men through the air. It has been very much improved nowadays, and is being built by almost every manufacturer.

The Wright planes are made by the Astra Company in the following way :—

Two flat spars 12.5 m. in length are placed parallel to each other at a distance of 1.35 m. apart, and have their fore-edges rounded off in order to offer less resistance to the air (see fig. 51). The ribs are constructed of two flat members, curved in the manner previously explained. Small blocks of oak nailed between them preserve this curvature. The rear ends of the ribs are not secured, but are permitted to slide freely one on the other, thus yielding to any sudden air-pressure put upon them. The oak block *m* is screwed into the front spar, and the ribs, which are made of ash, nailed on to it (see fig. 51). The rear spar, being much flatter than the front one, is nailed in place between the rib-members.

Sometimes the ribs are cut out of planks 1 centimetre in thickness, and joined in front by a piece of sheet metal

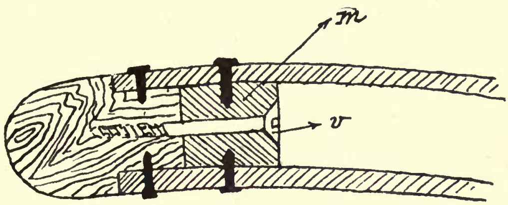

FIG. 51.

14 centimetres in length. In this case the rear spar is nailed over the rib-members.

The surfaces, when finished, are united by a system of upright members which has been patented by the Wrights. Rigidity is ensured by means of iron sockets which hold the ends of the upright, and prevent them from moving by means of a small bolt *b* (fig. 52). The ends of the uprights contain a slight concavity in order to clear the head of the screw *v* which fastens the socket to the main member or spar.

The top sides of the sockets are bent over and split to receive the wire stays, which are secured by split pins *g*.

The ends of the Wright surfaces must be capable of being warped, and must be hinged, and so a movable structure is necessary. This is shown in fig. 53. The parts G and H are capable of movement relatively to the bolt F.

It is clear from the above that the methods used by the Wrights are very economical, and applicable to all bi-

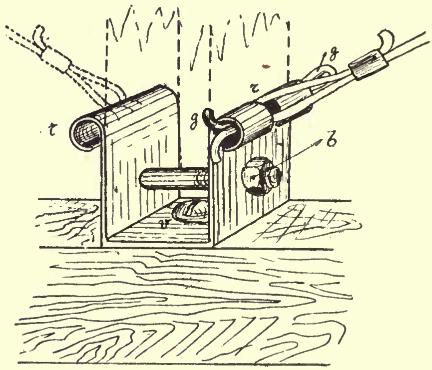

FIG. 52.

planes. The surfaces, moreover, are constructed very solidly, and easily warped.

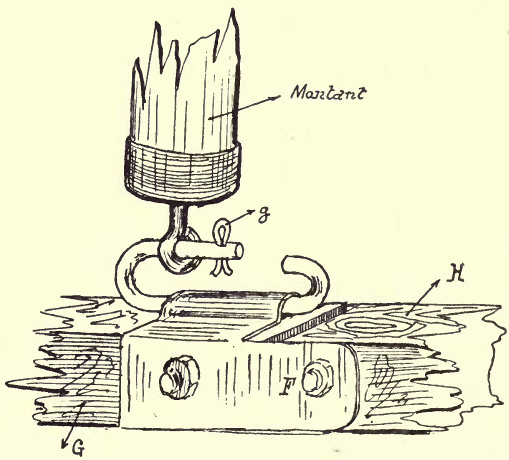

FIG. 53.

The Voisin surfaces are constructed in their general lines after the same fashion, but as they are not capable of being warped, they are much more rigid than those of the Wrights. The uprights are fusiform in section and carefully polished. The sockets which connect them to the surfaces are made of aluminium, and fixed to the main spars with eye-headed screw-bolts, which also serve to receive the wire stays (fig. 54).

Sometimes ordinary bolts are used, on which small steel connections for the wire stays are threaded before they are screwed into position.

Where bamboo is used for the uprights, a special way of assembling must be employed. The socket in such a

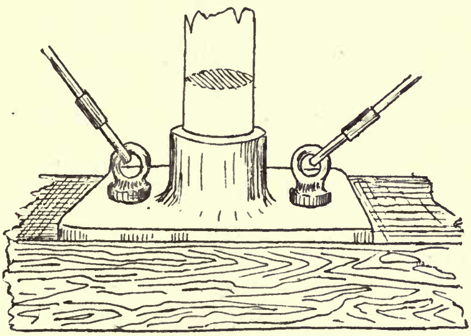

FIG. 54.

case is composed of two pieces of iron bound tightly together with steel wire. The end of the bamboo is slightly tapered with a file, and a piece of wood inserted to prevent crushing. But however great the care that may be taken in the assembling, a bamboo structure cannot compare in the point of strength with hickory or pine, as used in the Voisin machines.

III.—*Monoplane surfaces*

Monoplanes are the most interesting from a constructional point of view, on account of the problems that they offer. The framework of their surfaces is quite remarkable. The surfaces have for a long time been made in wood, and this method is still adopted in many cases, but steel also has recently come into use.

The surfaces of the Antoinette monoplanes are entirely made of wood, and all the cross members are of the same thickness (fig. 55 shows the fineness of the construction).

The main spars are of sufficient length to allow them to be joined together and secured to the fuselage. The ribs in this case are composed of two thin ash laths, with ties placed between them at intervals throughout their entire length.

In other machines it has been found better to cut them out of solid wood and pierce them with holes. The wings of the Blériot monoplanes are built up of ribs cut from wood 1.5 centimetres in thickness, which are inserted in a strong steel tube, with one-third of their length projecting in front of it. In this case the steel tube performs the same office as a propeller arm.

In order to strengthen the rear portion of the wing, six transverse members are placed parallel to the steel tube, and at the ends of the surfaces thin strips of curved wood are placed, to which the covering is attached.

The Esnault-Pelterie machine is entirely built up of steel tubes of all thicknesses welded together. The Jatho and the Hippsisch aeroplanes in Germany, of which we have previously spoken, are made in the same way. After the wings have been made, they are fixed to the aeroplane in such fashion as to unite them firmly to the fuselage, and the connection reinforced by a system of wire stays radiating from a mast in the fuselage. To facilitate this, holes should be provided in the steel tubes of the framework, or, better still, rings brazed on before the covering is attached, so that the wire stays may be fastened to them. The surfaces are covered with special fabric of which we have spoken in the chapter on Materials. The application of this fabric to the framework is an extremely delicate operation, as it must be stretched evenly and present a smooth surface. There are several ways of doing this, either by gluing it on to the wooden edges or by lacing it. Wright, who always uses simple methods,

FIG. 55.

merely nails the fabric on the cross spars and ribs, upholsterer-fashion.

The operation of gluing the fabric must be performed with care, as it is very difficult to repair any mistakes.

It is excellent for the machines which are not likely to undergo any alterations, but in general it is best that the fabric should be laced. If this is done, when there is a wing to be repaired the covering can be taken off, and replaced afterwards. On the Voisin machine the whole of the covering is laced, but only the tail of the Antoinette is treated in this manner. The fabric of the wings is stretched on, glued, and then varnished, in order to minimise the skin friction.

In cases where the surfaces are warped, the direction in which the threads of the fabric run is of importance. The weft should lie parallel to the line of flexure. The Wrights have adopted this method in their biplanes and patented it.

When the fabric has been placed in position in a monoplane, it only remains to stay the machine, which is done by joining different points of the wing-surface to the fuselage by steel wires ; this tends to preserve their shape while in flight. These wires are often attached to the end of a very strong upright fixed in the fuselage, as in the case of Blériot XI., in which the upright was a steel tube with four supports.

IV.—*The curvature of the cross section of the wing-surfaces*

We have not previously stated what form the ribs of the wing-surfaces should take ; it is, however, of the utmost importance, and a point upon which the efficiency of the aeroplane depends. Formerly they were true planes, containing no curve whatsoever. Experience showed later that the lifting power under these conditions is a great deal less than when the surfaces have a curve, with its centre nearer the forward edge than the rear. Nature herself provides us with an example of this in the wing of a bird.

Lilienthal, the great German pioneer, was the first to show the proper ratio between the arc of the curve and the surface. He gave it as one-twelfth of the width, and expressed the opinion that the curve should reach its highest point near the forward edge of the surface. These figures were arrived at by studying birds, and in the aeroplanes of Captain Ferber and the Wright Brothers they have proved their value. However, we do not think they ought to be accepted without reserve, for it is not our purpose to copy birds. Nature has fashioned these wonderful creatures, who, nevertheless, can only fly when they are perfect. If we copy them at all, we must reproduce every part of them so as to obtain the same results, but as we cannot do this, we must follow out our own ideas.

In our opinion, we ought not to copy the curve of a bird's wings, because they are provided both for flapping and gliding flight. No comparison can thus be made to our aeroplanes, which only glide. Moreover, according to Professor Marey, the head of a bird follows a sinuous course, to allow for the variations in the relative positions of the sustaining force and the centre of gravity. The wings, of course, reproduce this oscillation, which has no parallel in aeroplanes. It follows, then, that careful experiments should be made before adopting a curved surface. The work of a laboratory is better in certain cases than the easier method of observing Nature, and the results of the experiments of Sir Hiram Maxim are of more value for aviation than the works of Marey, Mouillard, or Pettigrew, interesting though they be. But the curve of the sustaining surfaces has not the importance with which it is usually credited.

The wings of the Antoinette are absolutely symmetrical and are very efficient. What is of importance is the angle of incidence of the plane. The same problem has already been faced in hydraulics and thermodynamics in the case of steam- and water-turbines. The fluid, whether of air or water, must flow regularly around the surface without disturbing its continuity, and it must split the energy due to its velocity V into two parts, the one producing resistance to forward motion, and the other giving lift.

A curvature of a proper shape should increase the latter and decrease the former. The air should then leave the surface with the vertical velocity v, so as not to interfere with the following masses of air. In a word, for the curve should be a good one, the air must be pressed downwards as soon as it reaches the surface with this constant velocity ; and in order to produce lift it ought to possess a uniform acceleration, which will compensate v and preserve its minimum value.

It is easy to reduce these considerations to an equation giving a parabolic curve, which must have its highest point near the forward edge. From this it can be seen that the parabola, which already possesses astonishing qualities both in optics and physics, retains them in aviation also. In addition to those mentioned, one occasionally meets with curves of an extraordinary nature, arrived at by practical experiments, and sometimes without any theoretical grounds ; but no good results can ever be obtained by the construction of aeroplanes on these lines.

CHAPTER VII

MOTORS

The theory that the aeroplane motor must of necessity be of extreme lightness is of ancient origin ; it was confirmed by the late Colonel Renard, who expressed the opinion that artificial flight would only be rendered possible when the weight of the motor was reduced to 1½ kilos (3.3 lbs.) per HP. Even at the present time many engineers sacrifice reliability to lightness, with the consequence that the working of the motor is seriously affected. When will it be understood that the best motor for an aeroplane is the ordinary motor-car engine, with its weight suitably reduced ? Figures are the best proof. At Le Mans, Wilbur Wright flew with a passenger weighing 100 kilos (220 lbs.) by means of a 25 HP motor. His motor might, therefore, equally well have weighed 4 kilos (8½ lbs.) more per HP. At Issy, Blériot, in his monoplane No. XII., flew with an extra weight of 240 kilos (530 lbs.) driven by a 35 HP E.N.V. motor weighing 77 kilos (170 lbs.). He could therefore have flown with a motor of the same power weighing $77 + 240 = 317$ kilos (700 lbs.), or 9 kilos (20 lbs.) per HP. So that Colonel Renard's figures need not be too seriously considered.

On the other hand, it would be a mistake to overlook the importance of the reduction in the weight of the motor. For the future it is of equal, if not of greater, importance than was the case in the olden days with the motor car.

It is perfectly evident that the lighter the motor of an aeroplane, the greater will be the quantity of petrol that can be carried, and, consequently, the greater the distance it can cover. At a future period, when small machines designed to carry only one person are being built—machines that will really be equivalent to the motor bicycle—the lightness of the engine will be of great importance, since it will enable the span, the total weight, and consequently the cost, to be reduced. But it is unquestionably a mistake to hold that artificial flight in itself is dependent on a motor of excessive lightness.

From a wholly different point of view, however, reduction in weight of the motor is not to be decried, since it has led, and will in future lead, to interesting discoveries. Reduction of weight was first achieved by manufacturers by cutting down their material: angles were rounded off, shafts and connecting-rods were cut down to the lowest possible diameter. In some cases new systems of cooling were invented, in others the fly-wheel was suppressed. Subsequently, when the structural material could be reduced no further, the very principles on which the working of the motor was based were revised. Two-cycle motors made their appearance as automobile racing was nearing the end of its vogue, since when we have seen in succession rotary motors, valveless motors, and a host of other interesting types, which, by going to the root of motor-design, have paved the way for the discovery of several new principles in practice no less than in theory.

Until now we have only considered the internal-combustion motor driven by petrol. At the present time it is the only engine universally employed, and in all probability the type will endure for many years to come. It has the enormous advantage that its fuel, petrol, is exceedingly light. Its flexibility, moreover, is increased every day by the application of new inventions. Its solitary drawback, which by the way seems to have very little terror for our constructors, is that it entails a high speed of rotation, which necessitates the use of transmission by bevel or chain—both of which absorb a good deal of power and lower the efficiency—if slowly revolving propellers are used. On the whole, however, this drawback is not very serious, for in practice we have seen that aerial propellers can perfectly well be mounted direct on the shaft.

Nevertheless, a tribute should here be paid to the lifelong labours of the two great pioneers, Clément Ader and Colonel Renard, to whom is due the credit of having reduced the weight of the steam-engine to its lowest point.[1] The marvellous steam-engine built by Ader for his "Avion III.," with which he flew 300 metres at Satory, can still be seen at the Conservatoire des Arts et Métiers in Paris. Colonel Renard also built a very light steam-engine at Chalais-Meudon, whose most remarkable feature was its aero-condenser, and he was, moreover, the first to propose to apply the electric motor to aerial vessels. The first air-ship which was dirigible in fact as well as in name, *La France*, carried a dynamo supplied with electricity from a wonderfully-designed battery, which to this day has never been surpassed. To this reference to the electric motor we may here add that the discovery of a *light* magnetic metal would render it immediately applicable to aviation.

Although this is mere speculation, for the present at all events, it may be observed that, should this problem ever be solved, the aeroplane of the future would be propelled simply by an armature in motion between two electro-magnets. And since we have embarked on speculation, we may mention that the time is not far off when the wireless transmission of electrical energy through space, by hertzian waves or other means, will be realised. The experiments along these lines of Mr

[1] The late Professor Langley and Sir Hiram Maxim, as a matter of fact, both reduced it further: the former, in 1901, built an engine developing $1\frac{1}{4}$ HP with a total weight of just under 7 lbs. The latter, in 1894, built a couple of compound steam-engines, weighing together 640 lbs., and developing a total of 362 HP, or $1\frac{3}{4}$ lb. per HP.—Eds.

Mark O. Anthony with a model dirigible, and of M. Gabet with his submarine torpedo, indicate that this problem is almost solved. The ideal motive power would then have been found, the more so since the velocity of rotation of the armature could be varied by means of a simple rheostat. For the present, however, these are only dreams, whose wings are apt to carry one farther even than those of an aeroplane. It would, after all, perhaps be better not to attempt to attain the ideal at a bound, but rather to advance methodically, contenting ourselves for the moment with the internal-combustion motor, and seeking rather to perfect it.

The internal-combustion motor owes its rapid development to the motor car, and the aeroplane motor has been evolved by the efforts of those workers who sought to reduce the weight of the engine invented by Daimler. Many engineers have worked at the problem, with the result that it has been solved in several different ways. Any attempt to describe in detail every aeroplane motor would inevitably increase the length of this book beyond all possible limits, so that we shall confine ourselves, firstly, to a description of the general characteristics of the aeroplane motor, and secondly, to a more detailed account of some of the best-known types which have already been successfully tried in flight.

To reduce the weight of the motor-car engine, and so produce an aeroplane motor, the first necessity was to suppress the fly-wheel. This was accomplished by increasing the number of cylinders, whose pistons act in succession on the motor-shaft, and so rendering the work exerted on the shaft more constant. By these means the necessity for a fly-wheel, which is designed to store up power at the moment when it is at its highest, in order to yield it up again when it has become negative, is abolished in principle. But here arises the difficulty, that a large number of cylinders requires a corresponding increase in the length of the shaft, which is therefore weakened if the same section is retained. This difficulty has been overcome in practice by various methods. Some manufacturers, such as M. Levavasseur and many others, have disposed the cylinders in two rows, inclined to each other at an angle; this is the "V"-shaped arrangement. Others, particularly M. Esnault-Pelterie, have adopted the fan-shaped arrangement, which very greatly reduces the length of the shafts. These motors will be dealt with in detail later on.

This, then, was the origin of the motors with "V" and "fan" or "star" arrangement. But another type of motor has lately become prominent, and has played a part in some of the longest flights yet made—the rotary motor. This motor possesses the enormous advantage of dispensing with water-cooling and its heavy accessories. Its high velocity of rotation in the air in itself produces all the cooling that is necessary.

There are grave difficulties in cooling a motor with fixed cylinders, on account of the directly opposite requirements of the radiator and the aeroplane. If the radiator is placed orthogonally (*i.e.* at right angles) to the direction of flight the cooling is excellent, but the resistance to the air is enormous. If, on the contrary, the radiator does not meet the air with its full surface, resistance is diminished, but only at the cost of rendering the cooling inefficient. We are therefore placed on the horns of a dilemma. In the Voisin aeroplanes the radiator is placed transversely to the direction of flight; other builders, on the other hand, place the aluminium tubes laterally along the length of the body, as in the case of the "Antoinette" monoplanes. In other cases, again, the superficies of the radiator is utilised as a carrying surface. Several fixed-cylinder motors, finally, are cooled by a current of air forced through a surrounding jacket by a ventilator mounted on the shaft. But in every case we are finally brought back to the same result, that cooling is only obtained at the loss of power.

Hitherto we have only referred to the means adopted to lighten the motor that are outwardly visible. But many other methods have been tried. In some motors, in fact, the carburettor has been suppressed, and the petrol is simply fed into the cylinder-head by appropriate means: this is the method adopted by Levavasseur in the "Antoinette" motor.

Another new departure in motor construction, originating in the development of the aeroplane motor, is the arrangement of the valves required in the rotary motor. Some of these will be mentioned in the detailed descriptions of the various motors. Methods of ignition, finally, offer a wide field for active experiment; the same holds good for many other departments of motor design, so that we cannot doubt the eventual perfection of the internal-combustion engine, high though the level of excellence already attained.

This brief study of the motor question is best concluded by a description of some of the leading types.

I.—*Fixed-cylinder motors*

(a) *Antoinette* (figs. 56 to 59)—The "Antoinette" was the first of all aviation motors, and even of light motors of every description. In former days the "Antoinette" motor boats carried off many of the great races. Even at the present time this motor is the lightest of all, and was used in the first flights of Santos-Dumont, Farman, Blériot.

Its design, due to M. Levavasseur, presents many interesting and ingenious features. It belongs to the type already mentioned in which the fly-wheel is replaced by a large number of cylinders mounted in the shape of a V. The number of cylinders varies from 8 to 16 and 32. Its exceedingly low weight—about 1 kilo ($2\frac{1}{4}$ lbs.) per HP—is forcibly illustrated in the extraordinary photograph of a man carrying one of these 100 HP motors on his shoulder

—a feat which may well be compared to Atlas supporting the world.

The forged steel cylinders are cooled by water circulating within a red copper jacket which is deposited round the cylinder walls by an electro-chemical process which gives a sheet of extreme thinness. It is well known that

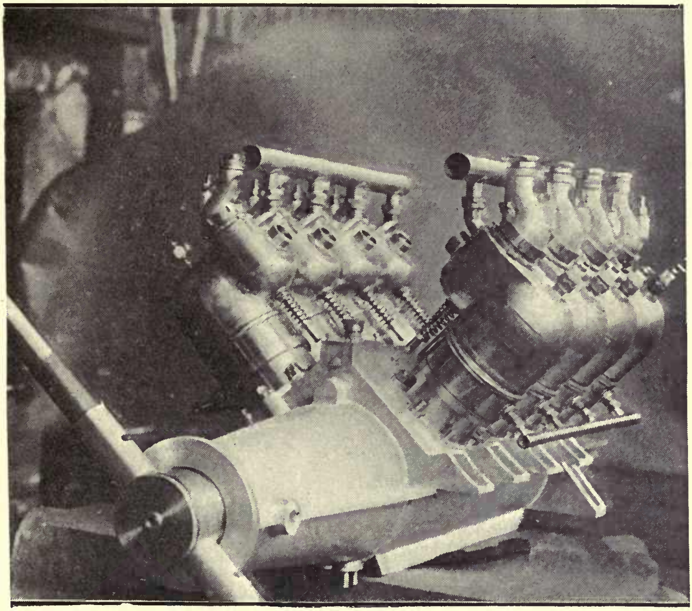

FIG. 56.

different metals expand in different degrees when subjected to the same temperature. In order, therefore, to neutralise differences in expansion which are set up when the motor is working, the walls of the copper jacket contain what may be described as a fold, which allows them to stretch if need be. The motor is bolted to the aeroplane frame in the simplest manner, as in the ordinary motor car. The screw-propeller is mounted direct on the crankshaft outside the crank-case. The water heated by contact with the cylinder walls is rapidly cooled through being passed through a radio-condenser, and the drops of water condensed in the aluminium tubes are collected and

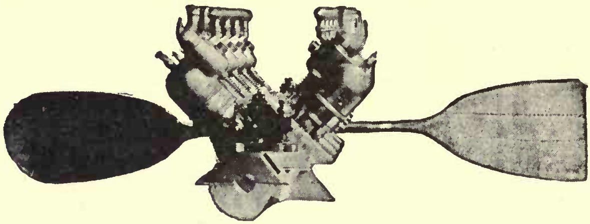

FIG. 57.

pumped back into the tank. Aluminium tubes, 4 metres in length, arranged laterally along the sides of the body, compose the radiator. The petrol is fed direct into the

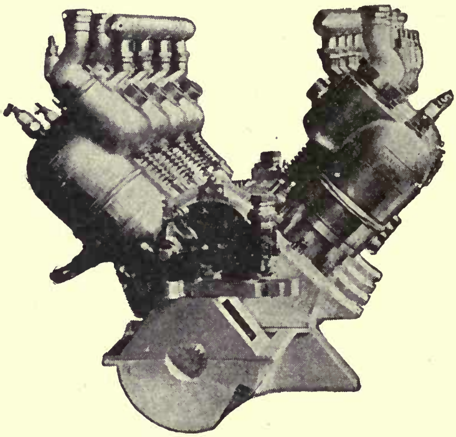

FIG. 58.

cylinders, in the quantity required for each explosion, by a distributor.

The "Antoinette" motor therefore possesses several novel features. On Latham's monoplane it has already rendered a brilliant account of itself. The type most generally employed is the 8-cylinder 50 HP, the strength of which is indisputable. After many a severe accident, when the remainder of the machine has been reduced to a state of wreckage, the motor has been found intact.

(b) *Anzani* (figs. 60 and 61)—The famous monoplane Blériot XI. was driven by an "Anzani" motor on its cross-Channel flight from Calais to Dover. In its design are embodied many features derived from M. Anzani's

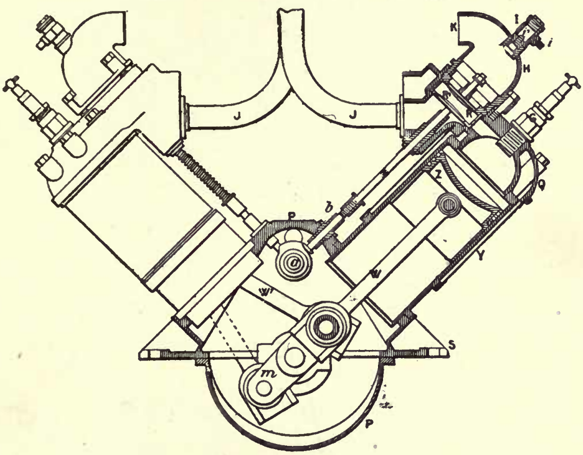

Fig. 59.

year-long experience of motor-bicycle racing. Strength and reliability are its chief qualities. Aluminium is dispensed with as far as possible, steel and cast iron being its chief structural materials. It is cooled by the action of the air on the fins.

The cylinders are arranged fanwise, and inclined to each other at an angle of 60°. The method of ignition renders it equivalent to a motor with 6 cylinders placed starwise. In consequence, the motor-couple is extremely regular.

The most general type is the 6-cylinder 24 HP.

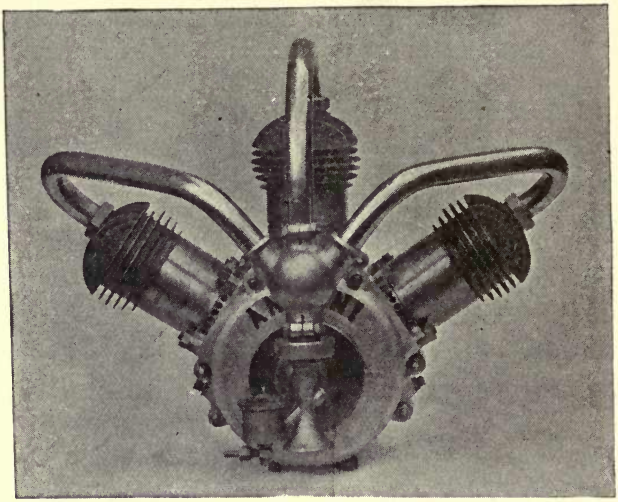

FIG. 60.

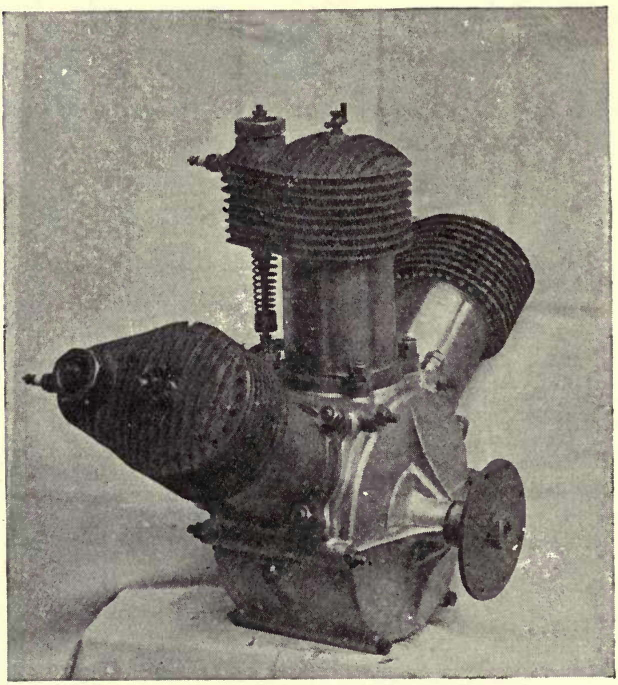

FIG. 61.

(c) *Esnault-Pelterie* (figs. 62 and 63)—The "R.E.P." is perhaps the most carefully designed of existing light motors.

The composition is remarkable from every point of view. Starting with the simple laws of the structural strength of various materials, and drawing upon his wide

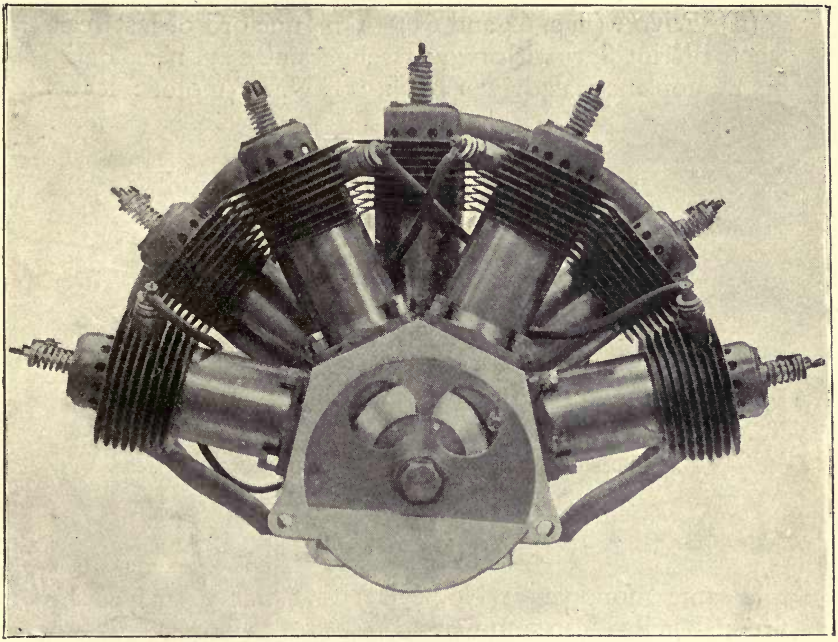

FIG. 62.

knowledge of the most recent developments of metallurgy, Esnault-Pelterie has succeeded in producing a motor which gives a maximum HP with a minimum weight. The strength of materials never exceeds a certain value; hitherto this strength has only been called upon to furnish the highest possible result during a very small fraction of time. Esnault-Pelterie has started from the principle of lengthening the duration of the maximum effort, and has succeeded in utilising the whole force of cohesion of metal.

From the point of view of its working, the "R.E.P." motor needs no special mention; its construction alone deserves attention.

The cylinders are arranged fanwise, and act on the same crank. Ignition is by high-tension magneto.

(d) *E.N.V.* (figs. 64 and 65)—On June 3rd of last year, when Blériot flew with two passengers at Issy, near Paris, his monoplane was driven by an "E.N.V." motor: it was

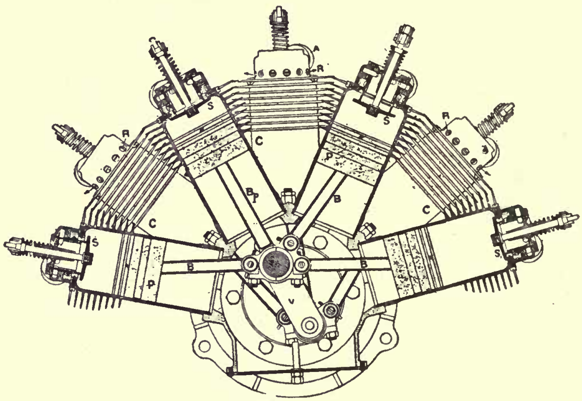

FIG. 63.

this same monoplane (No. XII.) that was destroyed by fire at Rheims last summer.

The only feature that calls for special mention is the lubrication, which works very efficiently by a pump which causes a continuous circulation of oil on the frictional surfaces, and is regulated by a float.

The cooling is effected on the same principle as in the "Antoinette" motor, by water circulating in a red copper jacket.

The most usual type has 8 inclined cylinders, 100 m/m bore by 130 m/m stroke, and develops 50 HP at 1000 r.p.m. Its weight is no more than 75 kilos (165 lbs.).

The crank-shaft is hollow, and the webs are dispensed with in favour of discs.

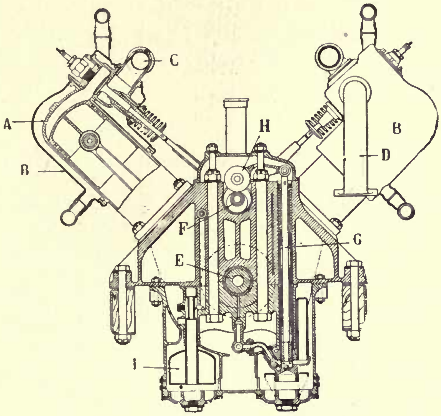

FIG. 64.

(e) *Gobron* (fig. 66)—"The Gobron" motor embodies the famous principle of opposed pistons, which gave rise

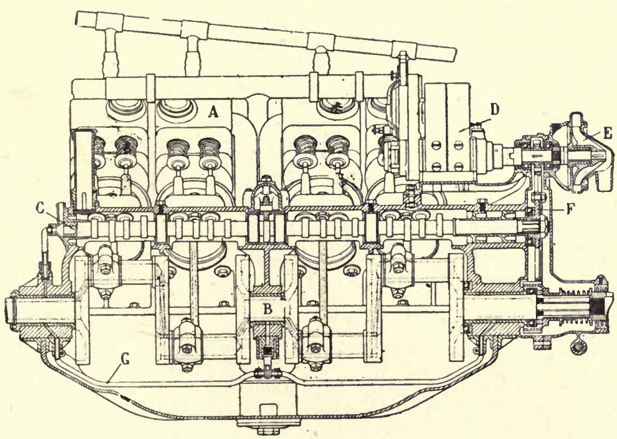

FIG. 65.

to so much discussion at the time of the Grand Prix Motor Races. It has 8 cylinders, placed crosswise. Each cylinder contains a pair of pistons working in opposite directions.

The motor develops 80 HP and weighs 150 kilos. Its fuel consumption is no more than 35 cubic centimetres per HP-hour. It has been used on the Bréguet and Gobron aeroplanes.

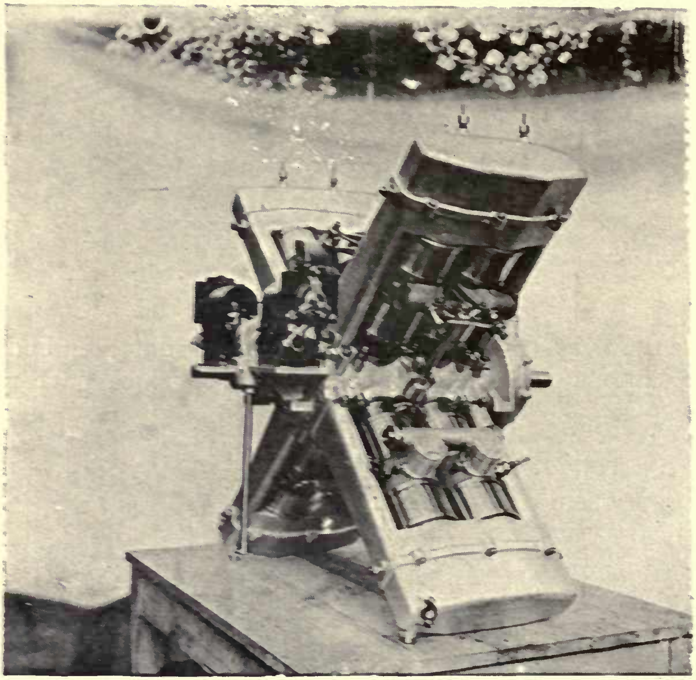

FIG. 66.

(f) *Dutheil and Chalmers* (fig. 67)—On M. Santos-Dumont's miniature monoplane it has given proof of excellent qualities. It is noteworthy by reason of the small space it occupies and the simple manner in which it can be mounted on an aeroplane. The cylinders are horizontal and opposed. A point to be noticed is the excellent hemispherical combustion-chamber, which is devoid of any space that can interfere with the perfect explosion of the mixture.

The ignition of each cylinder is absolutely independent of that of the others, so that the motor is started with the greatest ease. The position of the cylinders absorbs nearly the whole of the vibrations, so that the motor can be mounted on the very lightest and most fragile of machines.

It is built with 2, 4, or 6 cylinders, opposed in pairs, and working on a crank-shaft with 2 or 3 throws placed at 180°.

(g) *Farcot* (fig. 68)—This motor is of entirely novel design. It has 8 horizontal cylinders, placed starwise around a crank-chamber which contains the vertical shaft.

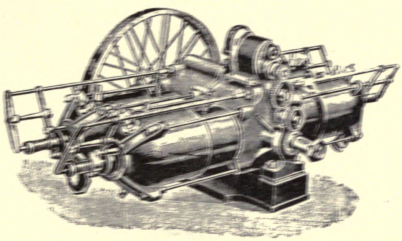

FIG. 67.

Cooling is by air-fins, but is aided by a large ventilator which propels the air on to them. The only drawback of this method is, that it causes the loss of a part of the power that could otherwise have been utilised for propulsion. The inlet valves are particularly ingenious. No aluminium is used in the construction, and the strength is kept unimpaired. This motor is sold in the following powers—30, 50, and 100 HP, which weigh respectively 40, 50, and 98 kilos (88, 110, 216 lbs.).

(h) *Clerget*—This motor, which is mounted on Tatin's aeroplane, belongs to the class of motors with cylinders placed starwise in a horizontal plane. The fly-wheel is situated outside the crank-chamber, and horizontally above the motor. To M. Tatin's great annoyance, this gave rise to the curious error that his aeroplane was fitted with a gyroscope to ensure stability.

(i) *Other types*—Space forbids us to describe separately each remaining type of fixed-cylinder motors: among the better-known are Renault, Wright, Buchet, Bayard-Clément, Panhard-Levassor, etc., in France, and Argus, Neckarsulmer, F.N., Pipe, Fiat, Körting, Ellehammer,

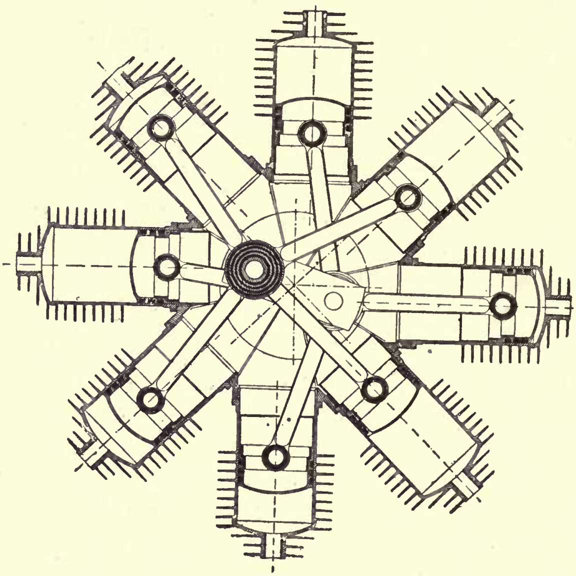

FIG. 68.

etc., in other countries (fig. 71 and following). Their general features are rendered clear by the photos and diagrams. Special mention should, however, be made of the three-cycle Korvin and Rebikoff motor, which was exhibited at the Salon of 1908.

II.—*Rotary motors*

Until now, the only motors dealt with are those whose cylinders are fixed to the chassis, and which are cooled by

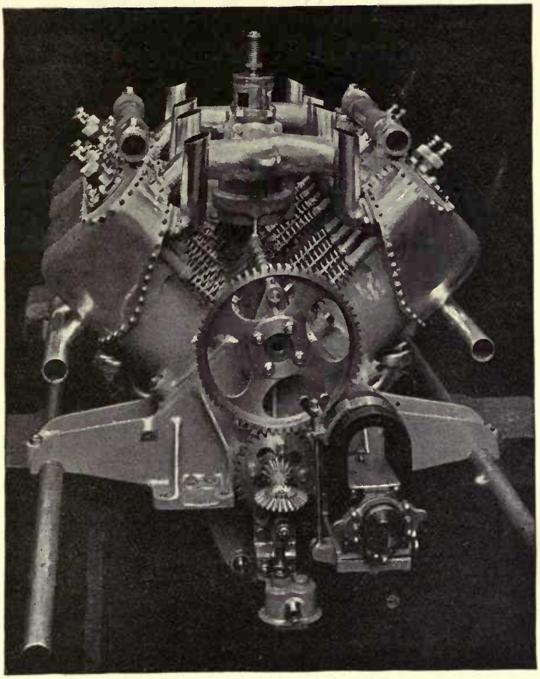

FIG. 69.—Siddeley-Wolseley Motor.

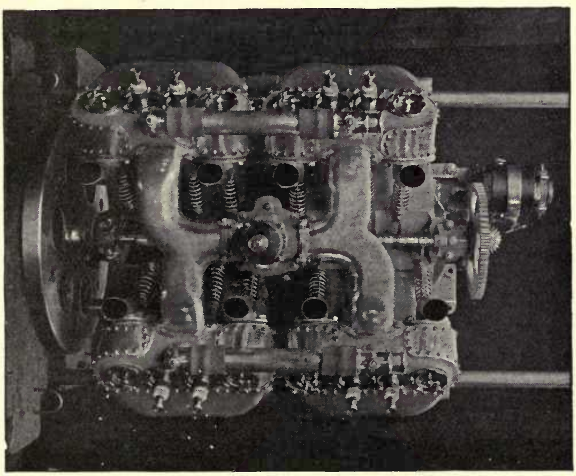

FIG. 70.—Siddeley-Wolseley Motor.

various external methods. A word remains to be said of the motors whose fixed shaft serves as an axis of rotation

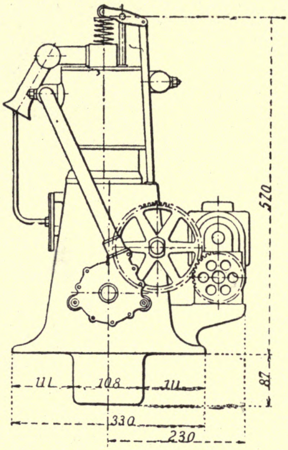

FIG. 71.—Wright Motor.

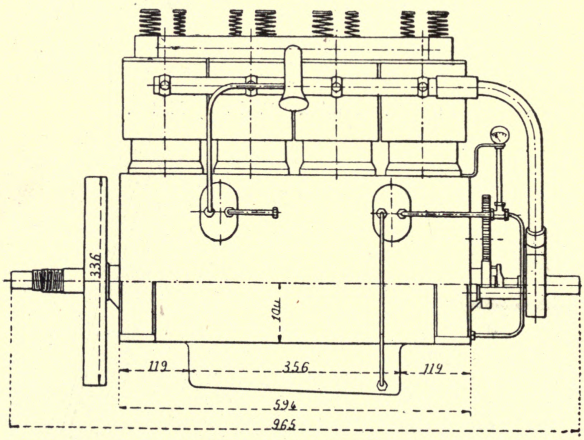

FIG. 72.—Wright Motor.

for the cylinders: these are known as Rotary Motors. By their high velocity of rotation these motors have undoubtedly solved the problem of air-cooling, but, on the

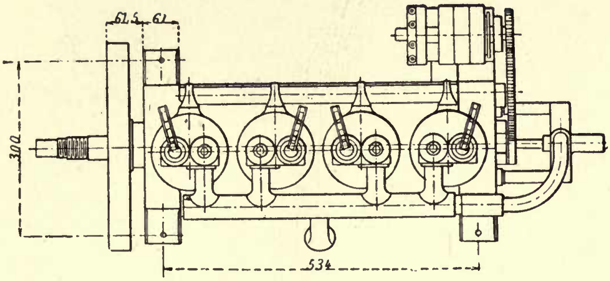

FIG. 73.—Wright Motor.

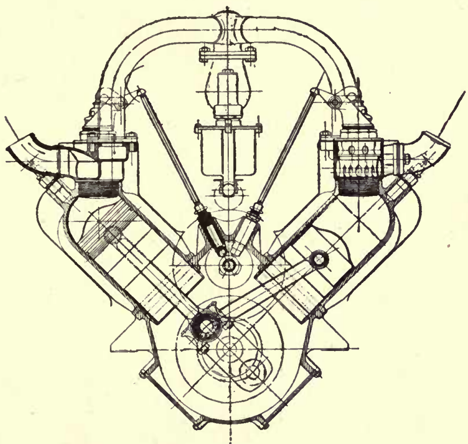

FIG. 74.—Pipe Motor.

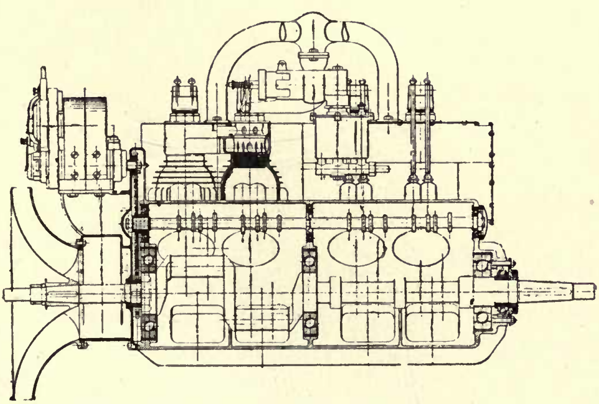

FIG. 75.

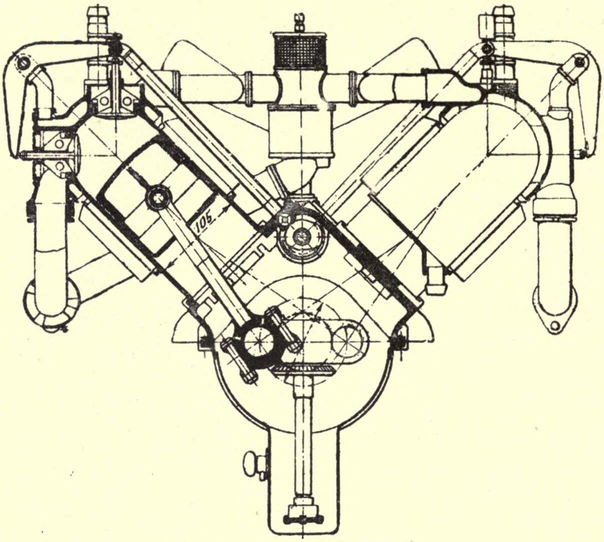

FIG. 76.—Rumpler Motor.

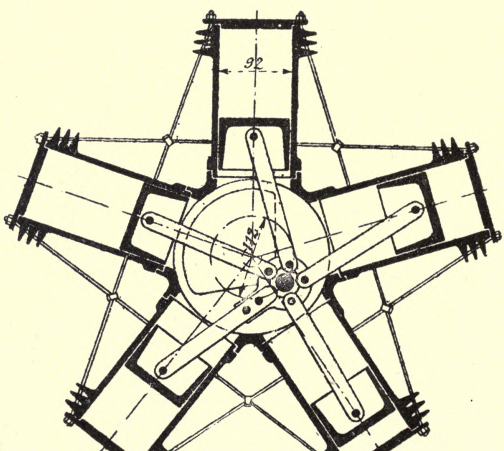

FIG. 77.—Ellehammer Motor.

other hand, it is evident that in their case the feeding of the petrol into the cylinders and the ignition are points of much complexity. Satisfactory rotary motors, as a matter

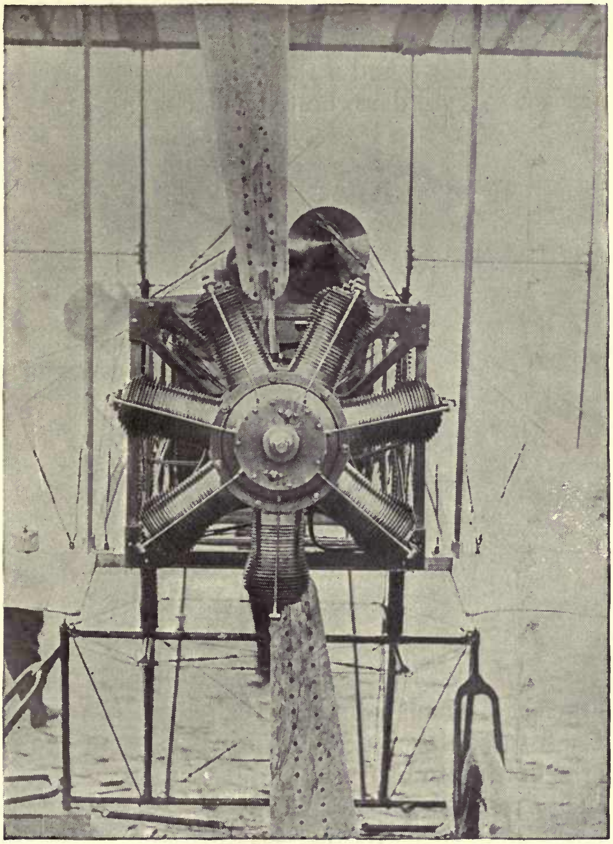

FIG. 78.

of fact, have not existed until the last few months, for previous engines of this type, such as the "Burlat," only pointed the way to success. The great Rheims Aviation Week last year first demonstrated that the rotary motor had arrived, and would last for the next few years, even if it should not prove to be the motor of the future. The fine flights of Farman, Paulhan, Sommer, and others have demonstrated this fact beyond dispute.

The best known of rotary motors is the "Gnome," which still holds the world's record of 4 hrs. 17 mins. 53 2/5 secs. (figs. 78 and 79).

It has seven cylinders, bolted to a crank-case turning

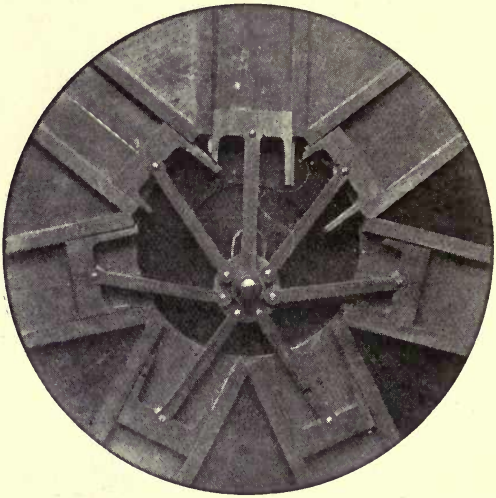

FIG. 79.

round the shaft which is fixed to the body. The enormous centrifugal force developed during rotation of course requires the bolting to be uncommonly perfect. To prevent irregularity of working, the valves had to be designed in such a way that their action was not interfered with by the centrifugal force. These various features have been successfully incorporated in the "Gnome" engine, and have rendered it one of the most reliable motors in existence.

To the best of our knowledge, no other rotary motor has given satisfactory results. This, then, concludes our examination of the aeroplane motor. Should the reader desire further information on this question, he can do no better than consult those works that are entirely devoted to this subject, together with the catalogues of the manufacturers.

In conclusion, we hazard the conjecture that in the future the petrol motor is likely to be superseded by the explosion turbine, which would give us, weight for weight, powers undreamed of to-day.

CHAPTER VIII

THE FUTURE

The chief aim of this book has been to give the general public a thorough understanding of the true nature and possibilities of mechanical flight, but this aim cannot be realised unless we glance briefly at the radiant future that stretches before it.

Born as it was but a few years ago, aviation has not yet attained a sufficiently advanced stage of development to allow every member of the public to grasp its enormous future influence on commerce, sport, and warfare.

Although the time may still be far removed when we shall witness the passage of some aerial liner plying between Paris and Tokio, in a short while—a few months —we shall see the sportsman and the tourist winging their flight over the countryside; for, with Lilienthal, they are "seized with the vague longing to glide along noiselessly in a majestic flight, high above the green forests and blue waters."[1] Aviation has made this dream come true.

Even though the aeroplane should possess no purely commercial future, it is certain that touring aeroplanes will be manufactured in large quantities for many years to come. Before very long the motor car of the air will have become common, and largely patronised on account of its speed and unique qualities.

Aviation will develop, as the motor car did a few years ago, with astonishing rapidity. Before ten years have elapsed the laws and regulations of the air will have

[1] Otto Lilienthal, *Der Vogelflug als Grundlage der Fliegekunst.*

passed into the daily life of the community; the aeroplane will be as common as a bicycle to-day; its low price—due to the fact that the motive power will gradually be decreased—will bring it within the reach of everyone.

Is it likely that the dream of many inventors will ever be realised, that the aerial bicycle, cycloplane, aerocycle, or whatever it may be called, will ever become a fact? We cannot believe it, although it would be unwise to make a dogmatic assertion on the point.

Reliable experiments have proved that the muscular power of a man is hopelessly insufficient to raise the necessary weight. No doubt, in future, flight will be possible with very low-powered motors (3 HP or even less), but we firmly believe that the irreducible minimum must be fixed at 105 kilogrammetre-seconds, that is, 2 HP.

Of late years many discussions, which for the greater part have reached no definite result, have raged round the question of what form of machine will eventually survive. Strange to say, the very success of the aeroplane has brought forth a class of inventors who cling desperately to their pet ideas in the face of all evidence. When will the "ornithopterists," the "entomopterists," and the other visionaries, whose names indicate the creature whose method of flight they seek to imitate, understand that the aeroplane forms the only economical solution of the problem of aerial navigation?

The screw-propeller, according to them, is a device which wastes the power transmitted to it by the motor. But this argument is utterly false, and need not be refuted. Then, in addition to their onslaught on the screw-propeller, they assiduously seek to prove that the aeroplane glides on the air, but does not fly. What matters the precise way in which it is sustained so long as this is economical and duly safe? Side-winds and eddies are already overcome with ease by new devices, and the stability of the aeroplane is every day increased.

The flights of Farman, Latham, and Paulhan have adequately proved the security and efficiency of "the plane gliding on the air," which is not likely to be surpassed by any system of "beating, rotating, or gyrating wings." What is the object of these contrivances, which are based on complete ignorance of the laws of mechanics? Their inanity would be obvious enough if their inventors would only embody them in a *working* model. We are ready to be converted to the practicability of any system in the same way in which we converted those who scoffed at the aeroplane—by actual flight. As a matter of fact, the alternating mechanism of the wings would absorb four-fifths of the motive power, which, therefore, would be insufficient to procure sustentation. The hopeless impracticability of the beating-wing machine could be proved by many other excellent reasons, which, however, are too long to set down here, and sufficiently obvious to every sensible mind.

The aeroplane, then, is the one practical aerial machine. Nor is it difficult to decide between the respective claims of the biplane and monoplane. From the mechanical point of view the monoplane possesses greater efficiency: in stability it can be made the equal of the biplane, nor has it any greater difficulties of construction. The monoplane alone will survive; its high speed will render it indifferent to all atmospheric disturbances; its stability, therefore, will be perfect. Eventually the monoplane will be able to attain enormous speeds up to 150 and 200 miles an hour; every point on the surface of the earth will be brought within reach; communication will be rapid and constant; frontiers will disappear; and the nations will have approached within measurable distance of Utopia and international peace.

APPENDIX

THE BRITISH "GREEN" MOTOR

One of the most reliable aerial motors of British — or foreign—manufacture is the "Green" engine. It operates on the four-stroke cycle, and has four separately mounted vertical cylinders. Each cylinder is cast integrally with its crown and vertical valve-chambers in high-grade steel, and is machined both on the exterior and the interior. The valves are situated in the head. The cylinders have polished copper water-jackets, devoid of soldered joints and seams, and pressed from a single piece of sheet metal. The method of attaching the jackets to the cylinders is quite original, and provides for the contraction and expansion of the steel cylinder and the copper jacket independently of each other. The circumference of the openings in the jacket for the inlet and exhaust valves forms metallic washers for the joints, so that a jacket may be removed and replaced with ease, and without in the least impairing the water-sealing qualities of the joints.

The valves are of the mushroom spring-closed type in detachable cages, and are operated by an overhead cam-shaft. The undoing of two clamping screws allows of the cam-case being rotated to a sufficient degree for the purpose of obtaining easy access to the valves and cages when one of them has to be removed.

The journals of the crank-shaft have a bearing between each throw. Inside the crank-chamber the upper half is webbed between each crank as usual ; cast integrally with each of these walls is a pair of solid columns, which are drilled out. Passing through the holes thus formed are bolts which serve to tie together the cylinders mounted on the crank-chamber and the crank-shaft bearings.

The magneto and the water circulating pump are placed in the same line and immediately in front of the crank-case at right angles with the crank-shaft, both being driven by worm wheels direct from the crank-shaft.

The general lubrication of the engine is effected in an entirely novel manner, as simple as it is efficient.

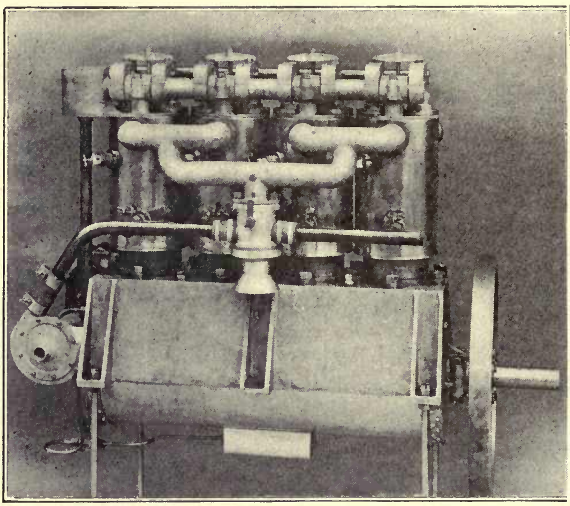

FIG. 80.

Running the entire length of the interior of the crank-case on one side, near the top, is the main oil channel cast solid with the crank-case, through which oil is forced by a small gear pump through leads at right angles communicating directly to each of the hollow columns through which the bolts pass, and thence to the main bearings and crank-shaft, which is hollow. The reduction of the diameter of the central portion of the bolts allows of sufficient room for the free flow of oil to the main bearings, from which it passes into the hollow crank-shaft, and is distributed thence to the connecting rods and cylinders.

It may be mentioned that the oil-ways serve a dual purpose by forming strengthening webs to the crank chamber.

By this system the use of separate pipes is dispensed with, and all the attendant dangers of interrupted lubrication through the leakage of a pipe or loosening of the union nuts are entirely avoided.

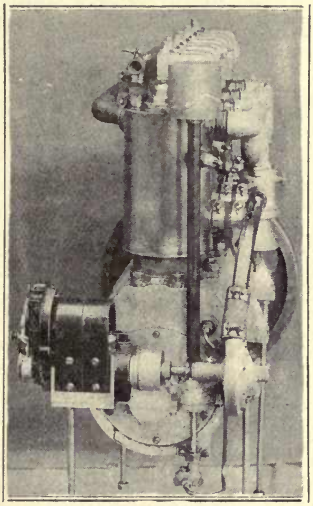

FIG. 81.

Special attention should be drawn to the fact that, notwithstanding their marked accessibility, all the working parts of the engine except the fly-wheel are enclosed in oil-tight, dust-excluding cases.

"Green" engines are made in two sizes: 35, 50–60, developing these powers at 1300 and 1250 revolutions per minute respectively. The weights are 152 and 246 lbs. respectively, completely equipped for running, but without the fly-wheel. The cylinder dimensions are 105 × 120 and 140 × 146 mm. respectively. In addition an 80–100 HP engine is manufactured which has eight cylinders, arranged in V formation.

The feature of these engines is their remarkable reliability and evenness of running. Mr Moore-Brabazon

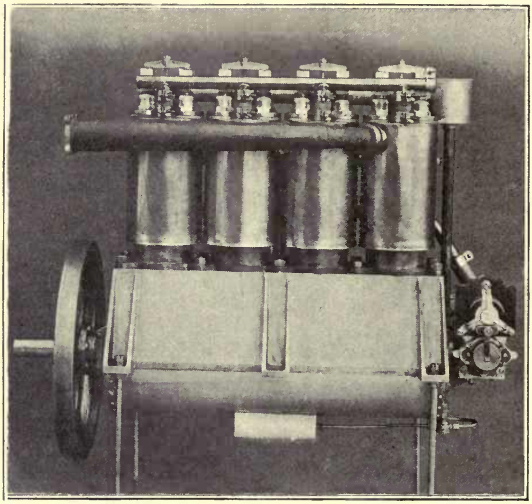

FIG. 82.

used a 50–60 "Green" engine on his circular mile flight, which won the £1000 *Daily Mail* prize on 28th October 1909. A 35 HP engine is fitted to the Army dirigible *Baby*, while the new military dirigible is fitted with an 80–100 HP "Green" motor.

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