THE ART OF AVIATION

A Handbook

UPON

AEROPLANES AND THEIR ENGINES

WITH NOTES UPON PROPELLERS

BY

ROBERT W. A. BREWER

FELLOW OF THE SOCIETY OF ENGINEERS
(GOLD MEDALLIST)
ASSOCIATE MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS
MEMBER OF THE INSTITUTION OF MECHANICAL ENGINEERS
MEMBER OF THE INSTITUTION OF AUTOMOBILE ENGINEERS
AUTHOR OF "THE MOTOR CAR"

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To a companion whose counsels I highly esteem in moments of success or depression, who has always been to me the truest of friends, this book is dedicated, in the sincere hope that the science of aviation will one day be advanced a step by

THE AUTHOR.

PREFACE.

THIS work is intended to deal more with the practical aspect of flying machines than the theoretical, and it is therefore written with the object of interesting the majority of the thinking public. The theoretical aspect of mechanical flight and aerodynamics has been so very ably dealt with, that it would be out of place to attempt to do more than touch on the fringe of the subject here.

The author of this book has been for some time more intimately connected with the construction of flying machines, and of engines of the high speed internal combustion type, and many practical notes upon these subjects are embodied herein. There are a number of works dealing with the underlying principles of dynamic support which may be consulted, and the author of this little work attempts to strike a line between the highly scientific and the purely descriptive side of this most interesting subject.

It has been necessary and advisable to introduce certain descriptive matter, and by the help of the illustrations this has been condensed as far as possible, only a few of the leading types of flying machines and their engines being dealt with. In several places throughout this book explanations are given of the use of various controls at present adopted in aeroplane practice, and hints on the Art of Aviation and the early difficulties of the learner, may prove useful to those who are contemplating becoming successful fliers. In a subject which makes such rapid strides as that of Flight it is difficult to be absolutely certain of data, makers varying their designs radically and frequently. Care has been taken to give correct figures when possible, and where mistakes or discrepancies occur the author trusts these will be excused.

There are a number of tables throughout the book and in the Appendix, which should prove of some use in working out aeroplane problems; but it is not intended that an aeroplane could be designed upon data contained herein; certain of the fundamental formulæ will be found in other works devoted more particularly to the mathematical side of the subject. The author is indebted to the proprietors of *Flight* for permission to make use of some of their drawings as a basis for the production of several plates at the end of the book. Acknowledgment and thanks are tendered to the proprietors of the *Aero* for the loan of numerous photographs, which are reproduced, and for permission to use certain tables of strengths of materials.

The illustration on the front cover is from an original sketch entitled "The Aerial Scorcher of the Future," by E. Wake Cook, Esq., by whose kind permission it is reproduced.

R. W. A. B.

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AEROPLANES AND THEIR ENGINES.

INTRODUCTION.

A CELEBRATED student of aeronautics recently observed that "if you had a tea-tray and a sufficiently light and powerful motor, together with effective propellers, nothing on earth could prevent your flying if you once got up the requisite speed." And this statement in its crudity is sufficient explanation of the possibility of attaining flight with a correctly designed aeroplane. We have here the three essential principles—the surface, the power, and the speed—and a combination of these, efficient as a whole, having an individual efficiency of each of its composing members, is the underlying essential principle of a flying machine.

To many it may seem that the flying machine is a recent development, and that it is only during the year 1909 that any success has been attained by machines of this description. Those who have been intimately acquainted with the private endeavours of inventors of such machines, can appreciate the enormous development which has recently taken place, and the tremendous amount of experimental work previously carried out. It is only the successful attainment of the actual art of flight which has attracted the attention of the whole world. Until recently, successful flights of biplanes have only been reported, and progress has therefore been carefully watched by the world at large, interest naturally becoming centred upon machines of this class. Any extensive flight which has been made with these machines has only appeared as an improvement upon a previous record. With regard, however, to monoplanes, in spite of many years of study and experiment, machines of this type had, at that time, only managed to flutter or take, at the most, long jumps across the ground.

Without previous warning or self-advertisement of any kind, we suddenly hear of extremely successful flights made by monoplanes. The only indication that serious work could be done by such a type of machine was perhaps the flight of M. Blériot from Toury to Arthenay and back with one stoppage on 31st October 1908, a distance of 14 kilometres in eleven minutes.

When, however, we come to study the question of aerial flight, we find that the earliest experimenters devoted themselves almost entirely to the monoplane principle. This was, no doubt, due to the endeavour of man to imitate mechanically the shape of the wings of a bird. There is, in the Victoria and Albert Museum, South Kensington, a model of a machine made more than sixty years ago by Henson and Stringfellow. The model was built in accordance with data given by Sir George Cayley, who made a very deep study of flight a century ago. It is stated that Sir George's insight into the problem of aviation was profound, but neither his own generation nor his successors realised his merit, for he was so much in advance of his time that it has needed an interval of a hundred years to demonstrate the truth of his assertions. Sir George Cayley anticipated the advent of aeroplanes as he foresaw the great difficulties associated with dirigible balloons on account of their huge size. He experimented to determine the lifting effect which could be obtained from surfaces moving through the air at slight inclinations to the horizontal. He also suggested the use of a tail as a means of obtaining automatic longitudinal stability, and he showed how the pivoting of that tail would enable it to be used as an elevator. He also deduced the advantage of wing flexion from his observations of bird flight.

Henson's model, which is shown in diagram in Plates I. to IV. and described in detail in Chapter III., was produced in 1843, and was for a steam-driven monoplane embodying Sir George Cayley's principles. It has two paddles 3 ft. in diameter, with their blades set at 45°, these paddles being placed behind the main surface. Behind the propellers is a fan-shaped tail which can be opened or closed, as well as moved in a vertical plane, by means of cords and pulleys, this latter movement causing the machine to rise or fall. The actual dimensions of the model are 20 ft. across the main plane by 3.5 ft. wide, giving 70 sq. ft. of sustaining surface to the main plane and about 10 sq. ft. to the tail.

It may seem, therefore, somewhat strange that over sixty years have elapsed before actual results have been obtained with a full-sized machine, but this is accounted for by the fact that it is only during the last few years that a sufficiently light and powerful motor has been produced.

In spite of the time which has been taken in the development of practical flying machines, and the enormous amount of experimental work that has been done, it is satisfactory to know that the loss of life which this work has claimed has been so small, particularly in view of the hazardous nature of the experiments. Probably this may be due to the intrepid nature of the experimenters, as although falls have been many, the type of man has been such, as generally escapes without serious injury. Now that the preliminary scientific work is practically completed, men of this type may perform the most unexpected feats of flying.

CHAPTER I.

A COMPARISON BETWEEN MONOPLANES AND BIPLANES.

WE cannot say whether one type of machine or another is the correct type for flying. Each one has its advantages, and if the general principles of design are correct, there is no reason why several types of successful flyers should not be produced.* From the author's point of view, however, the monoplane is the most likely to be satisfactory for certain purposes, and his reasons for this statement are as follows:—

Primarily with regard to safety. It is a well-known fact that in order to maintain reasonable stability in the air, it is necessary that the maximum velocity of the machine should be about twice the velocity of any gust which it is likely to encounter. It must be borne in mind that one depends entirely upon one's velocity relatively to that of the surrounding atmosphere, for sustentation, and that if these relative velocities are not maintained, the sustentation at once diminishes, and the machine comes to earth.

The monoplane is essentially a high speed machine, and whereas in the case of a biplane about 2 lb. per square foot is the average sustaining effect of the planes, in the case of a monoplane this figure must be nearer 5 lb. per square foot.† Owing to structural difficulties in manu-

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* The flights of the year 1909 confirm this theory.

† See Table on page 178.

facturing a large plane area of the latter type, the sustentation is naturally obtained as a result of speed, so that if the speed is kept high, it is possible to make the sustaining surface small. The question then arises whether a certain sustaining area should be put into one plane or several. The reasons in favour of the single plane are as follows:—

Monoplane construction is flexible to a certain extent, as the ends of the plane are only connected by guys, some of these being attached to the controlling mechanism which is operated by the aviator. This enables the plane to warp if struck by a gust of wind, and in most constructions a double warp results, that is to say, should a gust strike the trailing edge of one wing, this edge immediately tends to assume a position parallel to the earth's surface, that is, its angle of incidence is automatically altered by the pressure of the wind, and the interconnecting mechanism will lower the trailing edge of the other wing, thus tending to restore stability. One would think, therefore, that monoplanes would be able to fly on fairly windy days, and recently the exploits of M. Latham have proved this to be the case. The higher velocity of flight of the machine having the smaller surface area also tends to increase its safety by reducing the risks from gusts of wind.

The rigid construction of a biplane does not lend itself to this automatic action, and in addition the rigid connections between the two planes must be maintained by means of wood or metal supplemented by wires which all offer some resistance to the air, and the amount of resistance which is produced by a vibrating wire is surprising.

Now, considering the matter from the point of view of the biplane, we return at once to the question of velocity of flight and sustentation, and to the beginner the former is of great importance. The learner in every other sport is able to progress by easy stages, the motor car driver, for instance, may proceed slowly until he has obtained mastery of the art of steering. A flying machine, however, has a critical minimum velocity at which sustentation occurs, and such being the case, early flights must consist of flutters or hops until the budding aviator has obtained sufficient confidence to increase his velocity and remain for longer periods in the air. The biplane here has the advantage, as owing to its surface being generally of larger area than that of a monoplane, sustentation usually occurs at a velocity of approximately 30 miles per hour relatively to that of the air.

The beginner would be well advised to commence operations in a fairly still atmosphere and facing a wind of say 5 miles per hour. The soaring velocity of the machine relatively to the land must be, therefore, of the order of 25 miles per hour. In the case of some monoplanes a considerably higher velocity is necessary, and more nerve or confidence will be required in order to commence operations at these higher speeds; further, the first wish of the learner on leaving the earth being to return to it again as quickly as possible, this at high speeds becomes

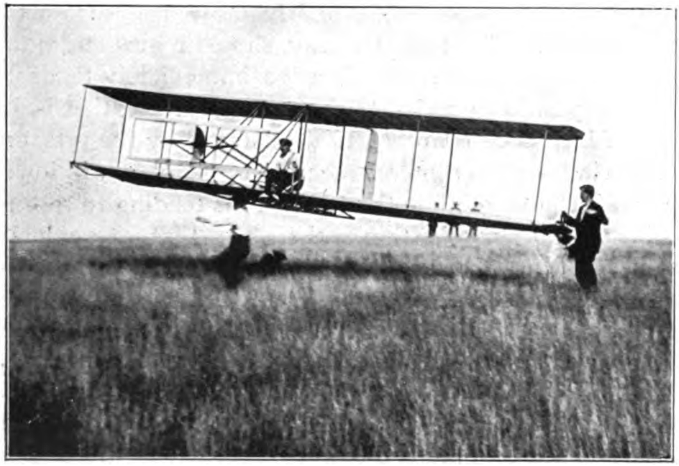

FIG. 1.—An Early Gliding Experiment, the assistants escaping below the Machine.

a dangerous proceeding. The question of the inertia of the machine as a whole must be taken into account, and a fall at a high velocity may be expected to be more serious than at the lower velocity of the biplane.

There is another point of great importance and one which the learner at once discovers on making his initial trials, and that is the great difficulty of judging one's position relatively to the earth, and also the velocity of the machine and its direction of motion in a vertical plane. Generally speaking, the position of the aviator in a biplane is more convenient from which to make observations of this character than is the case with a monoplane. In the latter machine the aviator's seat is usually near the trailing edge of the main planes, and when the machine is in flight these plane obscure the view almost entirely; unless an elevated landmark is available, the difficulty of locating one's position and direction must be very considerable.

Aero photo.

FIG. 2.—Bonnet-Labranche Monoplane, the Position of the Aviator's Seat will be noticed.

The forward position obtained in biplane construction does not entail these difficulties to anything like so great an extent, and particularly is this noticeable in the Farman machine, where the aviator has a clear view both forwards and directly downwards. It may be considered an advantage to be able to observe the front elevator which is in many instances fitted to biplanes as distinct from the tail of a monoplane, but on the other hand the latter machine usually has its engine in view of the aviator, but it is only the expert who has time to give any attention to it. With reference to engine position an important feature is often lost sight of, and that is the relative safety as far as the aviator is concerned of various engine positions.

We may say with some degree of certainty that the sadly fatal accidents to both Captain Ferber and M. Lefebvre were due to the engine being behind the aviator and crushing him when the machine fell forward. When the engine is placed in front this is not so likely to occur ; both positions, however, lend themselves to direct connection between engine and propeller, as instance the Blériot and Antoinette monoplanes and the Farman biplane. In some of the latest monoplanes this difficulty of observance is avoided by placing the aviator's seat below the main planes. It is quite remarkable how soon several beginners have acquired the art of flight with monoplanes, and provided one has sufficient nerve and presence of mind, the high engine powers now employed may in a measure account for these successes.

Learning to fly with a monoplane is undoubtedly a more simple matter than with a biplane of the Wright type, the former when of the Blériot type is much lighter, and its inertia in flight is therefore less. Successful beginners of the monoplane school vastly outnumber those who are learning to fly biplanes, and the time taken during the process is generally much shorter.

CHAPTER II.

THE FORM OF AN AEROFOIL, AND STABILITY.

FROM the earliest stages of the consideration of flight by man, Nature's shapes have been studied, with the result that observations of birds' wings in flight have been the basis for investigation (Fig. 3). It will be noticed that the model of Henson (Plates I. to III.) is fitted with wings in a manner resembling those of a bird, and that the planes are of arched section (Plate IV.). The section of the wings

Aero photo.

FIG. 3.—A Study of Bird Flight.

of birds which are capable of sustained flight are all of this form, and have a dipping front edge. It is a curious fact that this dipping edge has only been observed comparatively recently, the curvature and shape of the thickened leading edge is known as " Phillips' Entry."

Phillips' specification, No. 13,768 of 1884, shows aero-curves of some difference, some are shown in Fig. 4; A, however, was a replica of Henson's. The theory of Phillips was that the shape of the upper surface at his entrant edge caused the air to be deflected upwards after meeting the upper side of the entrant edge of the plane, and thus to form a partial vacuum above the after surface of the plane.

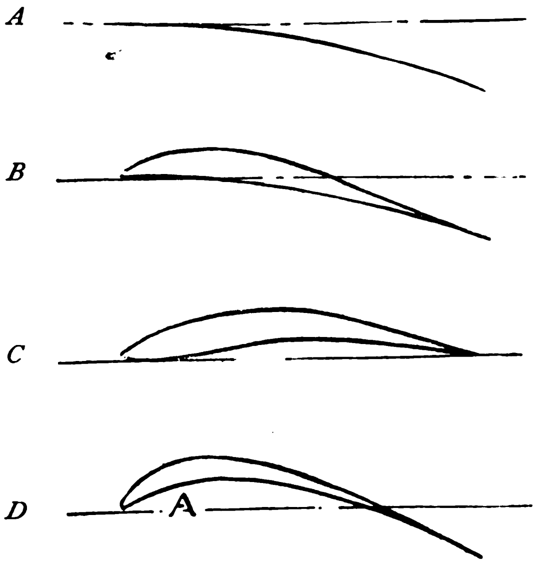

FIG. 4.—Phillips' Aerofoil Curves.

Fig. 4, A, shows a plain single curved surface of steel, the leading portion nearly horizontal so as to meet the air without shock. The body of air is gradually deflected downwards, and it is the reaction of this downward deflection of the air that causes an equal and opposite upward lift upon the plane.

The motion of the air in a downward direction should be gradually accelerated until the trailing edge of the plane is reached in order to secure maximum efficiency.

The form of the curvature to produce this result is therefore hyperbolic.

Structural difficulties occur in making a thin plane, such as shown in Fig. 4, A, so Phillips produced the design of Fig. 4, B, combining rigidity and strength of structure with his previous under curvature.

The whole of these designs were the result of a large series of practical experiments, and it will be noticed that the convexity of the upper surface must be made greater than the concavity of the lower one, the combination of these two curvatures at the leading edge producing a more pronounced vacuous effect above the aerofoil.

Phillips found that this vacuous space extended farther forward than in the case of the single curve, and the increased effect balanced the increased head resistance due to the blunter entry.

This blunt entry is, however, in no way really detrimental, as it conforms to true stream-line curvature, the trailing form being of greatest importance, as it is here that the maximum eddies would be produced in a badly designed body.

Phillips' specification, No. 13,311 of 1891, shows an aerofoil of the section given in Fig. 4, C, and is designed to have greater width in direction of motion, and is therefore made more substantial.

Greater lift can be obtained by increasing the chord up to a certain point without disproportionate increase of skin friction. Phillips does not favour the dipping front edge as in Fig. 4, D, in fact, he strongly condemns its adoption, due to the eddies formed in the leading portion of the concaved surface, marked A in the figure. He also states that it requires more power to propel such a surface, its drift is greater, and it has a tendency to dive downwards.

Lanchester states that the theory of Phillips is incomplete and erroneous, though that fact in no way detracts from the validity of the patents.

The question of dynamic support is the fundamental one of aeronautical science. Dynamic support can only be obtained in air as a result of putting in motion a mass of some sort, and that mass must be air. Newton's law is to the effect that momentum generated in a mass in unit time is proportional to the force acting upon it. In the form of an equation,

$$F = \frac{mv}{t},$$

where F = force, m = mass, t = time in seconds, and v = the velocity in units per second, and for a solid body this is easily understood.

In the case of air we must consider the mass to be the sum of an infinite number of particles of air which are set in motion by a moving plane, and the motion is imparted continuously to the particles the whole time the plane is in motion. This is equivalent to the movement of the whole mass of air which comes in contact with the under surface of the plane, this mass being deflected downwards by the curved plane. There is consequently an equal and opposite force acting upwards upon the plane, this force being divided into two components, that sustaining the plane in the air called the "lift," and that acting in a horizontal direction to overcome the skin friction of the machine this is called the "drift."

Now, continuing Newton's theory, when W = the weight supported, m = the mass of air projected per second, v = the velocity of *downward* discharge in linear units per second, we have :—

$$W = mv, \text{ or } v = \frac{W}{m},$$

and E = the energy expended per second :—

$$E = \tfrac{1}{2}mv^2, \text{ and} = \frac{W^2}{2m}.$$

If the weight to be sustained is constant, the energy expended varies inversely as the mass of the air moved per second. We find, however, in practice that the weight sustained by a plane varies approximately with the area of the plane and the density of the fluid, and as the square of the velocity of the plane relatively to the air.

The action of the plane being to deflect downwards a layer of air, when the angle of incidence of the plane is small it may appear difficult to contemplate the thickness of the layer of air affected. The layers of air in immediate contact with the surface will in turn affect those neighbouring them, and so on until the magnitude of the deflection becomes inappreciable, so that a considerable thickness of air stratum will be set in motion. Lanchester states that the factor limiting this thickness is the size and shape of the plane, as the more remote layers escape only by reason of the local circulation of air between points of greater and lesser pressure. This circulation depends upon the size and shape of the plane, and but little upon its angle.

Langley found that with superposed planes, 15 in. span by 4 in. chord, and at angles of incidence of less than 10°, such planes do not appear to have any loss of sustentation power if they are separated by a distance of 4 in. The conclusion, therefore, is that 4 in. will be a fair assumption as to the thickness of this layer of air. In considering the deflection of the stratum of air the elasticity of the medium must be borne in mind. An inelastic medium would have, of course, an infinitely thick stratum to deflect, as each thin layer would be deflected and lie parallel to its neighbour, *i.e.*, the medium below the plane would be deflected in a stream parallel to the trailing angle of the plane for an infinite distance below it, or would spread out laterally fanwise.

Owing, however, to the elasticity of the air, the amplitude rapidly decreases as we leave the vicinity of the plane, and eddy currents pass from the lower or pressure side of the plane to the upper or rarefied side.

If the air is abruptly parted, the sudden alteration of its relative momentum causes a thrust on the body causing this movement, the partial vacuum at the rear of the moving body increases this resistance, and the skin friction of the body has some effect depending upon the roughness of its surface.

The air on being parted does not move in smooth stream lines, but in a series of eddies, the kinetic energy of which must be supplied by the source of energy moving the body.

The shape of the body determines to a great extent the energy which will be lost in forming eddies, the magnitude of the energy will also be proportional to the square of the velocity of the body.

The dynamic resistance of a plane moving in a direction normal to its surface depends on the mass of air affected, and this is proportional to the area, so that—

If $P =$ the total pressure in pounds,
$S =$ the area in square feet,
$V =$ the speed in feet per second,
$k =$ the mass of a cubic foot of air divided by 2
$= 0{\cdot}0012$ at normal temperature and pressure,
$n =$ the ratio of the dynamic to the negative pressure and generally rather more than 2.

$$P = k\left(1 + \frac{1}{n}\right)SV^2,$$

and $k\left(1 + \frac{1}{n}\right)$ varies according to different experimenters from 0·0013 to 0·0017. Langley's value being the latter, and substituting it we have :—

$$P = kSV^2.$$

If the plane, instead of being moved in a normal direction, makes an angle of incidence, γ, to the direction of motion, the dynamic action is no longer symmetrical and skin friction comes into account, also the negative pressure decreases as the vacuous space behind the moving plane becomes less. For all ordinary angles of incidence between, say, 2° and 40°, the following relation holds good :—

$$P = 2kSV^2 \sin \gamma.$$

When the angle of incidence decreases to zero the resistance is that of the entrant edge and skin resistance. Lanchester makes this approximately :—

$$P \text{ (in pounds)} = \frac{2k\ SV^2}{20},$$

Thus the coefficient of skin friction is more than 5 per cent. of the coefficient of resistance.

Curved surfaces show a similar resistance to flat surfaces. When the curvature is definite the coefficient is somewhat higher.

The dynamic resistance over the whole surface is not symmetrical, the resultant pressure being ahead of the centre of the area, a distance depending upon the angle of incidence of the surface.

If Δ is the distance in feet from the entre of pressurec to the centre of area, and L = the length of plane in the direction of motion,

$$\Delta = 0.3\ (1 - \sin \gamma)\ L.$$

(Joëssel and Aranzini's formula.)

At normal inclination of, say, 10°, the centre of pressure is about one-third of the length of the chord from the leading edge. As the angle of incidence decreases, the centre of pressure moves forward until a critical angle is reached, when it rapidly moves backwards.

In order to have conditions of stability the centre of pressure and the centre of gravity must coincide*; if this is not the case a turning moment will be set up about the centre of gravity, the magnitude of which will be the intensity of the stress upon the centre of pressure into

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* In actual flight the centre of gravity should be slightly ahead of the centre of pressure. See page 17.

the distance between the centres of pressure and gravity. If the angle and the normal pressure are constant this turning moment is constant and can be neutralised by moving either the centre of gravity or that of pressure until the two coincide. Early experimenters endeavoured to move the centre of gravity by shifting their body or legs in imitation of a bird, which throws forward its head or legs to suit the prevailing conditions. The Wright brothers discovered that it was much easier and at the same time quicker to move the centre of pressure, and for this purpose designed the front elevator plane so that its sustentation powers could rapidly be altered by altering its angle of incidence (Fig. 5 and Fig. 6).

FIG. 5.—Mr A. Ogilvie's Wright-Clarke Glider on the Starting Rail, showing Control Gear and Front Elevator.

An aeroplane is longitudinally stable if the following two conditions are maintained (Chatley and Captain Ferber):—

1. That the longitudinal radius of gyration about an axis through the centre of gravity does not exceed—

$$\sqrt{\frac{37b}{P}}$$

where $P =$ weight of aeroplane in kilogrammes, and
$b =$ overall width of the machine in metres, the radius of gyration being in metres.

2. That the centre of gravity falls over the centre line between two points, one a little ahead of the centre of area of the sustaining surfaces, and the other near the forward edge of the aeroplane.

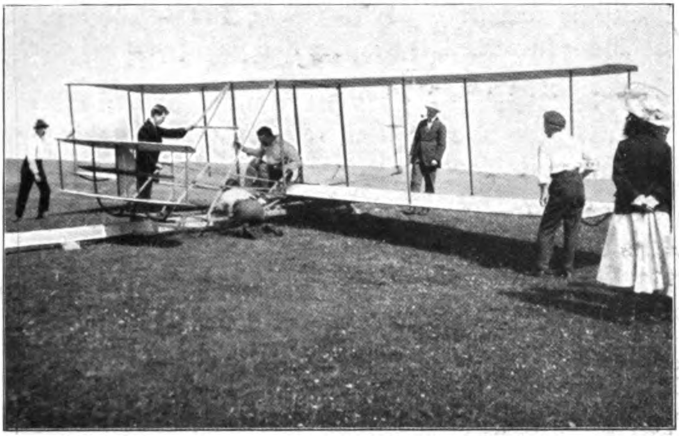

FIG. 6.—Messrs Ogilvie and Searight's Wright-Clarke Glider preparing for the First Experiment, the Angle of Incidence of the Elevator is Apparent.

The exact values of these positions involve complex equations.

If the centre of gravity coincides with one of these points, the machine is subject to two oscillations of long and short periods respectively, any increase of which would be fatal. The action of a machine in flight is somewhat as follows:—The resistance of the machine in flight tends to slow it, and to cause the front to dip; the centre of pressure moves forward, and tends to restore the plane to its original position; the downward velocity caused by gravitation tends to increase the speed of flight, so that if the machine is stable the conditions will balance. When the machine settles down to a condition in which the resistance due to the resultant velocity just balances the component of weight in the direction of motion, steady horizontal flight will ensue; if the velocity is reduced, the machine will drop and gain kinetic energy until its critical velocity is acquired. If, however, the velocity of the machine is increased, it will rise and gain potential energy.

Weight.—The relations between weight and sustentation area have already been referred to, and taking γ as the angle of incidence, when γ is small—

Let $\cos\gamma \doteq 1$, and $\sin\gamma = \frac{1}{3}$, and $S =$ the area $= 0{\cdot}004$,

$$2k = (2 \times 0{\cdot}0017) + 0{\cdot}0006 \text{ (a constant)},$$

$$W = 2kSV^2 \sin\gamma \cos\gamma,$$

$$W = 0{\cdot}0012\ SV^2,$$

$$S = \frac{W}{0{\cdot}0012V^2}.$$

If $V = 20$ miles per hour $= 30$ ft. per second, say

$S = W$; that is the area in square feet $=$ the weight in pounds.

To find the thrust required:—

If $H =$ the foot-pounds per second,

$R =$ the resistance of the machine in pounds,

$P =$ the total pressure on the planes in pounds,

$S =$ the area in square feet,

$$R = P \sin\gamma = 2kSV^2 \sin^2\gamma.^*$$

(Sine—cosine—tangent. See end of chapter for explanation.)

If $C =$ the projected area of the machine as a whole in square feet, a further resistance, CV^2, must be allowed.

$$H = (R + CV^2)V = (2kS \sin^2\gamma + C)V^3.$$

Thus the power varies as the cube of the speed.

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* See Table and Notes in Appendix.

If we decrease γ, and keep C constant, and keep in view the fact that γ has a limiting value determined by the weight of the machine so as to maintain the lift—

When the motion is horizontal,

$$W = P \cos \gamma = 2kSV^2 \sin \gamma \cos \gamma,$$

and when V is known, γ can be found; the value for V will be the soaring speed of the machine.

Now $H = TV$; that is, the thrust multiplied by the velocity is equal to the foot-pounds per second,

$$\therefore \frac{T}{W} = \frac{R + CV^2}{W} = \tan \gamma + \frac{C}{2kS \sin \gamma \cos \gamma},$$

and neglecting the second term which is small,

$$\tan \gamma = \sin \gamma = \tfrac{1}{3} \text{ or } \tfrac{1}{4},$$

$$\therefore T = \frac{W}{3 \text{ or } 4}.$$

Mr Thurston gives its value, however, as—

$$T = \frac{W}{6}.$$

If a propeller thrust of 12 lb. per horse-power, then *

$$12\ H = \frac{W}{4},$$

$$\text{then } W = 48\ H,$$

so that 1 H.P. would be required per 48 lb. weight as a limit.

Sine.—The meaning of this property of an angle can be simply explained as follows:—Suppose we have an inclined plane, and a wooden block is moved along it from the bottom to the top, the block will attain potential energy, or in other words its position with regard to its distance from the centre of the earth will be increased. The ratio of the height it will be raised to the length of the path it has traversed *up the inclined plane* is numerically equal to

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* The Anzani-Chauvière combination gives a thrust of approx. 10 lb. per H.P. against a fixed point, and $W = 33{\cdot}4H$ approx. in the Blériot XI. type. In flight, of course, this thrust is lower.

the sine of the angle that the face of the plane makes with the horizontal.

Tangent.—Supposing now that in moving the block along the plane the distance traversed is reckoned in a *horizontal direction only*, the ratio of the height the block was raised to the horizontal displacement will be numerically equal to the tangent of the angle that the face of the plane makes with the horizontal. It will be seen that *when the angle is small* the values of the sine and the tangent are approximately equal.*

If we have an elastic medium such as air, and the block or its equivalent is arranged to move on an inclined plane, being analogous to the angle of incidence of an aerofoil, and the block is moved, its path will not be upwards necessarily owing to the displacement of the elastic medium.

If the path of flight is horizontal, instead of the block or aerofoil attaining potential energy it will impart energy to the air, and the slip will be 100 per cent. The effect would be similar in the case of a solid to the block depressing or levelling out the inclined plane. Under such conditions it will be the tangent of the angle which concerns us. Now, still further making a supposition, the flight path is inclined upwards, this additional angle is applied adjacently to the previous angle, and the slip in the former conditions being exactly 100 per cent., the second angle must be considered for its sine value, so we have the sum of the tangent of the normal angle of incidence, and the sine of the angle of ascent. We can write this down as twice the sine or the tangent of either angle if we please, when the angle is small and the relation of one value to the other will be unity.

The **Cosine** of the angle is the ratio of the length of the path along the inclined plane to the horizontal path, and it is obvious that when the angle is small its value is approximately unity.

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* A table of these values is given in the Appendix.

CHAPTER III.

EARLY MODELS.

Henson's Machine (Plates I. to IV.).—This machine has been referred to in the opening chapter, and owing to the remarkable nature of Henson's discoveries, will be treated here in detail. Although Henson invented his machine in the year 1835, it was not until the year 1842 that he filed his final specification which was finally sealed on 29th March 1843. Henson is described in his specification as an engineer, and his foresight and ability should rank him as one of the foremost of his profession. The specification is for "Improvements in locomotive apparatus and machinery for conveying letters, goods, and passengers from place to place through the air, part of which improvements are applicable to locomotive and other machinery to be used on water or on land." The commercial instinct was here evident, although even at this present time aviation is still considered as a sport rather than as a commercial problem.

The specification describes the invention as relating first to the construction of locomotive machinery and apparatus for conveying letters, goods, and such like through the air; and secondly, to certain improvements in steam boilers and machinery. It is only to the first part that we will give consideration at present:—

> "If any light and flat or nearly flat article be projected or thrown edgewise in a slightly inclined position, the same will rise in the air till the force exerted is expended, when the article so thrown or projected will descend; and it will readily be

conceived that if the article so projected or thrown possessed in itself a continuous power or force equal to that used in throwing or projecting it, the article would continue to ascend so long as the forward part of the surface was upwards in respect to the hinder part. Such an article when the power was stopped or when the inclination was reversed would descend by gravity only if the power was stopped, or by gravity aided by the force of the power contained in the article if the power be continued, thus imitating the flight of a bird."

The first part of the invention consisted of an apparatus so constructed as to offer a very extended surface or plane of a light but strong construction resembling the wings of a bird when the bird is skimming through the air, but in place of these wings having any reciprocating movement as have a bird's wings, suitable paddles, two in number, were fixed at the rear of the main supporting planes.

In order to give control to the whole construction, a tail (Plate IV.) was provided capable of being raised or inclined, so that when the power acted to propel the machine, the tail, when inclined upwards, offered resistance to the air, thus causing the machine to rise on the air. Conversely when the inclination of the tail was reversed the machine was immediately propelled downwards, the path of flight being proportional to the inclination of the tail. In order to guide the machine as to lateral direction, a vertical rudder or second tail was provided, and according as this was deflected in one direction or another, so would the lateral path of the machine be directed. The main points in the construction of this machine were lightness combined with strength in respect to the machine itself—and lightness with respect to the magnitude of the power developed by the engine.

Plate I. represents Henson's machine with the covering fabric removed in order to trace more readily the construction of the framework. Plate II. shows the same machine with the covering in place. Plate III. shows the underside view of the machine with the covering fabric in place, and gives an idea of the appearance of the machine to an observer below when the machine is in flight. Other figures are shown giving details of construction to a larger scale. Plate IV. shows a side view of the main frame or wings. Plate IV., fig. 5, shows a plan of the tail for controlling the direction of the machine in its upward and downward direction, and Plate IV., fig. 6, shows a side view of the same tail. Plate IV., fig. 7, shows one of the frame bars which run from front to back of the machine, and it will be noticed that the construction of this bar or rib is exactly in accordance with modern ideas for the construction of this member. The arched form is also embodied though the curve is slightly different from the modern curve of Phillips. Henson states that he prefers the material to be wood or bamboo in order to obtain sufficient lightness combined with strength. Sections of the hollow wooden bars are also shown, and these are most interesting in view of modern construction, also the tightening screws for the bracing wires of the rigging.

It will be seen that the machine consists of a wide plane or surface extending on each side of the car or body of the machine.

This body is intended for the conveyance of the letters or goods referred to before. The position of the propelling mechanism is also shown, and it is distinctly stated that the location of this gear should be rather forward in the car, because, from experiment Henson found it desirable that the weight carried by such a type of machine should be forward.

There was no doubt some experimental determination as to the position of the centre of gravity, and incidentally of the centre of pressure upon the supporting surfaces, but no reference is made as to either of these two important influences in the design of the machine.

The machine was provided with three wheels so that it could run freely upon the earth without injury, and it was anticipated that, owing to the facilities for control offered by the tail, the car could be governed in its descent so as to come to earth at an incline so slight that in taking the ground, very little shock would be perceived by the passengers.

The wings were securely supported on the cantilever principle from two masts fixed in the car, which rise above the upper part of the car. From the upper ends of these masts the main planes are suspended on either side, and the framing of the planes was braced to the lower ends of these masts. The suspension was by wires, preferably of an oval section in order to minimise air resistance. A is the fore mast and B the hind mast, and the suspending wires (1) (1) descend to the points (2) (2) of the lateral main bars C, D on either side of the car, and thus suspend these bars from the masts.

The other suspending wires (3) (3) attached to the upper parts of the masts crossed each other, and were attached to the same points (2) (2) on the bars C, D, there being corresponding wires to the lower ends of the masts. Suspending wires (4) (4) were attached to the framework E, E, carrying the tail of the machine, and wires (5) (5) were taken from the upper part of the fore mast A to the front of the car, and wire (7) was fixed to the upper part of the fore mast, and attached to the hinder framing of the car. Other wire bracing is shown on the figures, and it will be noticed how complete was the triangulation of the system, the object being to obtain great stiffness and strength combined with lightness of structure.

The main bars C, D were made hollow, and the bar G was a plank of wood on edge, it being the central main bar; these three were fixed together by the end pieces H, H. The front bar I of the machine was combined with the other three main bars to form one framing by means of the additional bars H, J, K.

The covering of the framework was of strong oiled silk, and these coverings were to be fixed to light frames, capable of sliding to and fro on the main bars C, D, G in such a manner that the portion of the covering from the outer end of either side plane could be slid back from the beam K or J, as the case may be, by means of cords and a small windlass.

The object of sliding these frames was that they might be drawn up when the machine was not in use. We also have here an anticipation of a variable surfaced machine, which, if it could be practically worked out, would be of immense value, enabling a large surface to be utilised for rising from the ground or soaring, but capable of contraction for rapid flight. The tail also could be extended fanwise by means of cords and pulleys; other similar means were adopted for operating the tail and elevating rudder.

Henson's calculations show that 1 sq. ft. of supporting surface would only sustain ½ lb. of weight of the machine, including machinery, fuel, and load, and his first machine was to weigh about 3,000 lb. The surface of the machine was to be 9,000 sq. ft. of main planes, and that of the tail 1,500 sq. ft. more, and he expected to obtain 25 to 30 H.P. from his steam engine.

CHAPTER IV.

PRINCIPLES OF DESIGN AND ENGINE PROBLEMS.

WHEN considering the design of a machine, the following points must be borne in mind: first, the weight of the complete machine with the aviator; second, the velocity at which this machine is to be projected through the air; third, the horse-power necessary to produce this velocity. The elementary principles which govern these factors are dealt with in Chapter II., but one cannot definitely fix on all these limits in an arbitrary manner. Certain fundamental requirements must be decided upon, and the other dependent features must be carefully worked out and the whole of the results modified to suit each other as the conception of the machine proceeds. For instance, we may decide upon the velocity of flight, then the question of the size of the machine depends to a great extent upon the weight of the machine itself, because the factors of weight, head resistance, and skin friction must be counterbalanced by the support which the atmosphere affords when acting upon the lower surface of the supporting planes. Now the weight of the machine depends upon the weight of the motor, while that in turn depends upon the horse-power which it must exert. So that as the design proceeds it will be seen that certain matters crop up which necessitate slight modifications in order to fit in with the calculation for the whole machine. Great importance must be attached to the horse-power of the motor, because with any particular size of machine an increase of thrust to that machine makes an enormous difference, as will be seen from the actual performances which have been carried out in France. Take, for instance, the performances of Blériot and Farman, who, each with small machines, succeeded in carrying, besides himself, first one passenger and eventually two; the ratio of weight of these two passengers to the weight of the complete machine must have been very considerable. Increased weight can, as has been already shown, be carried by increasing the horse-power of the engine, combined, of course, with a suitable propeller for transforming that horse-power into horizontal thrust.

Referring to the data given in Chapter II., we may take as an average that one thrust horse-power is required for every 34 lb. weight of machine, for aeroplanes of the usual types as made in 1909, flying at a speed of 30 miles per hour. This value cannot be taken as a hard and fast figure, and it depends naturally upon many ruling considerations such as air resistance and head resistance and the design of the propeller.

The work required to impart a given speed to any machine is equal to $\frac{1}{2}mv^2$ in foot-pounds per second. The attainment of flight, therefore, resolves itself into the expenditure of foot-pounds of work upon some resisting medium. It does not signify whether these foot-pounds are expended by the engine itself or by a falling weight or any other similar means. In addition to the above factors, the skin friction of the machine and the friction of its wheels or runners upon the ground must be taken into account. It is evident, therefore, that in a machine of the usual type which relies entirely upon its engine to overcome this initial friction, the power of the engine must be sufficient for the purpose, and greater than that required to propel the machine at its soaring velocity in the air. Generally speaking, the difficulty of finding a suitable level starting track, upon which a high velocity can be attained, also necessitates the use of a fairly powerful motor, as the distance to be traversed upon the ground depends upon the acceleration of the machine, and the greater this is, the shorter will be the preliminary run. As the surface of the plane is a constant quantity and cannot at present be increased when it is desired to rise from the ground, this larger engine power should be provided in practical machines so that when in actual flight the engine will work below its maximum capacity. In the author's opinion this is a desirable state of affairs, particularly in view of the fact that an engine working at full load for continual periods is difficult to maintain, as has been proved upon the Brooklands track in the long-distance motor car races.

The exact value of the power required to propel an aeroplane will vary with each particular type of machine. As an indication of this power we will take the coefficient of traction as being equal to one-sixth of the weight of the machine, *i.e.*, $T = \frac{W}{6}$, in which case a machine weighing 1,500 lb. would require a thrust of 250 lb., and one weighing 250 lb. would require 67 lb.

The thrust horse-power is the product of the thrust in pounds and the speed of flight; thus if the flying speed of the machine is 40 miles per hour, and the thrust required is 250 lb., the horse-power =

$$\text{Thrust H.P.} = \frac{250 \times 40 \times 5280}{60 \times 33{,}000} = 27.^{*}$$

Now this figure must be modified to allow for losses in the engine and the transmission, and for the efficiency of the propeller, and taking a reasonable figure as 50 per cent. for the sum of these losses, at least a 50 H.P. engine (B.H.P.) would be desirable. Considering now the assumed smaller machine, the thrust of 67 lb. for a machine weighing

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* The Blériot XI. machine requires a thrust of 180 lb. against a fixed point for a total weight of 700 lb. $T = \frac{W}{4}$, and in flight approx. $T = \frac{W}{7}$ = 10 thrust horse-power.

400 lb. (the "Demoiselle" weighs without the aviator 242 lb.), we have, at 35 miles per hour, 6·25 thrust H.P. Hence, say, a 12 B.H.P. engine, showing that a comparatively small engine can suffice to propel and sustain a machine of these dimensions. These engine powers are only for horizontal

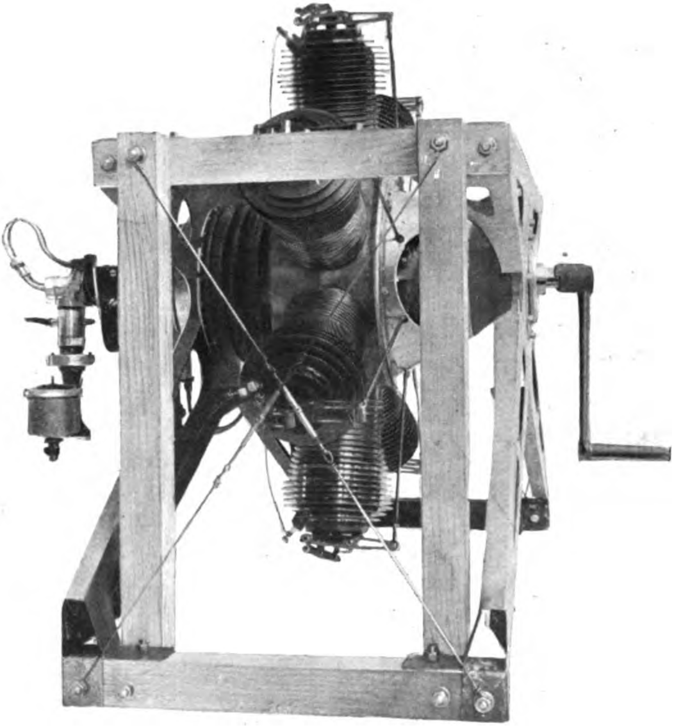

FIG. 7.—"Gnome" Engine erected in the Testing Frame.

flight and make no account of the power required for ascending.

Flying machine engines are by no means settled down to one or even two conventional types, and scarcely any two makers of repute are producing similar engines. The main differences may be classified into arrangement of cylinders, number of cylinders either odd or even, and radiation either by water jackets or by air direct.

The arrangement of the cylinders in star-shaped or radial form allows of a short crankshaft and a good distribution of impulses. Engines of this type were originally fitted only to monoplanes.

The Gnome engine (Fig. 7), however, has proved so successful that biplanes are fitted with it, notably the Farman machine.

Radial engines are either arranged with stationary or rotary cylinders, advantage being taken of the rotating mass in the latter instance for the elimination of a separate flywheel. Rotary cylinders, however, have several disadvantages, one of which lies in the power required to overcome the air resistance set up by the rotating cylinders at high speeds, in the Gnome engine this is about 15 H.P.

There are mechanical difficulties also, and the means adopted in overcoming some of these will be appreciated when reference is made to the description of the Gnome engine in the next chapter.

When the cylinders are of the vertical fixed type or of the Vee arrangement, the engine is more nearly similar to the ordinary motor car engine, but such increases in the number of cylinders as are now quite usual in flying engines permit of the entire elimination of the flywheel.

Some of the eight-cylinder engines will run at speeds as low as 150 revolutions per minute without falter, no flywheel being fitted.

The problem of radiation is somewhat simpler in a flying machine engine than in that of a motor car, as in the former case the engine itself is placed in an exposed position. The velocity of flight produces air currents of considerable magnitude, thus making direct air cooling of comparatively large engines a possibility. The elimination of water jackets with their attendant radiator, pump, and body of water enables the weight of the propelling mechanism to be reduced, but at the same time reliability of running may be impaired. By reliability is meant the duration of period of running consecutively, developing maximum power.

The engine problem has in the past been the retarding factor in the attainment of mechanical flight. This problem is divided into two parts: (1) maximum power produced with an engine of minimum weight, and (2) reliability of the engine which will not overheat when running for long periods at full power. The difficulty of keeping flying engines running for lengthy periods is an accepted fact, and generally speaking a water-cooled engine has a better chance of maintaining a normal working temperature than has an air-cooled one, but perhaps not to the extent which is represented by the guarantee of Duthiel-Chalmers. This firm guarantees a twelve-hour run with their water-cooled motor (Fig. 8), having two cylinders, 125 mm. diameter, but with their air-cooled motor, with the same cylinder diameter, they guarantee only a one hour's run. In considering these figures we must also take into account the fact that the water-cooled engine weighs 7·5 lb. per horse-power, whereas the air-cooled engine weighs only 3·1 lb. per horse-power.

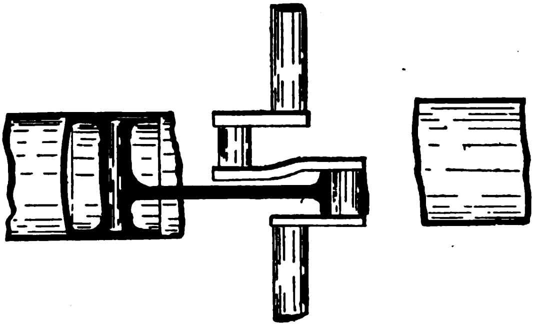

FIG. 8.—Diagram of the Duthiel-Chalmers Two-Cylinder Opposed Engine.

Modern tendency has all been towards the design of ultra-light engines, in which aluminium has been adopted as one of the principal materials; steel cylinders and pistons also form a feature in modern engine construction. Aluminium is generally an undesirable material, for many reasons, for use where heavy stresses occur, such as in crank chamber construction. It is also unreliable as a fixing for studs, and in the majority of cases could well be replaced by suitable pressed steelwork. Such a material carefully proportioned would be infinitely superior to aluminium in every way, even though its weight were little more than that of aluminium for the same purpose. Take for instance the upper half of the crank chamber—this is primarily a fixing bed for the cylinders in a four-cylinder motor of ordinary type. This portion of the engine also acts as a support for the crankshaft, and acts as a distance piece between the cylinders and the crankshaft. It has to withstand the stresses due to the thrust of the pistons, transmitted to the crankshaft through the connecting rods. The upper half of the crank chamber is therefore in tension between the cylinder faces and the main bearings, and it must be longitudinally stiff to prevent the crankshaft from springing. The duties to be performed do not conclude here, as the cylinders must be firmly held on account of the side thrust of the pistons due to the angularity of the connecting rods. It will be seen, therefore, that great strength and rigidity are required, and in the author's opinion this can best be obtained by steel suitably designed with ribs between the top face and the main bearing brackets. The holding-down bolts of the cylinders can be made use of as in the Green engine, to retain the main bearing caps in position, and thus strengthen the whole construction. Magnalium is being used in some engines to replace aluminium; it is light and strong, but somewhat expensive.

Perhaps the most important problems in connection with aerial engines are those of lubrication and carburation.

Lubrication.—Taking the former first, we know from experience of racing motor car engines how great a part is played by efficient lubrication of the pistons and the crankshaft bearings. The author's experience on the track has shown that ample lubrication makes a very great difference in both the speed and general behaviour of the engine, but in some engine designs this may be attended with difficulties of carbonisation and sooting. In the case of aerial engines such a result would be disastrous, misfiring might cause a broken propeller or a stoppage of the engine.

There is, however, the question of the quantity of the oil supply, every addition of weight counts, and economy must be studied, the lubrication must therefore be certain, efficient, and no more.*

Motor car engines of the last two years have shown very great improvements in systems of mechanical and positive lubrication, and these details are being carried out even to a finer degree in some of the recent aerial engines. Lubrication systems in detail are dealt with in other chapters on engines, but the principles are all important. Very serious and expensive breakdowns have occurred through failure of lubrication owing to the delivery or suction pipes of the lubricating pump becoming choked or nipped. In one case a large end bearing seized, causing the piston to be drawn out of the cylinder; the connecting rod was bent, and eventually broke off at the large end. The result was that the piston and its connecting rod were thrown violently through the side of the crank chamber, narrowly missing the aviator in their flight through the air.

Steel cylinders and pistons require special attention as regards lubrication, as two surfaces composed of this

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* Difficulties in connection with piston seizure are sometimes wrongly attributed to lack of lubricant, cylinder distortion due to unequal temperature of different parts of the walls of air-cooled cylinders is often the real cause of this seizure trouble.

material seize more readily than two cast-iron surfaces in contact owing to the fibrous nature of the material.

When splash lubrication is relied upon for the cylinder walls, the problem is somewhat similar to that in motor car design, as the inclination of the engine in a fore and aft direction will be approximately the same in both cases under ordinary working conditions.* One of the conditions of the tests of engines for the Patrick Alexander prize is that the engines must be run for a period of one hour in either direction at an inclination of 15°. Direct coupled engines for aerial work have an extra bearing, viz., the thrust bearing, which requires lubrication, as the whole of the thrust of the propeller must be taken up from the end of the crankshaft. Special arrangements are provided in other engines for the lubrication of the cylinder walls by means of direct oil feed. Rotary engines receive their oil supply for this purpose by the aid of centrifugal force.

The exact quality or specification of the lubricant for any particular engine or season can only be determined satisfactorily by experiment. Paulhan used for his Gnome engine at Brooklands a mixture of castor oil and petrol in equal proportions. It is the duty of the oil manufacturers to supply a satisfactory lubricant, and outside the scope of this book.

Carburation for Aerial Engines.—The problem of the carburation for the engines of flying machines differs in some respects from that of motor car engines. In the first place, these engines run usually at or near full power, they are not required to be throttled down to any extent, and in some engines no provision is even made for this purpose. Only when engines of extra large size are fitted is such a

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* Somewhat similar precautions are taken, so that all the connecting rod ends shall dip to the same extent in the oil provided in the base chamber, separate oil trays and channels are designed for each rod end. These channels are always kept to the same oil level by means of an oil pump and overflows.

provision necessary. Seeing that usually no clutch is interposed between the engine and the propeller, it is impossible for the engine to race since the resistance of the propeller increases as the cube of the rate of revolutions, and increase of propeller speed can only be obtained, therefore, at a greatly increased engine power. The problem is somewhat analogous to that of a motor boat engine, and in practice the same method of pumping fuel direct into the engine or into the induction pipe is sometimes resorted to. In the author's opinion, however, such a proceeding is not desirable, and he prefers the adoption of a carburettor, to any direct and positive methods of fuel feed when petrol is the fuel utilised. The reasons for this opinion are as follows:—

Primarily, the question of economy is of considerable importance, particularly where long flights are attempted, as the weight of fuel to be carried has an important bearing upon the relations of weight to lift, and the success of any long distance attempt is generally dependent to a great measure upon the adequacy of the fuel supply. An efficient utilisation of the fuel carried will enable a more lengthy flight to be maintained, other conditions being complied with, and the weather remaining favourable.

Fuel feeding operated directly by a pump may continue in regular proportion for some time, but owing to slight wear of the moving parts a considerable difference in the actual delivery may occur. If the pump could be relied upon to give a regular and proportionate flow in accordance with engine speed, such a method would be admirable in cases where no throttle valve is fitted. We cannot, however, as before explained, compare the conditions of an aerial engine to those of a motor car engine, as the propeller effect bears a definite relation to engine power.

When the machine is moving through the air the power required to rotate the propeller at any given speed is the same, for immediately the machine leaves the ground it is air speed and not earth speed that counts. Whether the machine travels with or against the wind its speed relatively to the air remains approximately constant, so that its petrol consumption will be constant, and proportional to engine speed.

On the road, however, such conditions do not obtain, as the road resistance varies from time to time, necessitating a greater or less petrol consumption with the engine running *at the same rate of revolution.*

In the latter case a carburettor is essential, though in the former it has been shown to be not so. A carburettor, however, is desirable on account of its possibilities for finer adjustment, more perfect carburation by means of a suitable spraying device, and adaptability for throttle control. The fact has been pointed out that the power required to raise the machine from the ground is greater than that required to maintain the same machine in flight, so that when in actual horizontal flight it becomes possible and sometimes desirable to throttle down the engine and reduce the rate of revolution of the propeller. This can only be done satisfactorily and economically when a carburettor is fitted. Attention has been called to the fact that carburation troubles have occurred to several of the leading aviators, and the author attributes these to the lack of provision for supplying sufficient heat to the fuel spray or incoming air during the carburation process.

Sufficient heat must be supplied to equal the latent heat of evaporation of the petrol, that is, in a given time the number of thermal units transmitted to the carburettor or induction pipe must equal the latent heat of the fuel, multiplied by the quantity of the fuel vaporised, in any given time.*

If this is not done, two alternatives present themselves: the first is the addition of an excess of fuel to reduce the

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* This subject is fully dealt with in "The Motor Car," by the same author. Hot air pipes are now being fitted to some aerial engine carburettors.

drop of temperature which occurs, or a diminution of the quantity of air passing to the engine. Both of these are bad policy; the former results in a waste of fuel, and the latter in a reduction of the power developed by the engine. The effect of either method is to enrich the proportions of the mixture and thus raise its freezing point. Owing to the temperature of the upper atmosphere being lower than that on the earth's surface, and also owing to the exposed position of an aerial engine, these questions are more important in the cases of such engines than in those of motor car engines, yet they appear to have been somewhat overlooked. It may be argued that the high temperature of air-cooled cylinders is taken advantage of for the purpose of supplying heat to the partially carburated air, but this does not prevent the carburettor itself from freezing.

It would appear that the adoption of a very volatile spirit with a low boiling point tends to aggravate matters, and we hear of at least one celebrated aviator resorting to a somewhat less volatile spirit in cold weather. The exact effect is not quite easy to explain, except in the following manner. When a spirit is very volatile, the greater portion of it is evaporated either in the carburettor itself, or in the induction pipe. A great drop of temperature will therefore take place in this vicinity if no heat is added.

On the other hand, with a less volatile spirit, the greater part of the fuel is carried in suspension in the form of fine particles into the engine cylinders, and the heat of the burnt gases and that radiated by the cylinder walls suffices to complete the evaporation process.

The author is obtaining special samples of petrol in order to further investigate this matter with air-cooled, water-cooled, and oil-cooled cylinders.

CHAPTER V.

DESCRIPTION OF SOME LEADING ENGINES.

Antoinette.—This engine (Figs. 9, 10, and 11) is the production of a firm which has been engaged for many years in making light motors, and the 50 H.P. engine used by Latham in his first attempt at the Channel flight has proved since that M. Levavasseur's work is both excellent and ingenious.

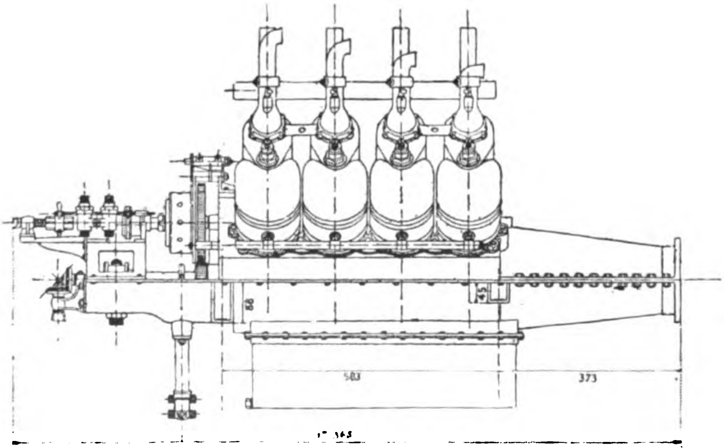

FIG. 9.—Antoinette Engine, Elevation.

The first essentials of an internal combustion motor for aviation are that it should be light, give ample power, and at the same time be free from vibration.

These considerations of vibration are dependent upon the two following factors :—

1. That the centre of gravity of the whole of the moving parts remains stationary.

2. The turning couple is constant.

Of these two problems the former is fairly easy of attainment, but the latter cannot be realised except by the employment of a certain number of cylinders. When four cylinders only are used, the couple varies between positive and negative, but when the number of cylinders is increased to eight the turning moment is always positive, and to all intents and purposes constant. In the Antoinette motor, therefore, eight cylinders are employed, and the vibration is practically nil. The adoption of eight cylinders also gives overlapping impulses, and it can be so arranged that the motor will run in either direction by simply sliding the camshaft so as to bring another set of cams into operation. In the Antoinette motor this is accomplished in a

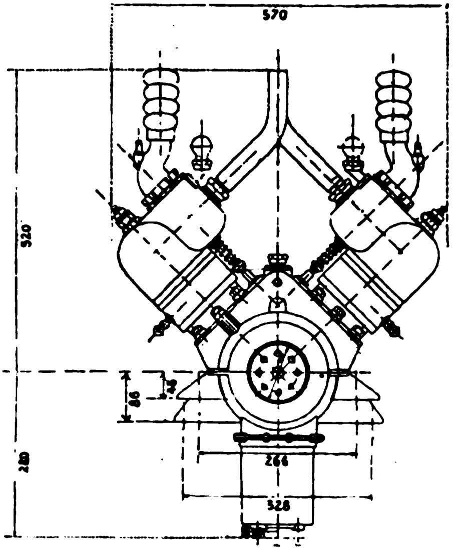

FIG. 10.—Antoinette Engine, End Elevation.

very simple manner by means of a knob fixed at the end of the shaft.

The cylinders are made in blocks of four in one solid piece of steel complete with their valve boxes. They are fixed on the top of the crank chamber at an angle of 90° to each other, *i.e.*, the centre lines of the cylinders are inclined at an angle of 45° from the vertical. The pistons are made of cast iron, and the crankshaft has four crankpins, so that two opposite connecting rods actuate the same crankpin. One camshaft operates all the inlet and exhaust valves. The water jackets are formed in an interesting manner of electrolytically deposited copper. Each jacket is a separate sleeve formed with the casing round the valve box, and so arranged that the exhaust valve spindle guide is also water jacketed.

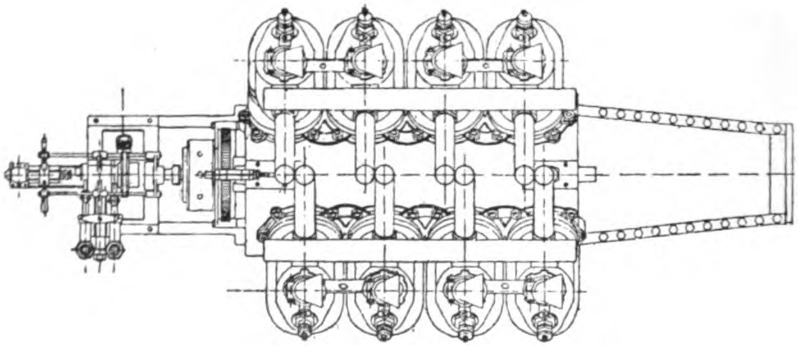

FIG. 11.—Antoinette Engine, Plan.

A particularly neat manner of fixing the jackets to the cylinders is adopted; the jackets themselves slip over the tops of the cylinders and valve boxes, the sleeves are then given a turn so that the cylindrical part of the jacket is made concentric with the cylinder itself, and the whole slides down till the lower edge covers some grooves formed circumferentially round the cylinders, and is here soldered.

The train of gears operating the engine mechanism comprises the usual pinion mounted on the crankshaft engaging into a wheel with twice the number of teeth on the camshaft. The ignition finger is attached to the camshaft, the ignition being by means of a single trembler coil capable of giving 800 sparks a second. The secondary distributer conveys the current to the plugs on the eight cylinders.

A small magneto or high frequency exciter driven by the engine may be fitted, thus ensuring perfect ignition.

It will be seen that owing to the high rate of sparking, each plug receives ten sparks during the time the distributer contact is connected to it.

The regulation of the motor can thus produce great flexibility, and it will run as slowly as 150 to 200 revolutions per minute, and from that up to its full speed.

The crankshaft is made of a special steel, and the five bearings on which it is carried as well as the connecting rod bearings are of bronze. The timing of the engine is so arranged that no two rods connected to the same crankpin are receiving impulses at the same time. As has already been explained, the engine will run equally well in either direction, and that adopted can be the most suitable for the particular purpose in view.

The water circulation is by a gear-driven pump feeding two water manifolds, each having four branches. The water enters the jackets at their lower ends and leaves at the top; it flows from a tank which is always full of water and placed above the cylinders.

A small oil pump is used to ensure perfect lubrication; the oil is taken from the bottom of the crank chamber and pumped through a copper pipe fixed along the top of the chamber and pierced with a number of spray holes which allow the oil to spray in all directions. The crankshaft assists in splashing the oil, which eventually falls to the bottom of the chamber. The lower cover of the crank chamber is made with three partitions dividing the chamber into four compartments which are all at constant oil level whatever be the inclination of the motor, as the partitions are of the same height. This ensures each big end dipping into the same amount of oil at every revolution.

An oil channel conducts the oil to one end of the chamber and to the sump of the oil pump, maintaining the oil reservoirs always at the same level, the oiling is thus automatic. The working of the pump can be ascertained by opening a small cock placed on the delivery pipe from the oil pump in a convenient position.

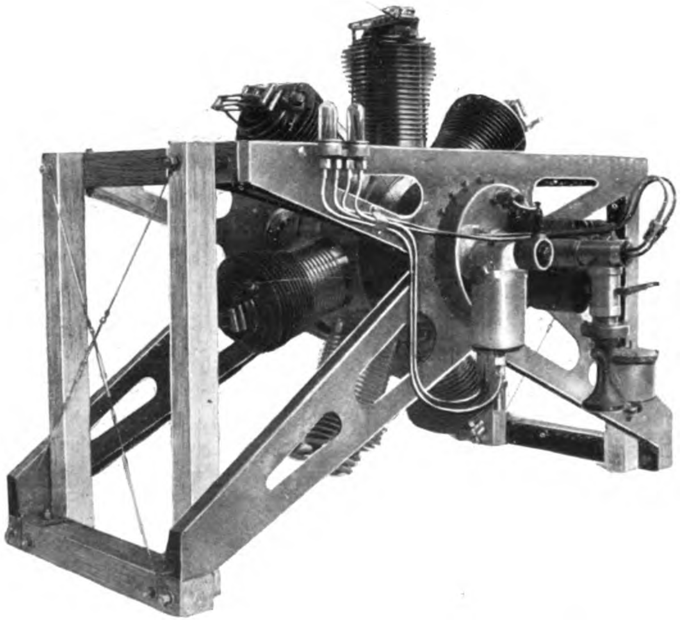

FIG. 12.—"Gnome" Engine, showing Carburettor and Lubricator in Position.
(*Photos by permission of Messrs Gauthier & Co.*)

Carburation is effected by a small petrol pump worked by the motor, drawing petrol from the tank and delivering it to eight small distributers placed on the inlets to the suction ports. Strainers are interposed in the petrol pipe to prevent foreign matter entering the distributer, and the amount of petrol delivered to the cylinders can be varied at will by altering the stroke of the pump.

It becomes a simple matter to adjust the petrol supply to suit the varying atmospheric conditions, and to obtain the best and most economical proportions of mixture of petrol and air.

Gnome.—The seven-cylinder Gnome engine (Fig. 12) is of the rotary star type, air cooled. The best known type is the seven-cylinder 50 H.P. engine which has chrome-nickel steel cylinders machined with their ribs out of solid blocks of metal (Fig. 13). These cooling ribs are of maximum dimensions near the cylinder heads and diminish in size as they approach the crank chamber, and no aluminium is used in the whole construction. A steel plate or disc forms each side of the crank chamber, seen in Figs. 25 and 26, and the two discs are located on twice the number of dowel pins as there are cylinders, as shown in Fig. 14. No bolts are employed to fix the cylinders to the crank chamber as they fit into circular orifices bored around the

FIG. 13.—"Gnome" Engine Cylinder, showing the Groove into which the Locking Ring Fits.

FIG. 14.—"Gnome" Crank Chamber, showing Slots for Cylinder Retaining Rings and the Bolt Holes passing through the Chamber between the Ring Slots.

chamber (Fig. 15), and when in place, steel rings (Fig. 16) are fitted into grooves turned in the cylinder trunks; these rings are securely held in place by the seven long bolts which hold the end plates of the crank chamber in position, the bolts are parallel to the crankshaft, one being between each neighbouring pair of cylinders.

FIG. 15.—"Gnome" Engine, showing Method of Attaching the Cylinders to the Crank Chamber.

FIG. 16. "Gnome" Engine Cylinder Locking Ring. This Ring fits on the Groove round the outside of the Cylinder Trunk when inserted into the Crank Chamber.

The seven connecting rods (Fig. 17) operate upon a single crankpin on the stationary crankshaft (Fig. 18), whilst the cylinders themselves revolve together with the crank chamber to which the propeller is fixed. A problem presents itself on account of the rotation of the cylinders causing the cooling air to impinge on one side of the cylinders only, that is the leading side; the trailing side of the walls will not meet the cool air but will be surrounded by eddies of warmer air. This tends to distort the cylinder bore from its true form when hot, so that special provision must be made for keeping a tight piston joint. Ordinary rings would be too stiff for this purpose, and resort has been made in the Gnome engine to a flexible type of joint similar in shape to the cup leather of an hydraulic piston. Leather naturally cannot be used, so a light ring of L section brass is employed. This ring is split and makes a close joint where the ends butt, and is used merely as a jointing material.

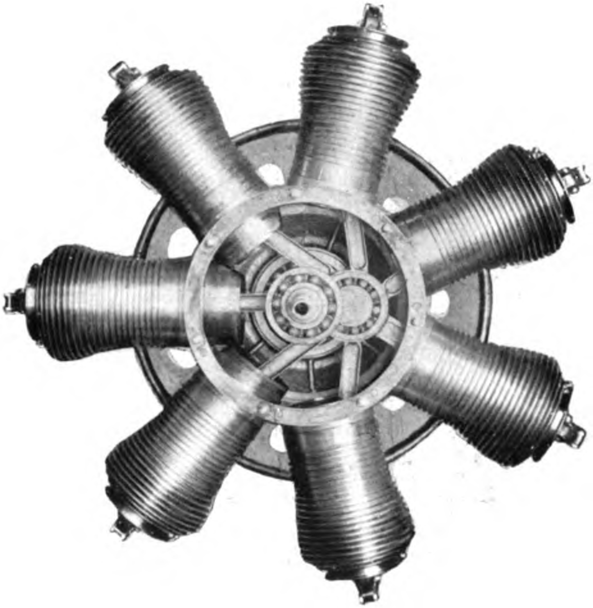

FIG. 17.—"Gnome" Engine with one end of Crank Chamber removed. Showing Assembly of Connecting Rods and Arrangement of Ball Bearings.

The necessary rigidity of fixing is maintained by means of a cast-iron ring placed inside it, and fitting in a wide groove in the steel piston. The piston (Fig. 19) is a fairly loose fit in the cylinder, so as to eliminate risks of seizing.

FIG. 18.—"Gnome" Engine Crank Shaft, the Oil Pipes are shown in Position.

The arrangement of the seven connecting rods is as follows:—One rod is made in one piece with a large double disc end (Fig. 20) forming the outer race of a ball bearing running on the crankpin. At intervals of 51½° around these discs, six attachment pins are held between webs or discs (Fig. 21), thus dividing the points of attachment into seven equal angular intervals. The remaining six connecting rods are attached to pins at these points, and it will be seen in Fig. 17 that their obliquity in course of revolution will be greater than that of the rigidly connected rod. It is necessary, however, to locate the big end disc to one of the rods to prevent it rocking on the crankpin.

The carburettor, which is, of course, stationary, feeds the engine through the hollow crankshaft into the crank chamber (see Figs. 17 and 18), and each piston draws its mixture from thence into the cylinder through an automatic inlet valve situated in the middle of the piston head (Fig. 22). An awkward problem had to be tackled in designing these inlet valves on account of the centrifugal force affecting their mass. An automatic valve must of necessity be light, and controlled by a light spring, in order that the maximum quantity of explosive mixture shall enter the cylinder. It would be impracticable to retain these automatic valves on their seats by springs designed stiff enough to counteract centrifugal force at high speeds, such as at 700 revolutions per minute.

Under varying rates of revolution the effective pressure of the spring upon the valve remains practically the same, whilst the force acting upon the spring varies. That is to say, that when the engine is being rotated by hand at starting, the springs which would work well at high speeds would be too stiff to allow the valves to open at all. This difficulty has been overcome in a very ingenious manner in the design of the Gnome engine, by counterbalancing the mass of the valve by two other masses of equal magnitude; the force upon these two smaller masses acts through two short levers in a somewhat similar manner to the levers and weights operated by a carburettor float. The two fulcrums are extensions of the valve guide, and the two inner

FIG. 19.—"Gnome" Piston and Short Connecting Rod.

FIG. 20.—"Gnome" Main Connecting Rod, showing Holes for Subsidiary Pins.

FIG. 21.—"Gnome" End Ring of Main Connecting Rod.

FIG. 22.—"Gnome" Engine Gudgeon Pin and Piston Head; the Inlet Valve is not Shown.

ends of the levers engage in a slot cut through the valve stem. Whatever the force acting on the valve, an equal and opposite force acts upon the valve stem through the medium of these two small levers. Two flat springs are fitted over the two balance weights, which they partly embrace, and these serve to return the valve to its seat at the end of the suction stroke of the engine. These springs are easily detachable.

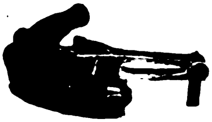

FIG. 23.—"Gnome" Engine Exhaust Valve Rocker.

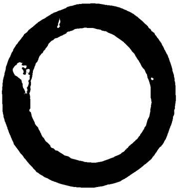

FIG. 24.—"Gnome" Engine Contact Plate.

FIG. 25.—"Gnome" Engine Crank Chamber Cover (Propeller End), showing Gearing operating the Cam Ring.

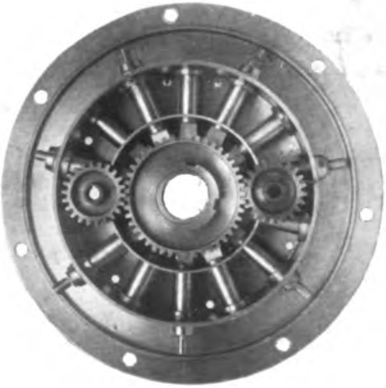

FIG. 26.—"Gnome" Engine Crank Chamber Cover. High Tension Distributer and Pinions driving Oil Pump and Magneto.

The exhaust valves are situated in the centres of the cylinder heads and are operated by twin balanced rocking levers (Fig. 23) actuated by long push rods, each being moved by a separate cam. The object of the weights is to relieve the cams of undue stresses owing to centrifugal force acting upon the valves. A spring retains each valve on its seating, and the balance weights are so regulated as to keep a slight pressure on each valve, which allows the engine to keep running should a valve spring accidentally break. The exhaust gases escape directly into the atmosphere.

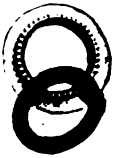

FIG. 27. "Gnome" Gear Wheel which drives Half-Time Gear Train.

In this engine the cylinders are placed radially and equidistantly around the shaft, as seen in Fig. 15, and are all on the same plane, but the valve mechanism requires the cams which operate the exhaust valves to be placed in different planes. The odd number of cylinders enables the firing to be carried out through equal angular intervals (Fig. 24), as in an engine working on the Otto cycle two revolutions must be completed before the whole set of cylinders has operated. With an even number of cylinders direct sequence would be necessary.

FIG. 28.—"Gnome" Lubricating Pump. This Pump and the Magneto are driven from the same Spur Wheel.

The two ends of the crank chamber are closed by steel plates. That at one end of the motor (Fig. 25) carries the cams and distribution gear in addition to the ball bearings, and a provision for fixing either transmission gear or the propeller, that at the rear (Fig. 26) carries a thrust bearing in addition to a large ball bearing. The cams which are in the forward casing are seven flat steel collars with one boss keyed on to a spindle and driven from a set of reduction gearing attached to the revolving crank case (Fig. 27).

FIG. 29.—"Gnome" Spur Wheel driving the Lubricating Pump and the Magneto.

Lubrication is by means of a two-cylinder reciprocating pump (Fig. 28) driven in a similar manner to the magneto (Figs. 29, 30, and 31). It is fitted with an oil distributer having seven ways, and its action is independent of the viscosity of the oil and of any negative pressure in the crank chamber. When the engine stops, any surplus oil can be drained out of the cylinders by opening the lowest exhaust valve. The five-cylinder engine is of 30 H.P. and has a bore of 100 mm. by 100 mm. stroke and weighs 60 kilogrammes; the seven-cylinder engine gives 50 H.P. at 1,200 revolutions per minute with cylinders 110 mm. bore by 120 mm. stroke, and weighs 76 kilogrammes or 3·3 lbs. per horse-power. No flywheel is necessary with these engines.

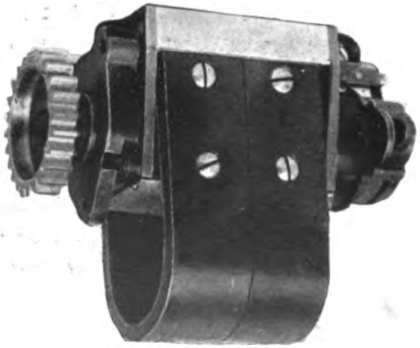

FIG. 30.—"Gnome" Engine Magneto. This is fitted upside down.

Esnault-Pelterie.—This radial engine (Fig. 32) is constructed with fixed cylinders, and as there would be considerable difficulty in connection with lubrication were the cylinders arranged entirely around the crankshaft, what would be the three lower cylinders (in the seven-cylinder engine) are, therefore, fitted in their diagonally opposite position above the shaft but in a plane adjacent to the other four cylinders, thus giving the engine seven staggered cylinders. In order to prevent the lowest cylinder on the leading side from obtaining an excess of lubricating oil, the trunk of the piston is drilled with a number of holes. Experiment has determined the number and size of holes required to prevent an excessive quantity of oil finding its way up into this cylinder.

FIG. 31.—"Gnome" Engine Sight Feed Lubricator.

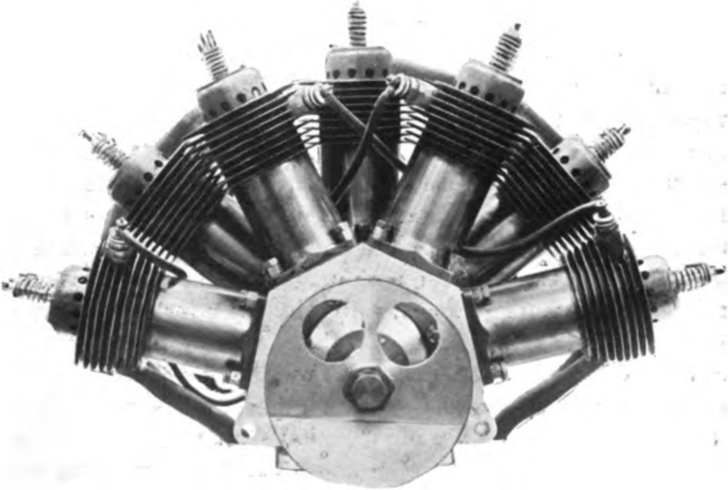

FIG. 32.—Seven-Cylinder 35 H.P. R.E.P. Engine.

The distribution of cylinders is so arranged that a cam with two humps actuating the inlet and exhaust rotates at a speed of (N – 1) times the speed of the crankshaft, and in the opposite direction to it. N = the number of cylinders. This cam has $\left(\frac{N-1}{2}\right)$ humps of equal height arranged upon its periphery. The firing sequence is 1, 3, 5, 7, 2, 4, 6, 1.

The *Crankshaft* is arranged with two crankpins set at an angle of 180°, and owing to the fan-shaped disposition of the cylinders it is possible to so shorten the crankshaft that the stress in the material is reduced to a minimum. In order to accomplish this arrangement four connecting rods actuate upon one crankpin, whilst the other three are connected to the other pin. The crankshaft itself weighs 2½ kg. for the 30 H.P. engine, and in this shaft no stresses exceed 15 kg. per sq. mm. under working conditions. The bearings have a very large surface, especially those which carry the thrust of the propeller.

The *Connecting Rods* are of particular interest because one of the heads receives three rods and the other four. One large end in each group is a solid piece, and this end is arranged to receive the requisite number of loose rods which are fixed in turn to it. In order to reduce the weight of the rod ends, an amount of material has been cut away without affecting the area of the bearing surfaces. The small ends of the rods are machined in such a manner that the pressure is carried by the exterior of the eye which is fitted to the piston head, as well as by the gudgeon pin; these two surfaces work in conjunction with each other and are bushed with gun-metal in each case. The rods themselves are of H section steel.

Cylinders and Pistons.—The cylinders are able, on account of the special types of valves, to be made completely symmetrical around their centre lines. They are each fixed to the crank chamber by three bolts having nuts and lock nuts. The pistons are made in one piece and are fitted to the connecting rod ends as above described

Valves.—Those in the 1909 type are of a special type. They open in the first place to admission, and then to exhaust. The valve itself is held in a cylindrical sleeve which has at its outmost end a series of holes drilled through it, through which the mixture enters the pocket. When the valve is lifted 4 mm. from its seat, these holes are covered by a fixed guide, and the valve on opening allows the exhaust products to escape. When the valve lifts another 4 mm. the holes become uncovered, and a flange on the valve sleeve covers the passage to the exhaust, so that the cylinder is put in direct communication with the inlet pipe. At the end of the stroke the valve returns to its seat and is completely closed. One of the chief points in this arrangement is that the sleeve between the valve head and the lifter is out of the path of the exhaust gas, thus reducing the tendency to seizure; in addition, the admission of the charge through the same valve tends to keep this valve from overheating in working. In the latest R.E.P. engines separate independent valves are fitted.

The engine is arranged with two inlet pipes, each of which has its own carburettor. The carburettor is made almost entirely of aluminium, and complete with its float weighs a little over 1 lb. The carburettors are placed at the base and on the outside of the crank chamber, but each feeds its mixture into a receiver within the case, from which the intake pipes lead to the cylinders. There are four leads from this receiver, three of them branching off to two cylinders each and one going direct to a single cylinder.

Lubrication is by splash, the compactness of the main organs and the position of the cylinders making it unnecessary even to use a pump. The oil is fed to the main bearings, then allowed to drip into the crank case, whence it is splashed up into the cylinders.

The ignition is by means of a special high tension magneto, running at half crankshaft speed, and has an ebonite distributer with the usual metallic contact. The cylinders are air cooled by means of fins, thus avoiding the use of water jackets, pump, and radiator. No fan is necessary, as the fins themselves have proved to be sufficient to keep the cylinders cool.

Anzani (Fig. 33, and Fig. 68, p. 145).—This engine chiefly claims attention as it was with the Anzani engine that Blériot's cross-Channel trip was accomplished. Blériot himself expressed the highest praise for this engine and its admirable working, although it is perhaps the smallest and simplest engine yet fitted to an aeroplane. The particular engine used was a three-cylinder air-cooled semi-radial type of 25 H.P., the cylinders jutting out from the upper half of the crank chamber. As a result of this construction the engine is very compact.

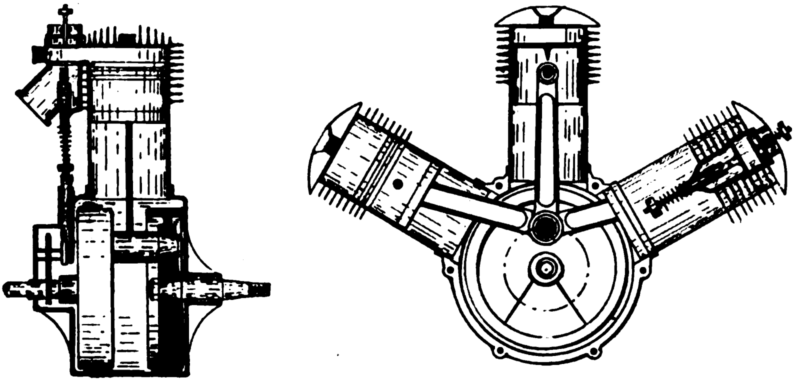

FIG. 33.—"Anzani" Engine. Type Blériot XI.

The cylinders of the standard engine are of the ribbed cast-iron pattern, the pistons being of cast iron with cast-iron rings. All the pistons actuate through their connecting rods on to the same crankpin, which necessitates two of the rod ends being forked. The angle between neighbouring cylinders is 60°, the firing sequence being 1, 3, 2. Taking No. 2 as the centre cylinder, from 1 to 3 is 180 – 60 = 120°, and the next interval from No. 3 to No. 2 is 360 – 60 = 300°, and from No. 2 to No. 1 is the same. The exhaust valves are cam actuated, but the inlet valves, which are situated above them, are automatic. The exhaust is remarkably free, as the piston on its outward stroke uncovers holes drilled in the cylinder walls, and the exhaust under pressure is thus expelled. The valves allow the exhaust gases to clear on the return stroke of the piston. The cylinder dimensions are 105 mm. bore by 130 mm. stroke.

As fitted to the Blériot XI. type of aeroplane this engine runs in a left-handed direction when looking towards the propeller from the front of the machine. A view of the engine from the rear is shown in Fig. 68, page 145, taken from a photograph of the machine at Hendon, which forms the frontispiece to this book. The three inlet pipes are fixed by union nuts to the cages retaining the automatic inlet valves and thence sweep downwards to the G.A. carburettor.

The ignition contact breaker is attached to the crank chamber at the opposite side to the propeller, the actuating cam being slipped over an extension of the crankshaft. This extension has a taper hole in its centre and four saw cuts are made at right angles in a longitudinal direction. A taper screw-ended plug fits into this hole and is the only means of locating the cam upon the shaft. Bowden wire control is fitted both to the contact rocker and to a segmental exhaust valve lifter.

Petrol is fed by gravity from a cylindrical tank, the rear end of which contains lubricating oil. The oil is put under slight pressure by means of a hand pump and passes through a sight feed lubricator to the crank chamber, channels being provided internally to effect the distribution of the oil.

Some difficulty may be experienced in properly lubricating the centre piston, and the author has had cause to suffer in this respect.*

The 35 H.P. water-cooled Anzani engine has four cylinders, in groups of two, set V-shaped on the crank

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* The weight of this engine complete is 65 kilogrammes, and its price is £120.

chamber, the angle between the centres of the two groups being 45°. These cylinders are of cast iron, fitted with steel pistons, having cast-iron rings. The exhaust valves, as in the 25 H.P. engine, are cam actuated and the inlets automatic.

The valve pockets are situated at the outside ends of the cylinders, *i.e.*, at the four extremities of the cylinders, and on the centre line of the cylinder blocks in each case.

The crankshaft has two crankpins, opposite connecting rods operating on the same pin, one rod of a pair having a forked end.

The crankpins are set at 180° to one another, and as the firing order is from one cylinder to the next one, actuating on the other pin, then to the cylinder situated diagonally across the set, and lastly to its neighbour, the firing periods are as follows:—No. 1 fires; then 180° elapses when the neighbouring cylinder fires, thirdly the diagonally opposite cylinder fires after 180°+45°, then its neighbour fires after 180°, and finally the diagonally opposite one fires at 180°−45°.

The crankshaft is supported on two bearings, and two flywheels are fitted within the crank chamber, which is vertically divided in the centre for the purpose.

The four inlet pipes sweep up in an easy curve from above the valve pockets, and return downwards to a central sphere situated between the cylinders to which the carburettor is attached.

The commutator for the coil ignition is attached to the outside of the crank chamber, and driven by a reduction gear.

The cylinder dimensions of the engine are 100 mm. bore by 120 mm. stroke, and at 1,600 revolutions per minute the horse-power is 35. The weight of the engine complete is 83 kg., and it is priced at £156.

The Pipe Engine (Fig. 34) is remarkable in many respects, principally on account of its air cooling, this being perhaps the largest scale on which air cooling has been adopted for so many stationary cylinders. The cylinders are eight in number, arranged in V formation in groups of four on the crank chamber, their centre line being at 90° to one another. The cylinders are 100 mm. diameter by 100 mm. stroke, giving 70 H.P. at

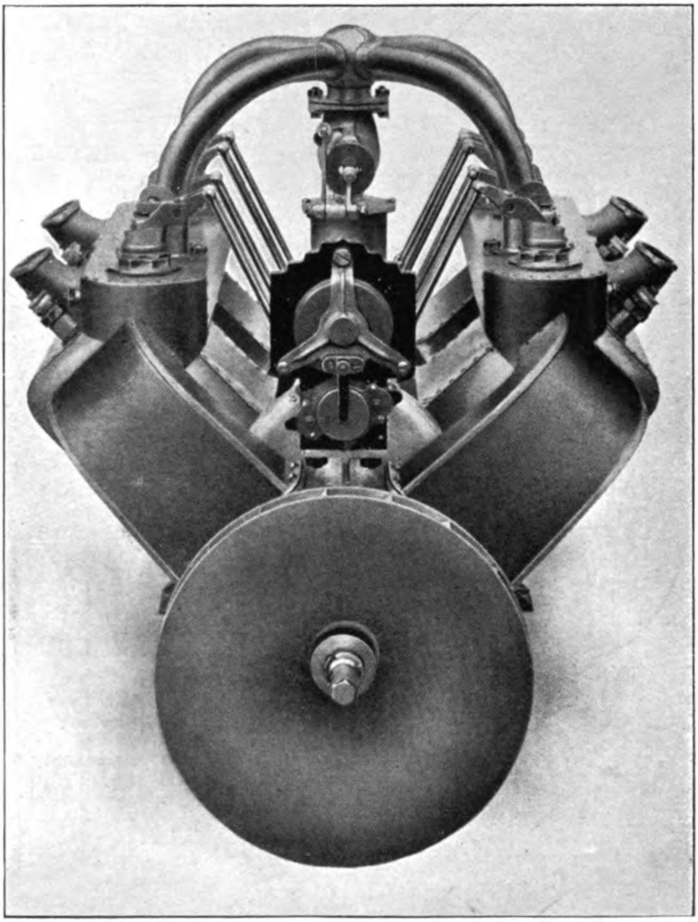

FIG. 34.—The "Pipe" Air-Cooled Engine.

(Photos by permission of the London Motor Garage.)

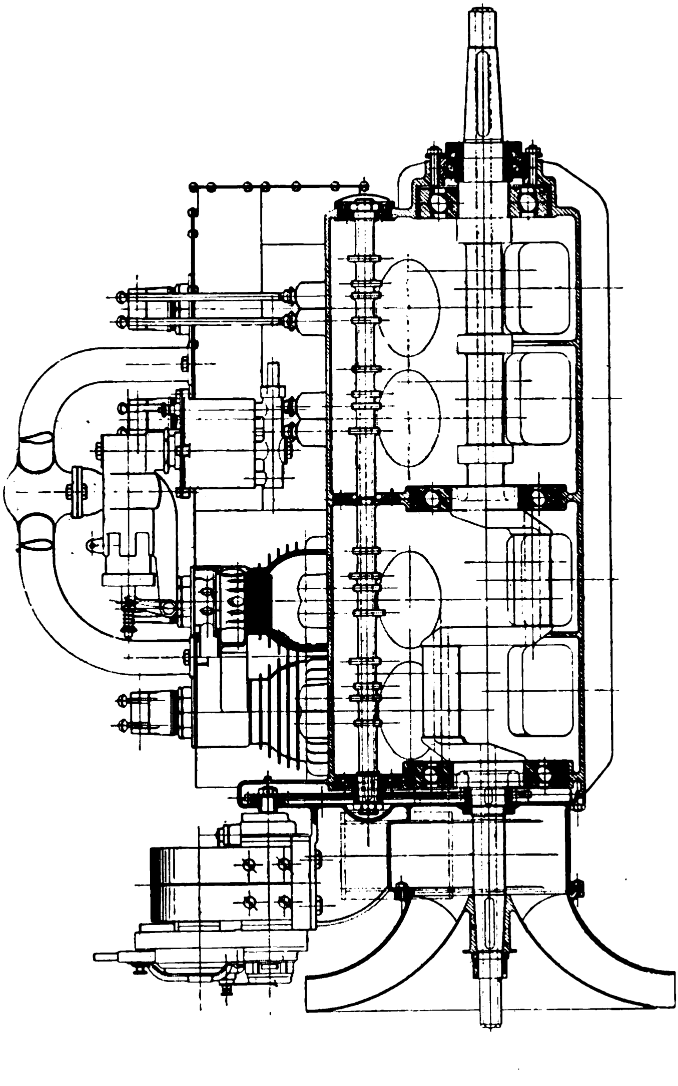

FIG. 35.—"Pipe" Engine. Longitudinal Section.

1,950 revolutions per minute, and 50 H.P. at 1,200 revolutions per minute. The cylinders (Fig. 36) are very compact and free from pockets, as both valves are contained in one cage set vertically in such a manner on the upper side of the combustion chamber that the centre line of the valve stems bisects a line passing across the top of the parallel portion of the piston at the centre line of the cylinder, when the piston is at the top of its travel.

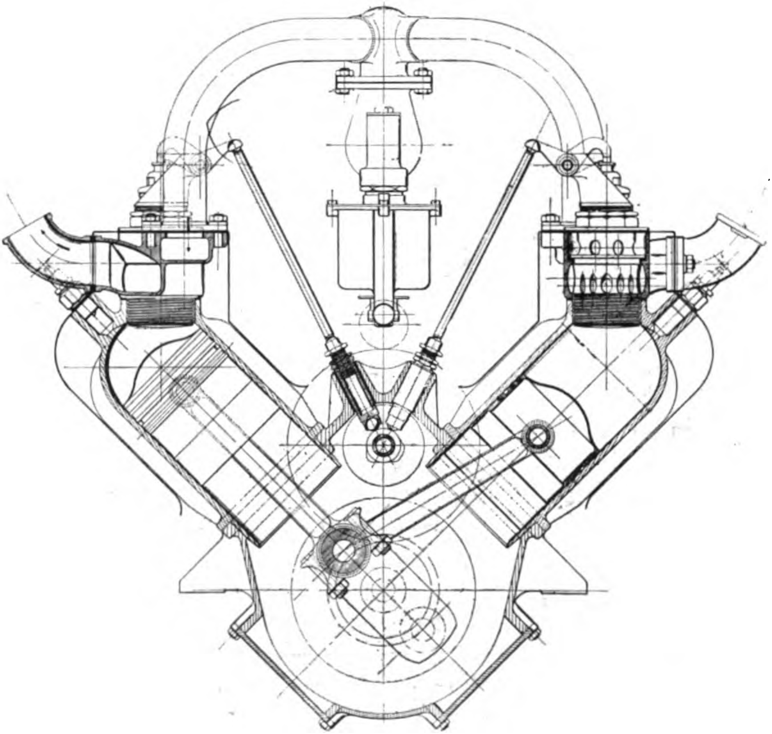

FIG. 36.—"Pipe" Engine. Transverse Section.

The pistons are dome-topped, similar to those employed in the Pipe motor car engines, and the crankshaft has four journals, opposite pistons actuating on the same one. The crankshaft is of a special steel of an elastic limit of 120 kg. per sq. mm., having an ultimate breaking load of 150 kg. per sq. mm.,* and at the same time a good ductility. It is carried upon three large ball bearings, and has a small ball thrust bearing at the propeller end. The other end of the shaft has a turbine-shaped induction blower keyed to it, fresh air is drawn through casings around the cylinders, which are in communication with the centre of the blower casing (see Fig. 35).

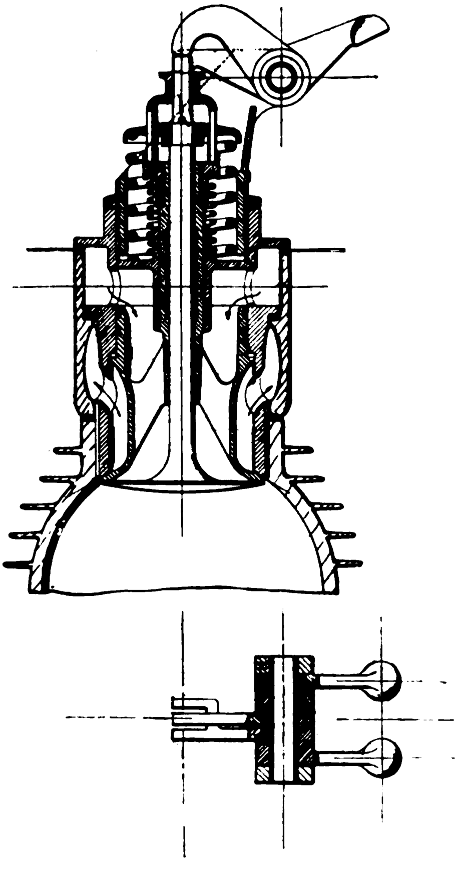

FIG. 37.—"Pipe" Engine. Valve Arrangement.

The single cam-shaft is carried inside the crank chamber at its apex, and is supported on three ball bearings; it is made in one piece with its sixteen cams, and of a specially hard steel (see Fig. 35).

The valve arrangement is on the concentric system (Fig. 37), each valve operated by a separate rocking shaft,

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* 76 tons per sq. in. and 95 tons per sq. in. respectively.

though both shafts run on the same bearing. The centre shaft has a single end pressing upon the inlet valve stem at the centre, this valve being of the usual mushroom form. The annular seating of this valve is on a second valve in the form of a sleeve which on being depressed carries the inlet valve with it, and opens a passage to the exhaust.

The inlet gases tend to cool the exhaust sleeve on their way to the engine, and thus to prevent any overheating which might occur.

The arrangement of the valve springs is worthy of attention. It will be noticed that the fork-ended lever actuating the exhaust valve presses upon a cap encircling the inlet valve stem, at the same time compressing a small spring below the cap and a heavier spring which the inlet valve washer is pressed against.

When the exhaust valve returns to its seat there is clearance between the washer on the inlet valve and the cap round the exhaust valve stem, so that only the thicker spring is actuating.

The ignition is by high tension magneto arranged to give a variable timing, and a single set of plugs is fitted in the centre of the top of each cylinder.

The carburettor is placed in the centre of the engine between the cylinders, and has four branch pipes, one serving each neighbouring pair of cylinders.

An extra air valve is fitted, which has an air dash-pot attached to its stem; variable speed is obtained by means of a special form of throttle valve.

The engine complete weighs 131 kg.

CHAPTER VI.

TYPES OF ENGINES—Continued.

The Gobron-Brillie aerial engine (Fig. 38) is built on the same principle as the motor car engine by the same firm, in that two pistons are fitted to each cylinder. The manufacturers claim that their engine is substantially constructed

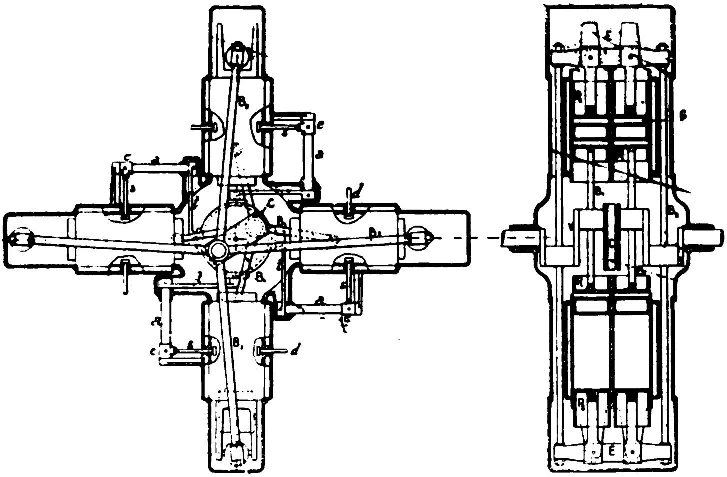


FIG. 38.—The Gobron-Brillie Engine.

as well as light, but that no undue sacrifice of weight has been made in the essential parts, and that it is owing to special neatness of design that this end has been secured. The engine consists of eight cylinders in groups of two, fitted in radial manner, the angle between the centres of the cylinders being 90° in each instance. The crankshaft is situated in the centre of the group, and has two throws and four crankpins, the two centre ones being in line, and the two outer ones in line with each other, but at an angle of 180° to the centre pins. The throw of the outer pins is slightly less than that of the centre pins. The inner pistons operate the centre crankpins in the usual manner by means of connecting rods, whilst the outer pistons are fitted with connecting rods operating reciprocating crossheads, one pair of adjacent pistons being connected to one crosshead. Return connecting rods are attached between the ends of these crossheads and the outer crankpins, these rods being in tension when working. In such an arrangement the combustion space consists of the cylindrical clearance between two pistons when at their inmost position, and the inlet and exhaust valves are therefore situated at the centre of the working barrel. The adoption of two pistons enables a long working stroke to be employed, combined with a low piston speed.

The arrangement for operating the exhaust valves is novel, consisting as it does of an eccentric cam C (Fig. 38), centrally located on the crankshaft, and actuating the valves through the levers *t* and the rocking arms *a*. The eccentric has a double groove connected together at one point, in which runs a shuttle. During rotation of the cam this shuttle runs from one groove to the other in turn, and thus operates the levers of one or other of the exhaust valves of the adjacent pair of cylinders at the proper moment.

The inlet valves are automatic, and fitted in boxes at the centres of the working barrels. Two carburettors are fitted, and the inlet pipes to all the valve boxes are of equal length. Two magnetos are also employed, each one firing in four cylinders.

There are thus virtually two distinct motors, which render the machine as a whole immune from total breakdown.

The magnetos are driven by skew gearing from the crankshaft, and are fixed to small seats formed on the side of the crank chamber. The cylinders are fitted with copper water jackets, and they have a bore of 90 mm. and a combined stroke of the two pistons of 160 mm. The engine develops 60 H.P. at 1,200 revolutions per minute, and 80 H.P. at 1,600 revolutions per minute.

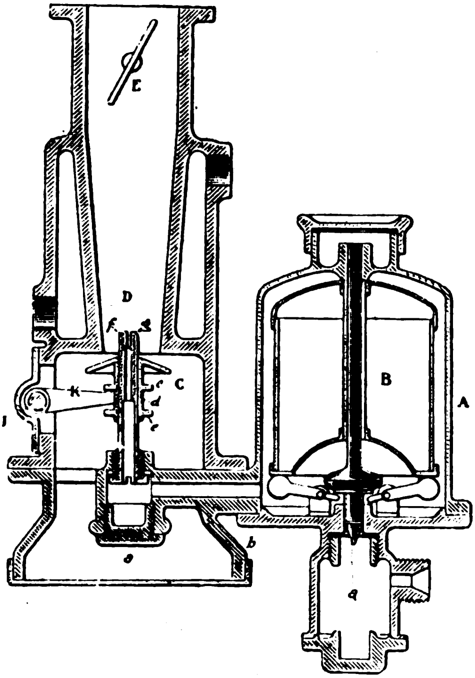


FIG. 39.—Gobron-Brillie Carburettor.

The water circulation is maintained by means of a rotary pump; the quantity of water required is about 3½ gallons.

A small gear pump draws oil from the lower part of the cylinders, and forces it back to the upper portion of the same. The Gobron carburettor (Fig. 39) is quite simple;

the usual float feed is employed, and the jet is situated at the lower end of a coned tube. Around the jet is a deflector valve, which is connected through links to the throttle valve. When this latter is opened or closed the deflector moves up or down in correct proportion, and only allows the proper quantity of air to pass the jet in accordance with the degree of throttle opening. This regulation is effected by means of a cam attached to the arm of the throttle E, which in turn operates the rod J and the lever K.

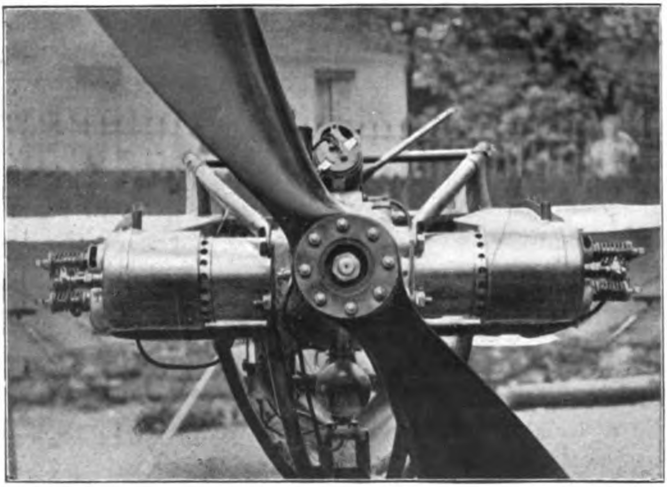
Panhard.—This firm is now making four-cylinder light engines of the orthodox vertical type, the cylinders are of steel, and are fitted with corrugated copper water jackets soldered in place. The cylinder heads are castings fixed by means of four bolts to flanges formed on the top ends of the cylinder barrels. The flanges have holes in them to permit the water circulating from the barrels to the heads without the use of external pipes.

The valves are on opposite sides of the cylinders in all patterns except the 35 H.P., and are fitted in pockets cast with the cylinder heads. The smaller engine has concentric inlet and exhaust valves situated on the cylinder heads. The dimensions of these engines are given in the table on page 84.

Aster.—The 50 H.P. Aster engine is of the four-cylinder vertical type, with the cylinders cast in one piece. A sheet-steel water jacket is riveted in position around this casting. An aluminium base chamber is employed, and the cylinders are fixed to it by means of lugs half way up the cylinder barrels. The cylinders are set *desaxé* to the crankshaft. The valves are all on the same side, and mechanically operated. The crank chamber is cast in one piece, and fitted with detachable end plates.

The 25 H.P. Darracq engine, which was originally fitted to M. Santos Dumont's little flyer "Demoiselle," has two horizontal opposed cylinders, 130 mm. diameter by 120 mm. stroke. The cylinders are made of steel cut from the solid, and are fitted with copper jackets, hard soldered in place. The valves are placed in the cylinder heads, and are each operated by push rods, actuating through short rocking levers attached to the cylinder heads.

In addition to the exhaust valve an extra means of escape for the burnt gases is provided by a number of holes about ½ in. in diameter drilled through the cylinder walls, which the pistons uncover on their outward travel. The magneto and water pump are placed on the top of the crank case, and are driven by an inclined shaft.



Aero photo.

FIG. 40.—The "Darracq" Engine as fitted to the Santos Dumont Monoplane.

Lubrication is by means of a pump, which sprays oil into the crank chamber. A single carburettor is fitted, a pipe leading the mixture to each cylinder.

Wright Engine.—This engine is made in France by

Bariquand & Marre, and also by Bollée, to the designs of the Wright brothers. The engine is as simple as possible, and its neatness of appearance is quite striking. The designers were unable to procure a suitable engine for their early experiments, and much time was expended in the initial stages of their flights with power machines in producing an engine which would work continuously under the severe conditions. The 30 H.P. engine, which is the only size made to their designs, has four cast-steel cylinders arranged vertically on the base chamber, the heads and valve pockets being in one piece with the cylinders. The valves are on the top of the cylinders and inverted, and they lie along the centre line of the engine arranged so that neighbouring pairs of inlets are together. The valves are interchangeable, the exhausts are operated by overhead mechanism actuated by long push rods, the inlets being automatic and fitted with rather stiff springs. Along the top of the base chamber a flat seat is machined, and on it ride four metal blocks on a rod; the blocks are drilled and the rod passes through them; a spring is slipped on to the rod on each side of one block and pressed against it by a collar. The rod is free to move endwise and motion is imparted to it by a small bell crank lever at the end of the crank case having its short arm cam shaped.

Depression of the long arm puts a compression on the four springs on one side of each of the four blocks, and as the valves in turn lift, the blocks slide under their stems and hold them open. This is the only engine control provided, as the magneto ignition is fixed and there is no throttle.

Petrol is fed into the bell-mouthed end of the inlet pipe by a small rotary pump forcing the fuel through a jet orifice and no heating appliances are provided.

The water jackets to the cylinders consist of aluminium sleeves which embrace the cylinder barrels only and are held in place by steel rings shrunk on. No water jacketing is provided for the cylinder heads. The connecting rods are tubular steel and have the usual tee-shaped ends connected to bronze bearings. The dimensions of the engine are 112 mm. bore by 100 mm. stroke, and the weight 96 kg. The horse-power developed at 1,300 revolutions per minute is 30.

In the Wright machine a pair of nine-toothed sprocket wheels are attached to the end of the crankshaft behind the flywheel, and the drive is by chains to the thirty-three toothed chain wheels attached to the two propellers. The gear wheels which operate the camshaft and magneto are of fibre, outside the crank chamber and not cased in.

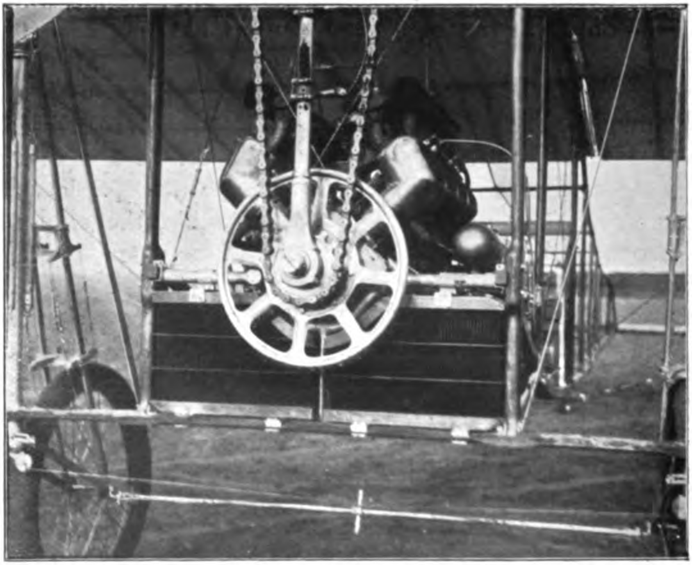


FIG. 41.—Eight-Cylinder 70 H. P. E.N.V. Engine fitted to Mr C. Grahame-White's Blériot Type XII. Monoplane.
(*Photo by permission of Mr C. Graham-White.*)

E.N.V.—The E.N.V. engine (Figs. 41 and 42) has eight cylinders in two groups of four, and situated in V shape upon the crank chamber, in order to ensure equilibrium without great length of crankshaft. The cylinders themselves are of cast iron, bored inside and turned outside to ensure equal thickness of metal and uniformity of the cylinder walls. Great care is taken to make every cylinder of exactly the same dimensions, so that the compression is equal in each. The connecting rods are attached in opposite pairs to the four crankpins. These pins are set at 180° and the two sets of cylinders at 90°. The crankshaft is supported on five ball bearings, there being one between each crank, also one thrust ball race at the forward end of

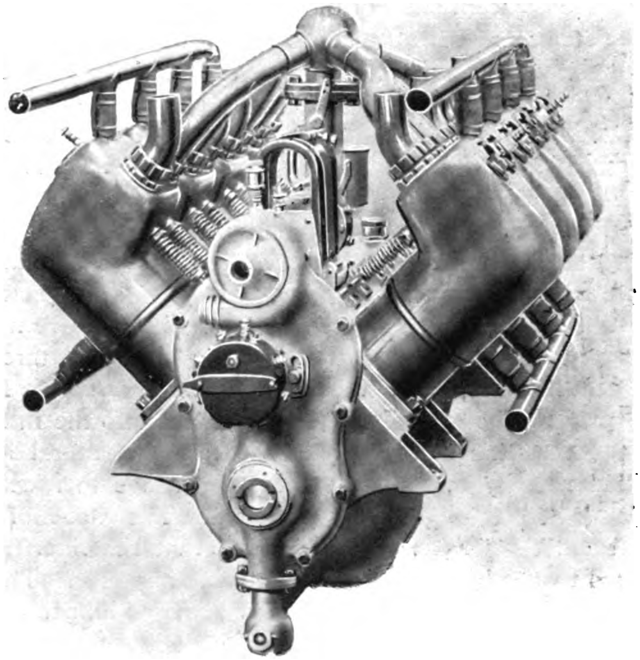


FIG. 42.—Eight-Cylinder E.N.V. Engine.

the shaft. The thrust race is to take the thrust of the propeller when directly connected to the crankshaft. The camshaft is made in one solid forging with its cams, the one shaft operating both sets of valves, *i.e.*, it has sixteen cams upon it. It is supported by one ball bearing at either end, and two plain bearings near the centre (Fig. 43).

The inlet and exhaust valves are placed side by side upon the adjacent sides of the groups of cylinders, and the valve stems are set at a slight angle to the centre line of the cylinders in order to reduce the clearance volumes of the cylinders. The cams actuate tappets through a large ball situated at the base of each tappet; this ball rides in a bronze sleeve and the tappet rod rests on the top of it.

The lubrication of this engine is carried out in a very ingenious manner. A piston pump of the hollow bucket plunger type is fitted in the latest models; this pump is operated by an eccentric fixed at the rear end of the crankshaft of the engine, the plunger has a ball foot valve which acts as the bucket valve, the oil being delivered through the eccentric rod, which thus forms the delivery pipe from the pump (Fig. 43). The oil then passes into the interior of the eccentric strap and thence through several holes drilled radially through the eccentric sheave to a central hole drilled through the crankshaft. The webs of the shaft and the pins are also drilled so that the oil is transmitted to the large ends of the connecting rods. The oil is thence forced, under a pressure of some 30 lb. per square inch, up the connecting rods to the gudgeon pins. The outflow of oil to these pins is particularly neatly arranged. The pins have longitudinal holes drilled through them, and each one has a radial hole leading from its journal in such a manner that the feeding hole in the bronze bearing of the small end of the connecting rod is only directly opposite to the hole in the gudgeon pin, and oil therefore only flows when the piston is on its upward stroke. The oscillation of the rod blinds the hole on the downward power strokes so that no oil then flows. It is claimed that

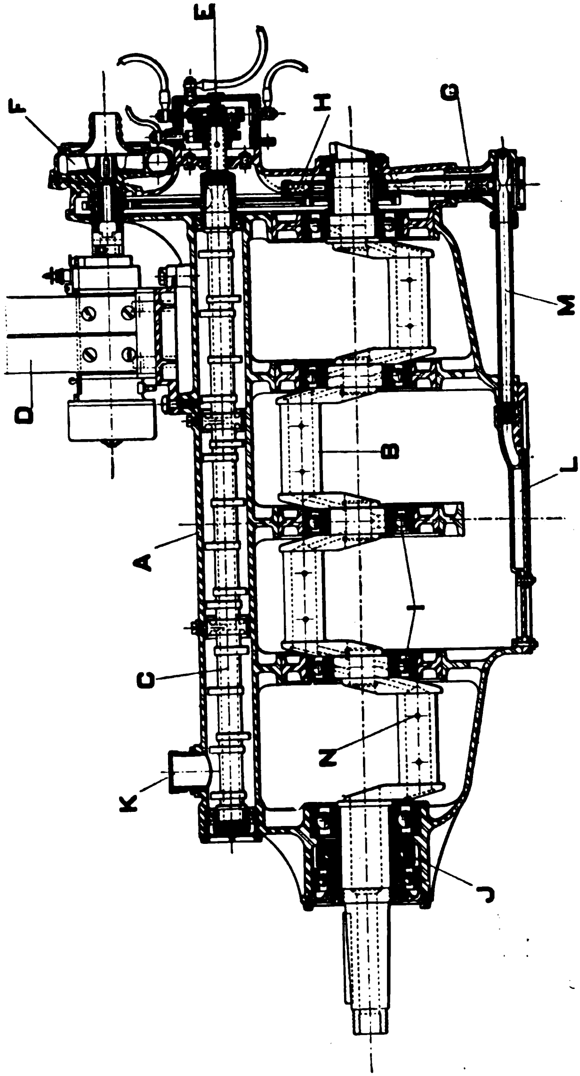


FIG. 43.—Crankshaft of E.N.V. Engine.

such an arrangement prevents smoking at the exhaust and ensures proper lubrication of the working parts. The consumption of lubricating oil is only 3 pints per hour when the engine is developing 60 H.P.

A central Zenith carburettor with double jet is fitted, and the four inlet pipes branch out from a ball fitted above the carburettor. Each branch pipe feeds two cylinders. The consumption of petrol is given at 0.6 lb. per H.P. per hour with both the 40 and 60 H.P. engines. On test, this was measured as 0.53 lb. per B.H.P. hour with the engine developing 1.3 times its R.A.C. rated power.

Particular attention has been given in designing this engine to the cooling arrangements, and it will be seen that each cylinder is fitted with an electrolytically deposited copper water jacket. The inlet and outlet pipes are attached at the lower ends of the jackets and between the valve pockets to short branches formed with the jackets, and the water circulation is maintained by means of a centrifugal pump.

The ignition is either by a magneto placed in front of the engine or by accumulator and coils. The magneto is driven by the crankshaft through inclined gearing at twice crankshaft speed. The driving pinion slides on the crankshaft in such a manner that the point of firing can be controlled, and also the position of the camshaft relatively to the crankshaft, by reason of the inclined teeth. The distributer for battery ignition is driven by the camshaft. Each cylinder can have two plugs fitted, and the two systems made quite separate and independent of one another.

The firing sequence is carefully arranged to ensure longitudinal balance and so that the pressure from two opposite cylinders is never upon one crankpin at the same time; it is carried out therefore as follows:—

Numbering the cylinders from the front end as 1, 3, 5, 7 for the left-hand four cylinders, and 2, 4, 6, 8 being the numbers of the four cylinders opposite to them, the firing is in the order of 1, 8, 5, 4, 7, 2, 3, 6, 1. The two opposite and diagonal cylinders fire, then two near the middle of the engine, then the other two diagonally opposite, and finally the remaining two middle cylinders.

The Green British-built engine (Fig. 44) is chiefly noteworthy from the fact that it was with this engine fitted to his Short plane that Mr Moore-Brabazon won the *Daily Mail* prize for the first flight of one mile out and home with an all-British machine. The chief claim made for this engine is its simplicity, and the accompanying figures (44 and 45) make this point apparent.

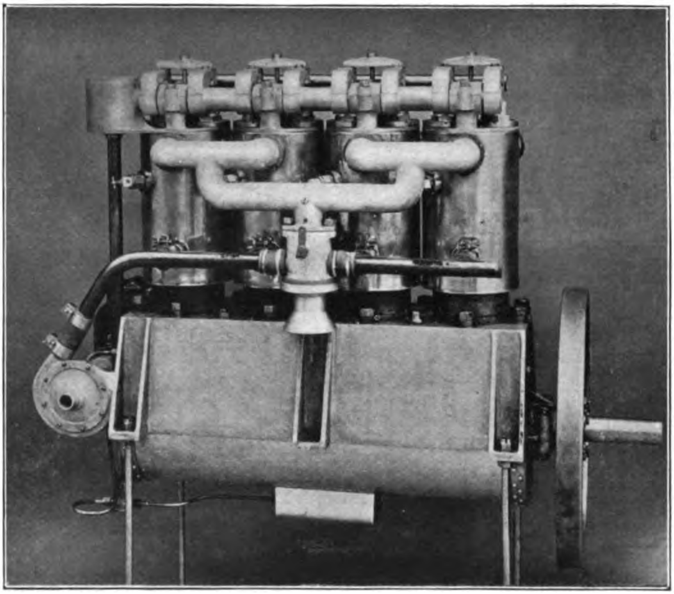


FIG. 44.—The "Green" Engine.
(*Photo by permission of the Aster Co.*)

Each cylinder barrel is cast separately with its vertical valve chambers in steel, and the metal is machined all over. The arrangement which allows for this machining enables all the cylinders to be made exactly uniform, and the vertical valve pockets reduce the areas out of direct line of firing. The water jackets are of thin copper pressed out of one piece, and 22-wire gauge thick. The joint at the lower end is made by means of a rubber ring

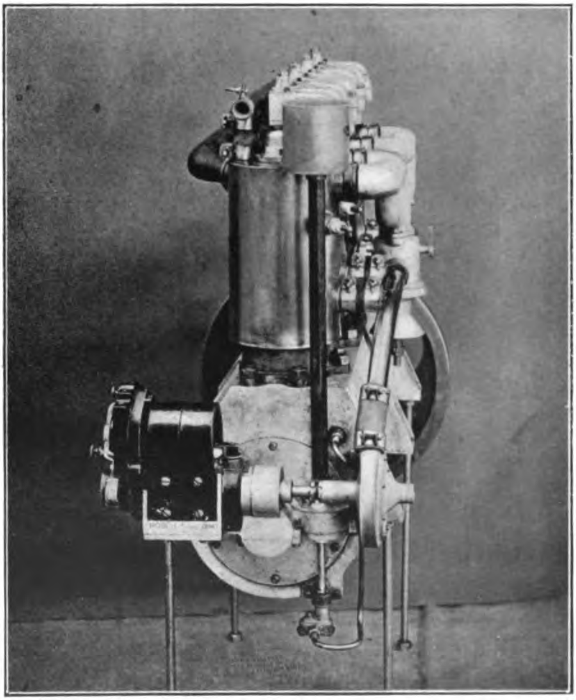


FIG. 45.—The "Green" Engine made by the Aster Co.

fitting into a groove in a flange formed on the cylinder body. The jacket end is slightly bell-mouthed, and slides on over this ring, thus allowing for expansion and contraction of the jacket on the principle embodied in the Crossley gas engine liners. All the ring joints round the valves and pipes are made of metal washers. The valves are of the usual mushroom type, inverted and retained in separate cages, held down in position by internal locking rings.

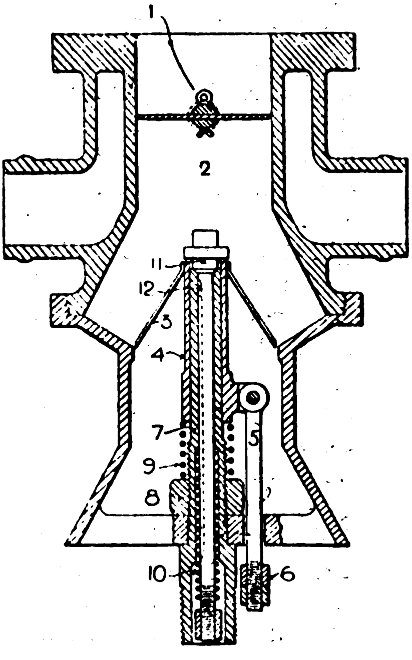


FIG. 46.—The "Green" Engine Carburettor.

The water jackets are carried round flanges made with the valve pockets, and secured to them by external locking rings screwed on to threads formed on the valve pockets for the purpose. The valve stems are not directly operated by means of the rockers, but a short tappet pin is interposed, being guided in a dome-shaped head over the valve spring and washer. The valves are operated by an overhead camshaft, each pair of cams together with the rockers being encased in a rotatable aluminium casing.

These casings rotate on bearings through which the camshaft passes, and the undoing of a single nut allows of a section of the cam case being rotated about the camshaft together with the rocker and short tappet pin. The valves can thus be drawn without in any way interfering with the adjustment of the tappet. By this arrangement also proper lubrication is ensured without the risk of oil travelling down the valve stems and into the cylinders. The method of supporting the crankshaft to the top half of the crank chamber is also noteworthy. The usual webs between each pair of cranks have a pair of solid columns cast with each. These are drilled out, and the bolts which pass through these holes, in addition to holding the bearing caps, also pass through the upper half of the crank chamber, and help to hold down the cylinders in position. Thus the working stresses are divided between the aluminium casting and the steel bolts, this arrangement making a strong form of construction.

The lower half of the crank chamber is of sheet aluminium, and forms an oil chamber with a large sump in the centre. The pistons and valve cages are of cast iron, the engine bearings are of bronze lined with white metal. The lubrication of the engine is carried out as follows:—An oil channel is cast solid with the upper half of the crank chamber and runs along one side throughout its whole length. Oil is forced through this by a small gear pump, and the oil is delivered from the main channel through holes at right angles to it directly into the hollow columns through which the main bearing bolts pass, and thence to the main bearings and hollow crankshaft. The bolts are reduced in diameter at their centres, so forming an annular oil channel. There are thus no pipes which may come adrift or leak.

The Simms British-built 50 H.P. six-cylinder engine (Figs. 47 and 48) is one of a type of engine which has been built for many years by the Simms Company for aerial work, but it has recently been re-designed, and its weight with flywheel reduced to 220 lb. This engine develops 50 H.P. at 1,200 revolutions per minute, and 60 H.P. at 1,400 revolutions per minute, being at the rate of 1 H.P. for 4 lb. of weight. The cylinders are of cast iron, with cast-iron water jackets, and their bore is 110 mm. with 110 mm. stroke. These cylinders are arranged in triple sets, and are at an angle of 120° to one another. The water circulation is by centrifugal pump, and the oil by a gear pump of gun-metal, and both are gear driven.

A train of operating gears is placed outside the crank chamber. The top pinion drives a Simms magneto, the intermediate wheel gears with a pinion wheel on the crankshaft and drives the camshaft, and the lowest pinion drives the oil pump. The carburettor is of an aluminium alloy, and combined with it is the throttle and air valve, which are formed as ports in the split halves of a sleeve, and arranged so that the air must pass through the throttle port, thus each has an independently controlled semi-rotary movement. These valves are held in position by a flat spring pressing upon their flanged covers, the carburettor being a simple single jet with a float feed and has no jacket.

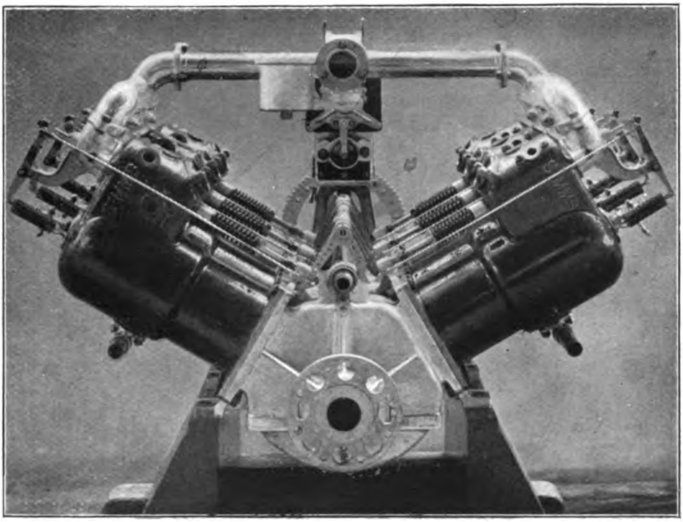


FIG. 47.—The "Simms" Engine.
(Photos by permission of Aero Motors Ltd.)

The three-throw crankshaft is hollow, and weighs only 14½ lb.; the oil is forced through it to all the bearings.

The whole of the valves are operated by a single hollow camshaft placed in a fore and aft direction between the cylinders and made in one piece with the cams. The inlet valves are on R. E. Phillips' system and semi-automatic. As a very small effort is required to move

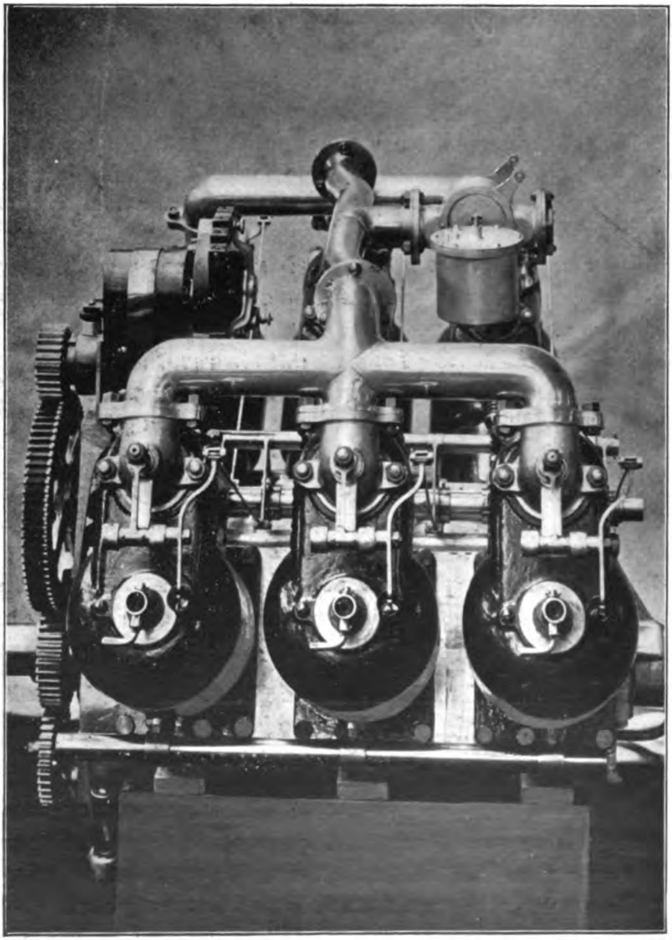


FIG. 48.—The "Simms" Engine.

them, the operating gear is of a light type, all stresses being tensile. . . .

The exhaust valves are of the underneath type, and worked by fingers pivoted about a common shaft with those of the inlet gear.

New Engine Company.—The type of engine now

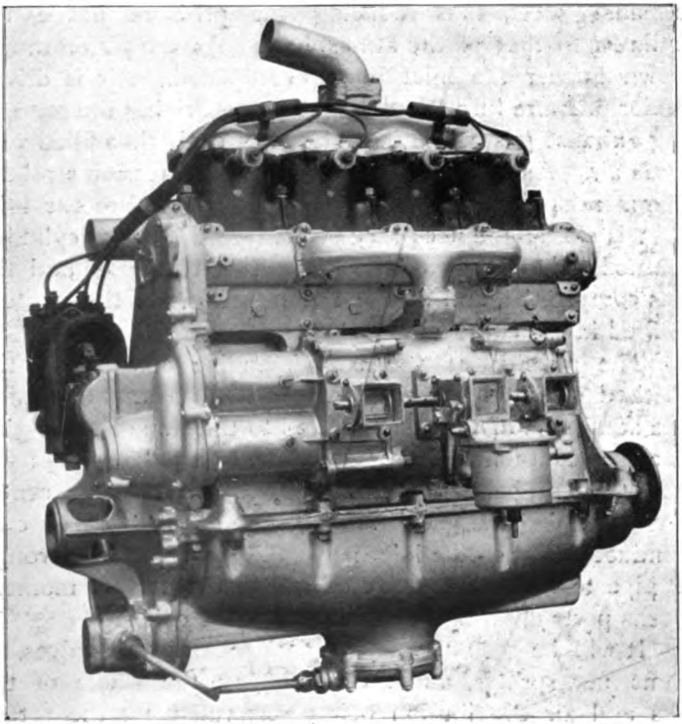


FIG. 49.—The New Engine Co.'s Two-Cycle Mort Engine. View of Pump Side. (*By permission.*)

made by this British firm is illustrated in Fig. 49, and is termed the "Mort" engine.

The engine works on the two-cycle principle, that is, an explosion occurs every time the piston is at the top of its stroke, and as compared with a four-cycle engine having the same number of cylinders, the torque is more even and the engine is considerably smaller and either lighter per horse-power or more robust for the power produced.

At the lower end of the cylinder is a ring of ports —on the one side for admission; on the other for the exhaust. As the piston descends, it first uncovers the exhaust ports, thus reducing the pressure inside the cylinder to that of the atmosphere. As the piston moves down further the inlet ports are opened. Air is driven under pressure through the inlet ports, driving the remaining exhaust gas before it. The cylinder is thus filled with fresh air. As the piston rises on the compression stroke it commences to close the ports. Slightly before the inlet port is closed the necessary gas is forced into the cylinder. Immediately afterwards the exhaust port is closed and the gas compressed, and at the top of the stroke the mixture is fired in the usual manner.

The novelty of the N.E.C. engine consists in the method of supplying the fresh air and gas and of timing the admission of the gas. Bolted to the side of the engine is a case containing a series of three rotary blowers of the gear type. The two end ones supply pure air, the centre one supplying the gas. Passages cast in the crank case conduct the air to the inlet ports, the gas being led through a pipe to a rotating valve which at the correct moment opens ports allowing the gas to enter the cylinder.

It will be seen there are no tappet nor slide valves, no cams, nor springs, and no valve gear, the whole of the gas and air distribution being performed by the rotary blowers and rotary valves.

Since there are double the number of impulses the power is approximately 75 per cent. greater than that of a four-cycle engine of similar dimensions.

The ports are large, and there is, therefore, no throttling of the mixture at high speeds; thus the power developed is in direct proportion to the rate of engine revolution.

The great advantages of the two-cycle system have always been admitted, but the difficulty has been in the method adopted for driving the air into the cylinder. It has hitherto been necessary to compress the air either in the crank chamber, or in a separate cylinder fitted with a reciprocating piston, thus adding to the complication and weight. These disadvantages are avoided in the Mort engine, whilst the advantages of the two-cycle system are retained.

These engines are standardised and built in three sizes, but the design is suitable for engines of the very largest powers.

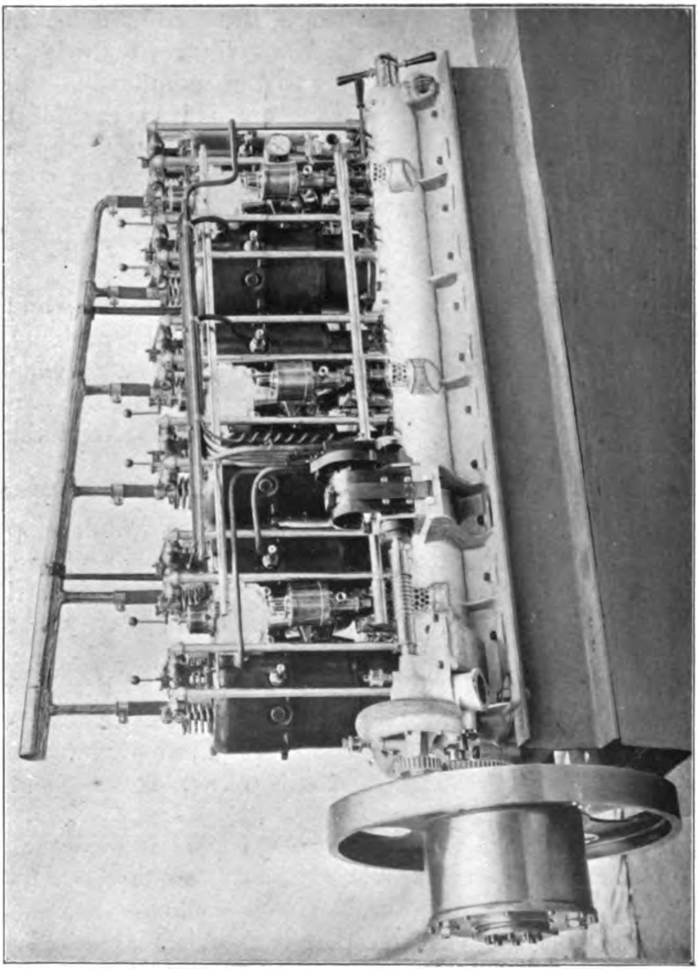
The smallest sized engine has two cylinders, and develops 12 H.P. at a speed of 1,000 revolutions per minute. When accelerated it will produce 24 H.P. at 2,000 revolutions per minute. The weight of this engine is guaranteed not to exceed 85 lb., the magneto about 8 lb. and the radiator about 11 lb. extra.

The next size is fitted with four cylinders, and develops 24 H.P. at 1,000 revolutions per minute, and will develop 48 H.P. when accelerated to 2,000 revolutions per minute. The weight of this engine is guaranteed not to exceed 155 lb. without the magneto, the latter weighing about 10 lb. and the radiator about 22 lb.

The third size is fitted with six cylinders, and develops 36 H.P. at 1,000 revolutions per minute and can be accelerated to produce 72 H.P. at 2,000 revolutions per minute. Its weight is not more than 210 lb. plus radiator about 38 lb.

It will be noted that a two-cycle engine is the equal in smoothness of running and evenness of torque of a four-cycle engine, with double the number of cylinders, and the makers of this engine claim that it produces practically no vibration.

The N.E.C. engines are guaranteed to produce their rated power at 1,000 revolutions per minute with the aeroplane travelling through the air at 25 miles per hour, and that they will require 25 per cent. less radiating surface than four-cycle engines of the same power.



Aero photo.

Fig. 50.—The N.G.A. Engine.

The lubricant is in each instance forced through a hollow crankshaft, and the ignition is by high tension magneto.

AERO-MOTORS AT THE FIRST OLYMPIA SHOW, MARCH 1909.

BRITISH.

TYPE.	Horse-Power.	Method of Cooling.	Number of Cylinders.	Bore.	Stroke.	Revolutions per Minute.	Weight in Lb.	Weight in Lb. per H.P.	Price in £.	Makers' Guaranteed Run in Hours.
Wolseley - -	50	W	8	3¾	5	1,350	300	6·0	600	4
N.E.C. - -	20	A	2	4½	4	1,500	...	...	...	4
,, - -	40	A	4	4½	4	1,500	290	7¼	250	4
,, - -	60	A	6	4½	4	1,500	...	...	...	4
Green - -	30	W	4	105	120	1,200	160	5·3	265	3
,, - - -	50	W	4	5½	5¾	1,100	236	4·7	365	3
,, - - -	80	W	8	116	140	1,100	...	...	...	3
Simms - -	45	W	6	110	110	1,100	220	4·4	450	3
International } -	12	A	2	2¾	2½	1,500	60	5·0	53	...
Rotary }	25	A	4	3¾	2½	1,500	80	3·2	105	...
,, -	50	A	6	5	4	1,500	130	3·0	210	...
,, -	50	A	8	4	3	1,500	...	...	...	...
FOREIGN.										
Metallurgique -	25	W	4	3	110	1,850	...	...	180	4
,, -	40	W	4	85	130	1,850	...	...	250	4
,, -	60	W	4	4	150	1,850	300	5·0	425	4
,, -	90	W	4	5	152	1,600	550	6·1	550	4
E.N.V. - -	80	W	8	100	130	1,000	300	3·7	...	5
Pipe - - -	70	A	8	100	100	1,950	289	4·1	600	...
Renault - -	50	A	8	90	120	1,600	264	5·3	520	...
Gobron - -	75	W	8	90	160	1,400	330	4·4	500	...
Miesse - -	130	A	8	130	130	1,200	245	1·9	...	2
Duthiel-Chalmers	18	A	2	125	100	1,200	56	3·1	150	1
,, ,, -	20	W	2	125	120	1,200	150	7·5	180	12
,, ,, -	40	W	4	125	120	1,200	250	6·2	320	12
,, ,, -	60	W	6	125	120	1,200	350	5·8	440	12
Gnome - -	50	A	7	110	120	1,200	165	3·3	520	5
,, - -	100	A	14	110	120	1,200	220	2·2	960	5
R.E.P. - -	20	A	5	85	95	1,400	115	5·7	320	3
,, - -	30	A	7	85	95	1,400	150	5·0	440	3
,, - -	40	A	10	85	95	1,400	216	5·4	560	3
Vivinus - -	50	W	4	106	120	1,600	...	...	240	12
,, - -	60	W	4	112	130	1,600	336	5·6	280	12
,, - -	70	W	4	115	130	1,800	280	4·0	320	12
Ripault - -	1¼	W	1	50	70	2,500	8	6·4	16	12
,, - -	1¾	A	1	65	65	1,800	...	...	16	...
Tani - -	15	A	...	...	...	10,000	15	1	...	...

A = Air cooled. B = Water cooled.

Cylinder dimensions in inches or millimetres.

AT THE END OF YEAR 1909 THE FOLLOWING ENGINES WERE ALSO MARKETED.

TYPE.	Horse-Power.	Method of Cooling.	Number of Cylinders.	Bore.	Stroke.	Revolutions per Minute.	Weight in Lb.	Weight in Lb. per H.P.	Price in £.	Makers' Guaranteed Run in Hours.
Anzani - -	10	A	3	85	85	1,800	72	7·2	48	...
,, - -	12	A	3	85	100	1,800	80	6·7	60	...
,, - -	25	A	3	105	130	1,600	143	5·7	120	...
,, - -	35	A	3	120	140	1,500	187	5·4	160	...
,, - -	45	A	3	135	150	1,400	231	5·1	200	...
,, - -	30	W	4	100	120	1,600	182	6·0	156	...
,, - -	60	W	4	135	150	1,400	319	5·3	312	...
Darracq - -	25	W	2	130	120	1,500	120	4·8	240	...
,, opposed -	50	W	4	130	120	1,500	242	4·8	400	...
,, vertical -	50	W	4	120	140	1,500	385	7·7	400	...
,, ,, -	100	W	4	170	140	1,200	550	5·5	600	...
Antoinette - -	24	W	8	80	80	1,500	110	4·6	328	...
,, - -	50	W	8	110	105	1,200	190	3·8	480	...
,, - -	100	W	16	110	105	1,200	330	3·3	920	...
E.N.V. - -	24	W	4	109	110	1,200	66	2·8	160	...
,, - -	50	W	8	85	90	1,700	155	3·1	350	...
,, - -	80	W	8	105	110	1,550	287	3·1 to 3·58	450	...
Wright - -	30	W	4	110	97	1,400	200	6·7	...	...
Mutel - -	24	W	4	98	125	1,300	176	7·3	270	...
,, - -	40	W	4	98	160	1,300	231	5·8	350	...
,, - -	50	W	4	120	160	1,300	282	5·7	440	...
Curtiss - -	30	W	4	3¾	4	1,200	85	2·8	250	...
Mors - - -	25	W	...	...	...	...	...	...	...	...
,, - - -	45	W	4	100	130	1,700	213	4·8	280	...
Gregoire - -	40	W	4	92	140	1,500	176	4·4	...	...
Brouhot - -	60	W	8	115	110	1,400	308	5·1	400	...
Aster - - -	12	...	4	130	140	...	...	...	...	...
,, - - -	50	W	4	130	140	1,000	241	4·8	400	...
Panhard - -	25	W	4	110	140	900	145	5·8	176	...
,, - -	35	W	4	110	140	1,000	198	5·7	400	...
Bouchet - -	50	W	6	100	150	1,100	286	5·7	...	...
Fiat - - -	50	...	8	...	...	...	132	2·7	...	...
Farcot - -	60	A	6	4	4¾	1,600	230	3·8	380	...
Renault - -	25	A	4	90	120	1,600	253	10·0	240	...
,, - -	50	A	8	90	120	1,600	370	7·4	440	...
Adams - -	36	A	5	4¼	3½	...	97	2·7	350	...
Vinot - -	45	W	4	103	130	1,600	343	7·6	...	...
N.E.C. - -	12	W	2	two-	cycle	1,000	93	7·7	100	...
,, - -	24	W	4	,,	,,	1,000	165	6·9	200	...
,, - -	36	W	6	,,	,,	1,000	220	6·1	300	...

The last three N.E.C. engines give twice the rated horse-power at twice the speed.

A = Air cooled. B = Water cooled.

Cylinder dimensions in inches or millimetres.

CHAPTER VII.

PROPELLERS.[*]

IF there is one essential part of a flying machine about which the least is really known, and with regard to which the greatest diversity of opinion is expressed, that detail is the propeller. It is not surprising, therefore, that the propeller is the least efficient portion of the whole combination of carefully designed mechanical appliances embodied in the complete machine.

As an instance of this being the case we only need reflect on the proceedings of some of the leading aviators at the meetings during the year 1909. Several propellers were to be found in the hangars, and these were tried in turn upon one machine with one engine. The method of procedure was as follows:—The machine was located upon the ground and attached to a dynamometer by means of cords. Each propeller was tried and dynamometer readings taken in order to determine which gave the best thrust at the most suitable engine speed. In order to further demonstrate the diversity of opinion upon propellers we have only to bear in mind that such an important consideration as that of the most suitable number of blades in any particular case is not definitely settled.

Air propellers are not governed by quite the same conditions as water propellers, as although each is a means of moving a column of air or water as the case may be,

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[*] The Author is indebted to T. W. K. Clarke, A.M.I.C.E., for some useful suggestions and criticisms in these two chapters.

the proportionate value of the coefficient of friction does not hold. By this is meant that although the mass of an equal volume of air and water is in the relation of about 1 to 800, the friction of the air upon the propeller blades as they cut through it is much more than $\frac{1}{800}$ of the amount of friction set up by water upon similarly shaped blades.

A propeller has two duties to perform, the first being to propel as large a volume of air as possible in a given time, which means area of propeller, speed of rotation and pitch; this must be done with the smallest possible consumption of power. Secondly, the blades themselves, together with the boss, must move through the air with the smallest amount of skin friction and head resistance. It will be seen that when the area of each blade is large, and the moment of this area about the centre of the shaft is high, much more power will be required to overcome skin resistance at a given rate of revolutions if the blade is at all humpy than if the blade area were smaller and the same rate of revolutions maintained. In the first place, the skin resistance of the larger blade is greater, and if the pitch of the blades is the same in each case it may happen that the larger blades will give no more thrust than the smaller ones, any extra "grip" which the larger ones may get upon the air being neutralised by the increased skin friction of the blades themselves.

FIG. 51. A Type of Wooden Propeller.

The effective width of the blade is also limited by the amount of air set in motion, as we find that when the maximum velocity is imparted to any molecule of air by the velocity and shape of the face of the blade, any addition of blade breadth cannot increase this velocity and only results in the increased skin friction already referred to.

We may set it down as an axiom that there is no standard shape or type of blade as regards normal projection which will be equally efficient under very diverse conditions of working. It is, however, possible to anticipate by measurement the best conditions under which any particular propeller will work. It is also possible to so arrange the design and number of blades that a column of air of a diameter equal to the diameter of the blades will be acted upon almost as though the air were a solid medium, *i.e.*, with a very small amount of slip. Major John Squires, of America, states in simple language the means of showing graphically when the correct number of blades is arrived at:—

> "If in plotting the thrust curve, the thrust units be considered as abscissæ and the blade units as ordinates, as more blades are added the curve becomes horizontal, and at this point a sufficient number of blades is indicated."

There are five variables to take into account in propeller design.

1. The speed of the machine and the power available.
2. The speed of revolution of the propeller, determined by the engine.
3. The area A (as below) which is governed by No 1, except it be limited by practical conditions of the design of the machine.
4. The pitch, which depends on 1 and 2, except in the case mentioned when the area A is limited, in which case it depends on this area A as well. The pitch is as important as the speed of revolution, and bears a close relation to it as the pressure caused by moving air varies as V^2.
5. The width of the blades, governed by all the above and by experimental results.

Referring now to the previous four variables in propeller design, Mr T. W. K. Clarke points out that there are two distinct classes into which propellers may be placed.

These may be designated by the following example for a 30 H.P. machine:—

If the speed of flight is to be 40 miles per hour maximum, a propeller diameter of say 7 ft. 6 in. would be required to give a high efficiency. In many cases, owing to faulty design of the machine, such a diameter might be either not permissible or inconvenient, and a 6 ft. diameter might be the maximum.

At the correct speed of the rearward air stream ejected from the propeller (which is equal to the speed of the machine plus the slip), the volume of air dealt with by the smaller propeller, even assuming a total disc area displacement, would be insufficient to produce the necessary propulsive reaction and to absorb the engine power. This can only be produced by increasing the pitch of the propeller and consequently the velocity of the rearward air stream, thus a very large slip results and the thrust per horse-power is much reduced, as will be seen in the next chapter. Such a modification of design gives rise to the usually accepted fallacy that air propellers involve a low efficiency and great slip.

Variations, therefore, of either rate of revolution or pitch varies the work done or expended as the cube of the variation, as we have a second power variable to begin with. Major Squires' experiments give briefly the following ideal results, for fixed propellers moving a column of air away from them.

P = pitch,
N = rate of revolutions per minute,
A = projected area of the air stream,
T = thrust per horse-power,
H.P. = horse-power.

1. Doubling N when P and A are constant, increases H.P. by N^3 and decreases T by $\frac{1}{N}$.

2. Doubling N and making $\frac{A}{2}$ with P constant, H.P. increases

as N^3 and decreases as A, which $\doteqdot$ increasing H.P. as N^2, and decreasing T as $\frac{1}{N}$.

3. Doubling N and making $\frac{P}{2}$ and A is constant, H.P. and T remain the same.
4. Doubling A when N and P are constant, H.P. increases directly as A and T remains the same.
5. Doubling A and making $\frac{N}{2}$ with P constant, H.P. increases directly as A, and decreases as N^3, H.P. decreases as $\frac{1}{N^2}$, T increases as $\frac{1}{N}$.
6. Doubling A and making $\frac{P}{2}$ with N constant, H.P. increases as A and decreases as P^3, $\doteqdot$ H.P. decreasing as $\frac{1}{N^2}$, and increasing T as $\frac{1}{P}$.
7. Doubling P when N and A are constant, H.P. increases as P^3, and T decreases as $\frac{1}{P}$.
8. Doubling P and making $\frac{N}{2}$ with A constant, then H.P. and T remain constant.
9. Doubling P and making $\frac{A}{2}$ with N constant, H.P. increases as P^3 and decreases as A, $\doteqdot$ H.P. increasing as P^2, and decreasing T as $\frac{1}{P}$.

0. Doubling N and doubling A with P constant, H.P. increases as N^3 and directly as A, $\doteqdot$ H.P. increasing as N^4, and T decreasing as $\frac{1}{N}$.

11. Doubling N and doubling A, making $\frac{P}{2}$, H.P. increases as N^3 and directly as A, and decreases as P^3, $\doteqdot$ H.P. increasing directly as A, and T remains the same.
12. Doubling N and doubling P with A constant, H.P. increases

as N^3 and as P^3, $\doteq$ H.P. increasing as N^6, and decreasing T as $\frac{1}{N^2}$.

13. Doubling N and doubling P, and making $\frac{A}{2}$, H.P. increases as N^3 and P^3, and decreases as $\frac{1}{A}$, $\doteq$ H.P. increasing as N^5, and decreasing T as $\frac{1}{N^2}$.

14. Doubling A and doubling P with N constant, H.P. increases as A and P^3, $\doteq$ H.P. increasing as P^4, and decreasing T as $\frac{1}{P}$.

15. Doubling A and doubling P, and making $\frac{N}{2}$, H.P. increases as A and P^3, and decreases as $\frac{1}{N^3}$, $\doteq$ H.P. increasing as A and T remains the same.

16. Doubling N and doubling A and doubling P, H.P. increases as N^3, as A, and as P^3, $\doteq$ H.P. increasing as N^7, or P^7, and T decreasing as $\frac{1}{N^2}$.*

Putting the above results into a simple form we find that—

$$\text{H.P.} \propto N^3 P^3 R^2,$$
$$\text{Actual thrust} \propto N^2 P^2 R^2,$$
$$\text{or } T \propto \frac{\text{H.P.}}{N \times P}.$$

Case 6 shows that by doubling the area and halving the pitch the power consumed is decreased to one quarter, and the thrust per horse-power is doubled when the rate of revolution is unchanged, that is to say, the engine speed remains constant, and it is the engine speed in the majority of cases which is one of the determining factors.

Increase of area increases the horse-power required in direct proportion whilst it does not increase the thrust

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* These results, in a somewhat different form appeared in *Flight*.

per horse-power, consequently multiplying the area by four, so that the original horse-power in the motor is absorbed, and the thrust per horse-power being doubled as above owing to the pitch being halved, the resulting thrust is double what it would have been with the original pitch.

It must be borne in mind that "area" refers to the area of the disc through which the blades revolve, as the air pressure created by the blades should be over the whole disc and not merely upon an area equal to the blade area.

In practice, however, no propeller in use does give the effect over the whole disc owing to eddies, and to the presence of the boss and the roots of the blades which give no useful propulsive effect to the air. Many propellers only give the work calculated on blade area, and thus the table should be used with due caution; it is given solely as indicating the relative results of different values of the constants and variables.

It should be noted, however, that propellers of equal efficiencies can deliver widely different thrusts per horse-power, as in cases 5 and 6 where the thrust per horse-power is doubled by halving the pitch and doubling the area.

The above data, it must be remembered, are for a propeller thrusting against a fixed point, and a higher thrust per horse-power does not actually signify that a higher efficiency is obtained. It is also to be borne in mind that conditions of fixed point thrust are not the same as when the propeller is moving forward into undisturbed air, and it does not follow that a propeller with a high thrust per horse-power will give greater speed through the air than one developing a lower thrust value.

Now considering a propeller moving forward through the air as is the case in actual flight, it is easier to assume that this propeller has cent. per cent. efficiency.

The work done by the propeller consists in moving a mass of air of known weight at a certain rate per minute, and in this way can be compared to a pump raising water through a vertical rising main.

If W = foot-pounds of work done per unit of time,
w = total weight of air moved,
w_1 = weight of a cubic foot of air, say 0·073 lb.,
$w \therefore = w_1 \times$ (total number of cubic feet of air moved in unit of time) say C,

$$w = w_1 \times C.$$

Now

$$W = \frac{wV^2}{2g} = \frac{Cw_1V^2}{2g}.$$

If R = revolutions per *second*,
A = area through which propulsive effect is exerted,
P = pitch of propeller in feet,
g = 32·2 ft. per second per second,
V = velocity of air in feet per second,

It will be seen that C is dependent on $P \times A \times R$, so the equation becomes

$$W = \frac{(PAR)w_1V^2}{2g},$$

$$V = P \times R$$

$$\therefore \quad W = \frac{(PAR)w_1(PR)^2}{2g},$$

$$W = \frac{P^3AR^3w_1}{2g},$$

$$\text{or} \quad \frac{P^3AR^3w_1}{2gW} = 1.$$

Substituting practical values in the above equation—

Let a 40 H.P. engine drive a propeller 8 ft. diameter (50 sq. ft. area swept) at 20 revolutions per second = 1,200 revolutions per minute. The correct pitch of such a propeller is required to be found (W = 22,000 ft.-lb. per second).

$$\frac{P^3 \times 50 \times 8{,}000 \times 0·073}{64·4 \times 22{,}000},$$

$$\therefore \quad P^3 = 48·5,$$

$$P = 3·65 \text{ ft.}$$

Thus we have the four values fixed for this propeller.

Now, calculating the thrust = T as before—

$$T = AV^2 \times 0{\cdot}00139$$

and $V = P \times R$

$$= 3{\cdot}65 \times 20$$

$$T = 50 \times (3{\cdot}65 \times 20)^2 \times 0{\cdot}00139$$

$$= 334 \text{ lb.} = 8{\cdot}37 \text{ lb. per H.P.}$$

1. If a 20 H.P. engine had been used, the pitch would have been 2·9 ft., and T = 232 lb. = 11·6 lb. per H.P.

If we retain the 20 H.P., and the revolutions per second are constant, and increase the pitch of the blades, at the same time reducing the diameter and area of the propeller. Suppose the pitch is 3 ft. and W = (now 11,000) ft.-lb. per second—

$$A = \frac{11{,}000 \times 64{\cdot}4}{27 \times 8{,}000 \times 0{\cdot}73}$$

$$= 44{\cdot}87 \text{ sq. ft., or a diameter} = 7{\cdot}5 \text{ ft.}$$

$$T = 44{\cdot}87 \times (3 \times 20)^2 \times 0{\cdot}00139$$

$$T = 224 \text{ lb.} = 11.2 \text{ lb. per H.P.}$$

2. Comparing the two results for a 20 H.P. engine we have:—

(*a*) Area 50 sq. ft., and air velocity 57·86 ft. per second.

(*b*) Area 44·87 sq. ft., and air velocity 60 ft. per second.

If we assume that the head resistance of the machine is equal to that of 20 sq. ft. in a plane normal to the direction of flight, and the head resistance is proportional to V^2, which appears as propeller slip, it is evident that the velocity of flight will be decreased by any addition of area, and its resistance in proportion to V^2. Let a = the added area = 20 sq. ft., we have—

$$V = \sqrt{\frac{AV^2}{A + a}}$$

and the resultant velocity of the machine in each case will be

1. $V = \sqrt{\frac{(2{\cdot}893 \times 20)^2}{50 + 20}} = 49$ ft. per second.

2. $V = \sqrt{\frac{44{\cdot}87 \times (3 \times 20)^2}{44{\cdot}87 + 20}} = 50$ ft. per second.

As a result we find that the propeller with the (2) lower thrust value (11·2 lb. per H.P.) gives a greater theoretical flight velocity than that with the (1) higher value (11·6 lb. per H.P.).

(These calculations are taken from Major Squires' paper.)

Rankin Kennedy approaches the subject of propeller calculation in a somewhat simpler form, taking the force required to propel a given volume of air astern of the propeller per second $=\frac{W}{V}$ as before, that is, the total foot-pounds of work done divided by the velocity of the air, thus giving a unit of "pounds"—

$$\frac{W}{V}=\frac{V \times C}{g}, \text{ or } \frac{V \times (AV \times 0{\cdot}073)}{g}$$

$$\therefore \quad W=\frac{C}{g}V^2.$$

If a propeller drives a column of air of 64 sq. ft. in area at a velocity of 20 ft. per second, it accelerates to that speed a weight of air per second—

$$(C \times w'_1) = w = 20 \times 64 \times 0{\cdot}073$$
$$= 93{\cdot}5 \text{ lb. per second.}$$

The equal and opposite force appearing as thrust at the propeller—

$$\frac{W}{V}=\frac{20 \times 93{\cdot}5}{32}=58{\cdot}5 \text{ lb. thrust.}$$

w = the foot-pounds of work done per second—

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

where χ = the efficiency coefficient of the propeller.

When the machine moves forward through the air at a speed = S in feet per second, the column of air leaves the wake of the propeller at a velocity (S + V). Rankin Kennedy here assumes that the velocity of the wake relatively to the surrounding air is the same when the machine is in motion as when at rest, but this is a fallacy.

The thrust of the propeller is then proportional to—

$$\frac{w(S+V)V}{g} \text{ or in pounds}$$
$$=\frac{0{\cdot}073(S+V)V\times A}{32}$$

showing the advantage gained by advancing the propeller in the air giving it a positive feed.

(S+V) probably increases, but V decreases as S increases, and the product V(S+V), and therefore the thrust, decreases as the speed of the machine increases.

If the theoretical efficiency were obtained it would

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

thus if S=60 ft. per second and the slip of the propeller =40 ft. per second—

S+V=100 ft. per second, this being the speed of the wake of the propeller relatively to the machine.

$$\text{The efficiency}=\frac{60}{60+\frac{40}{2}}=75 \text{ per cent.}$$

Now as S+V=100 ft. per second and the propeller revolved at 1,200 revolutions per minute=20 revolutions per second, the pitch would have to be $\frac{100}{20}=5$ ft.

We may consider the work to be done by the propeller upon the air in a different manner. The object of a propeller is to set in motion a given weight of air in a given time; the air must be accelerated from a state of comparative rest until it has acquired a certain velocity in the same way that a body, having potential energy, may acquire a certain velocity when acted upon by gravity for a certain known time.

Under these conditions—

$$V = \sqrt{2gh}.$$

Where $g = 32$ ft. per second per second,

$h =$ the height in feet through which the body falls,

$m =$ the mass of the body,

The energy imparted to the body $= \dfrac{mV^2}{2g}$.

If we take the mass as unity we find that the foot-pounds of air per second to be delivered by a propeller are proportional to V^2.

The total weight of air to be delivered in a second is the product of (1) the disc area in square feet (net value), (2) the speed of flight in feet per second, (3) the weight of a cubic foot of air. If this is multiplied by the energy imparted to a pound of air as obtained by $\dfrac{V^2}{2g}$ we have as a product the foot-pounds of energy imparted to the air at any particular speed. This divided by the speed will give the thrust obtained if the propeller is of nt. per cent. efficiency.

Say we have a propeller 7 ft. diameter = 38·5 sq. ft.; flying speed = 40 miles per hour = 58 ft. per second; speed of air delivered by propeller = 85 ft. per second; weight of a cubic foot of air in round figures = 0·08 lb.

$\dfrac{V^2}{2g} = 113$ ft.-lb. of energy imparted per pound of air.

If we take the effective area of the propeller = 30 sq. ft.—

$$\left.\begin{array}{r}\text{The total energy in foot-pounds}\\ \text{per second imparted to the air}\end{array}\right\} = 30 \times 85 \times 113 \times 0{\cdot}08 = 23{,}100.$$

$$\text{The horse-power required} = \frac{23{,}100}{550} = 42.$$

$$\text{The thrust of the propeller} = \frac{23{,}100}{85} = 272 \text{ lb.}$$

When considering the work done by a screw propeller, it is a common error to suppose that the whole of such work is performed by the face of the blades. It is a fact that the most perceptible air stream appears at the wake of the propeller, and that only slight indications of air motion are observable in front of it.

However, Mr Holroyd Smith's interesting fan experiment shows that it is the induced air rather than the air thrusted which has the greatest effect.

He takes a lighted candle and approaches it rapidly with a flat fan the surface of which is normal to the direction of motion. The approach of this surface produces no effect upon the flame, but when the surface is rapidly moved away from the flame the latter is at once extinguished by the rush of induced air. It follows, therefore, that the shape of the back of propeller blades is an important factor in their efficiency, and we see that this shape varies in several important firms' productions. The difference in the shape of the two faces of a propeller blade must be due to mechanical considerations of design. When we liken a propeller blade to an aerofoil we find that the convexity of the back of the blade is greater in proportion than that on the back of an aerofoil, as the magnitude of the stress upon the blade is greater. This stress is a somewhat complicated one, consisting first of a bending stress along the whole of the blade in its greater dimension, when considered as a cantilever supported at the boss. This stress is due to the moment of the total thrust upon one blade about the distance between the centre of pressure of the blade and its root.

Aero photo.

FIG. 52.—The "Cochrane" Propeller, diameter 5 ft. 6 in., gives a Thrust of 200 lbs. at 1,800 r.p.m.

There is in addition a bending stress along the lesser dimension of the blade due to the angle of incidence of the blade imparting energy to the air column which it moves, when the face of the blade is convex the motion imparted to the air should be a gradual acceleration.

This energy, it will be seen, is imparted by the trailing as well as by the leading edge of the blade, and it is still a disputed point as to the best distribution of material to resist these stresses.

Chauvière leaves the greatest mass of material in the form of thickness of blade in the vicinity of the trailing edge, the maximum thickness occurring about one-third of the width of the blade from this edge.

On the other hand, T. W. K. Clarke adopts the aerofoil design, and thickens his blades the same distance from the leading edge.

In addition to the stresses already referred to, there is a tension all over the sectional area due to the centrifugal force acting upon the mass of the blades and tending to burst them. The magnitude of this stress at the root of the blades is found from the formula for centrifugal force, where—

$$T = \frac{WV^2}{gr}.$$

W = weight of blade in lbs.
T = tension in lbs.
V = velocity in feet per second of the centre of gravity of a blade.
r = radius in feet.

It will be seen that in high-speed propellers this force may be of considerable magnitude, and where the tip velocity exceeds 250 feet per second wooden blades should be constructed of walnut or Honduras mahogany rather than of the softer timbers. An important feature in blade construction is uniformity of contour, and this must be maintained by the stiffness of the material of which the blade is constructed. Any involuntary deformation of shape due to impressed forces may result seriously, and involuntary increase of pitch should be guarded against. The shape of the leading edge of the blades is of great importance. This edge should curve forward into the air near the centre of its effective length ; it should have an easy and gradual entry in order to reduce the shock impressed upon the molecules of air. A high class propeller, such as the Chauvière, is constructed with a well-curved leading edge, with a very slight initial angle of incidence, this angle gradually increases owing to the concavity of blade face ; this concavity amounts to about 3 mm. at its maximum in the 7 ft. type at 1,500 r.p.m. for 25 H.P. engines.

A note on a few particulars of the Chauvière blades may be of interest. Looking at the propeller from the face the trailing edges of the two blades are in a direct line, which passes through the centre of the axis. The trailing edges are practically in a straight line in a direction normal to the axis but sweep forward about 3 mm. at the tip.

The tip of the blade is well rounded, and the leading edge sweeps well outwards and forwards, attaining its maximum width at 0·7 of the distance from the axis to the tip, where in one particular case this projected width is 220 mm., and the normal or perpendicular to the pitch angle is 55 mm.*

The blade has a constant pitch until it approaches the third tenth of blade length from the axis, where the pitch slightly decreases. The blade width also gradually decreases as it approaches the root.

The blades are covered all over with fine canvas, painted, and varnished to a high degree of finish in order to prevent the blades splitting, and to reduce the skin friction to a minimum. The roots or arms of the blades must be sufficiently strong to withstand the stresses to which they are subjected, and the boss must be of ample size on account of the tension on the two sides, in front of the leading edge of each blade, caused by the transmission of power from the engine shaft through the boss to the roots of the blades.

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* This propeller is for the Anzani 25 H.P. engine.

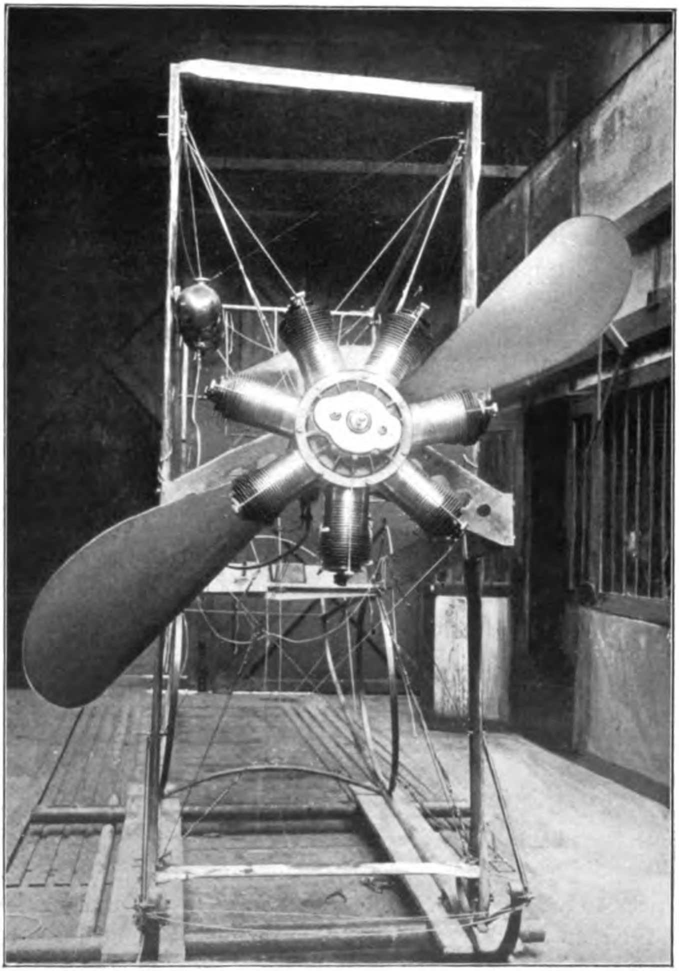

FIG. 53.—"Gnome" Engine fitted with Chauvière Propeller erected in a Biplane Fusilage.

The effect of the boss and arms of the blades, together with that of the presence of the engine or other driving mechanism, is to cause the stream lines of the wake to diverge, and also to produce eddy currents in the vortex immediately behind the centre of the propeller. Such being the case, we cannot definitely state the exact relation between the theoretical and actual air discharge, or, in other words, the ratio of net value of disc area to total disc area.

The study of aerial propellers is only in its infancy, and an enormous amount of experimental work remains to be done. The efficiency of present-day designs is abnormally low, and in many cases not more than 50 per cent.

There is evidently a very great scope for research and invention in this direction alone. The position of the propeller with regard to the planes is of great importance and the effect of disturbed air upon the thrust. and whereas in some types of machine the propeller works in undisturbed air, forcing turbulent eddies under the main planes, in others the conditions are exactly reversed.

CHAPTER VIII.

EFFICIENCY OF PROPELLERS.

MR A. E. SEATON, in calculating the thrust of a water propeller, does not agree that the thrust varies *absolutely* with the acting surface, as a square foot of surface at the tips will naturally be more effective than a square foot near the root of the blades. The statement that thrust varies directly as area is, therefore, somewhat misleading, as the *shape* of the blades must be taken into account, neglecting for a moment the questions of diameter and pitch. He therefore prefers to take the product of diameter and square root of blade area as one of the controlling factors, instead of the area, but he also agrees that the thrust varies inversely with the pitch ratio.

Let A = the aggregate area of active blade surface in square feet,

D = the diameter of the propeller in feet,

V = the velocity of the propeller in direction of motion of the vessel in feet per second,

P_r = the pitch ratio, *i.e.*, $\frac{\text{pitch}}{\text{diameter}}$,

G = ratio of distance of the centre of gravity of the blade face *from the boss* to half the diameter of the propeller.

We have for an ordinary screw propeller :—

$$\text{Thrust in lb.} = \frac{D \times \sqrt{A} \times V^2}{P_r} \times G.$$

The following values for G may be taken for common shapes of blades :—

Values of G.

Griffith's blade, broad - - - - - - =0·36
Griffith's blade, narrow - - - - - =0·33
Oval and leaf-shaped round tip - - - =0·40
Circular blade - - - - - - - - =0·42
Circular broad tipped - - - - - - =0·45 to 0·5
Square tipped blade - - - - - - =0.42

Seaton's example for an application of this rule for water is as follows :—

Diameter = 6·5 ft., pitch = 8 ft., revolutions = 360 per minute, area of blades = 12 sq. ft. leaf-shaped,

$$\text{Thrust} = \frac{6{\cdot}5 \times \sqrt{12} \times 48^2}{1{\cdot}23} \times 0{\cdot}40$$
$$= 16{,}830 \text{ lb.}$$

In all probability this rule would hold for air propulsion with the addition of a factor taking account of the masses of the two bodies, air and water.

Griffith's rules for blades give :—

Width of blade at widest part - $=\frac{1}{3}$ diameter of propeller.
Width of blade at tip - - $=\frac{1}{7}$,, ,,
Curvature of blade forward - $=\frac{1}{24}$ diameter.

The results of experiments show that with allowances for the difference in the densities of air and water about 800 to 1, the actions of air propellers are similar to those of water propellers.

The problem is not quite the same with air propulsion as in water propulsion, owing to there being no wetted surface factor to take into account in the former, and the air does not adhere to the surface as does the water. The diameter of an air propeller is not, therefore, limited by skin friction as is the case with a water propeller.

It has been shown how that the thrust varies with other variables, such as the area of the blades and the square of the speed, and that the power varies as the cube of the speed. The power and thrust increase with the diameter of the propeller, and the general opinion is that a slow speed propeller is necessarily more efficient than a high speed one.

Sir William White disputes this theory on the ground that for the last fifty years designers have been engaged on the production of an efficient slow speed propeller, and that modern high speed engines have only recently demanded propellers to suit their speeds of shaft rotation. He states that as the number of variables is so great, it is almost impossible to calculate out the most efficient type of high speed propeller for any particular requirements—this can only be settled by experiment. Also, when a suitable high speed propeller is produced to suit one particular case, no hard and fast rule can be formulated to apply the data obtained to all and every case.

The high speed propeller is a new problem, and as in the past it has taken years of investigation to arrive at an efficient slow speed type there is no reason to condemn the high speed propeller *per se* as inefficient.

There is another difference, however, between water and air propulsion, and that is in the feed or the manner in which the medium flows through the vortex.

When the propeller revolves against a fixed thrust point, in air which was previously stationary, the tendency is for the propeller to be surrounded by a vacuous vortex, owing to the small inertia of the air, consequently the thrust rapidly diminishes.

When, however, the propeller moves forward into fresh zones, its feed is more nearly assured, and if the propeller moves forward through the air at a velocity equal to its pitch multiplied by its speed of rotation, so that there is no slip, its efficiency is a maximum.

Professor H. Chatley has deduced the following formula for a screw propeller with 100 per cent. slip, *i.e.*, rotating with no lateral movement:—

Where T = thrust in pounds,
r = revolutions per second,
HP = the horse-power,
D = diameter of propeller in feet.

$$T = 0{\cdot}1 r \sqrt[3]{HP\ D^7}.$$

A more general and simpler formula than the above is—

$$T \propto HP^{\frac{2}{3}}\, R^{\frac{2}{3}}.$$

The following rule based on Mr W. G. Walker's experiments with fans must be applied where A is the ratio of projected area to disc area:—

$$A = \frac{4}{\pi r} \sqrt[3]{\frac{H}{D^5}}.$$

What happens when a propeller rotates in air is that the air itself, in addition to flowing laterally away from the propeller, is also driven out circumferentially, and returns from the rear to the front of the propeller. Maxim found that there was no centrifugal action until the pitch angle exceeded 45°. The air in motion in the vicinity of the propeller is one mass of eddies, though there is a comparative calm in front of the propeller owing to the small inertia of the air itself.

The thrust of an aerial propeller is a very varying quantity depending on a great number of conditions, and some very extraordinary claims are made in respect of certain designs. Mr Sidney Hollands has made a very large number of experiments with aerial propellers of the same diameter but with varying pitch, forms of blade, numbers of blades, and different cross sectional curvature of blades. He started with six blades but gradually reduced their number to two. He also found that with a two-bladed propeller greater efficiency was obtained with narrow tipped than with broad tipped blades. His best results were obtained with a blade tip one-third the width of the root, and a pitch angle of 15° at the tip and 30° at the root, giving a mean pitch angle of 22°. With a propeller of this type 6 ft. in diameter he obtained a maximum thrust of 26·5 lb. per horse-power when small power was applied, and nearly 20 lb. per horse-power at maximum working load. Thrusts as high as 75 lb. per horse-power have been obtained against a fixed thrust point by Herr Kress and others.

Comparing now the thrust obtained against a fixed thrust point with those in actual flight, we may take as an example the Wright propellers, which are undoubtedly highly suitable for the machine in question. If we take the horse-power of the engine as 29 to 30, and the speed of flight of the machine at 56 ft. per second, we have 550 foot-pounds of work done per second per horse-power,

$$= \frac{550 \times 30}{56} = 295 \text{ lb. total thrust with an ideal efficiency,}$$

$$= 9{\cdot}8 \text{ lb. thrust ideally per horse-power.}$$

The actual thrust of the two propellers is combined, 200 to 220 lb., equal to 7·35 lb. per horse-power. Lanchester takes the total thrust of these propellers at 155 lb. per pair.

In many cases about 7 lb. per horse-power is all that is obtained. The Chauvière propeller is one of the most successful that has been produced, and it will be recognised in some of the photographs in this book. Its details are in the possession of the author, but it is not considered expedient to publish them here, but these naturally vary in each different instance according to requirements.

There should be no difficulty in designing a propeller that would give 80 per cent. efficiency if Sir William White's reasoning is correct, and he speaks with authority; at present 50 per cent. is much nearer the mark. That is to say, that of all the power supplied by the engine of a flying machine, one-half is now wasted. Generally speaking, it is more economical to impart a small velocity to a large mass of air rather than a high velocity to a small mass, and for this reason large diameter is sought.

The less the theoretical slip of a propeller and the greater the horse-power to be transmitted, the greater should be the diameter.

Rigidity of blade should be observed, as flimsy blades are often a source of loss, owing to change of shape under load.

It is useful to notice that the product of the thrust in pounds per horse-power into the speed of the aeroplane could not exceed 550 ft.-lb. per second, so that at speeds of 27 ft. per second the maximum thrust would be 20 lb. per horse-power.

Maxim attaches very great importance to the smoothness of the surfaces of propellers. In one of his early experiments he tried a wooden propeller with no pitch, and found that he obtained no reading on his dynamometer though the propeller was 18 in. diameter. The power required here was too small to give a reading, but a similar propeller made of tin produced a measurable reading, no doubt due to the uneven surface of the tin. With blades of 18 in. diameter and 24 in. pitch, running at 2,500 revolutions per minute, a two-bladed propeller with flat faces gave a thrust of 14 lb.

The foot-pounds of energy per minute imparted to the air then equal the revolutions per minute by pitch in feet by thrust, and this value corresponded exactly with the dynamometer, showing that the skin friction was practically negligible.

Taking a propeller with blades of the same dimensions but of a concave section, and under the same conditions, the thrust produced was greater and more power was required to run it, and comparison with the dynamometer showed that skin friction was becoming apparent.

A third screw with a compound increasing pitch was tried and a much greater thrust was obtained, but the power expended was more than proportionately greater though the mean pitch was the same in each case.

Maxim's screws were thin, and although he tried thickening the blades in the centre, very little extra energy was expended. The larger screws were made of American white pine varnished and sandpapered and covered with linen fabric, coated with glue and finally with paint.

He found that very little skin friction was measurable with 16 ft. pitch and 17 ft. 10 in. diameter; he therefore disagrees that the skin friction is as great as is generally supposed, and attributes bad results to roughness of surface entirely. The metal French propellers are notoriously inefficient owing to irregularity of blade surface and to the arm on the back of the blade offering considerable resistance to the air.

French experimenters have produced some highly interesting and useful results of efficiency tests upon propellers thrusting against a fixed point. The following calculations are worked in C.G.S. units, and remembering that the French horse-power is slightly lower than the British, we take the value of 1 H.P. = 75 kilogrammetres per second.

When $P =$ the thrust in kilogrammes, $M =$ the mass of the air to which is imparted a velocity $= V$ in metres per second, the kinetic energy $= T$.*

$$T = \frac{1}{2}MV^2.$$

The consumed horse-power $= T^1$

$$T^1 = \frac{1}{75} \times \frac{1}{2}MV^2 = \frac{1}{150}MV^2,$$

the thrust per horse-power will then be

$$\frac{P}{T^1} = \frac{150}{V}.$$

From the above formula it will be seen that with a speed of wake of 10 metres per second the thrust per H.P. $= \frac{150}{10}$ $= 15$ kilogrammes per H.P.

---

* Note T is not the thrust, and that the notation is different in this example.

If the speed of wake is increased to 30 metres per second the thrust per H.P. $= \frac{150}{30} = 5$ kilogrammes per H.P. theoretically.

It will thus be seen that the theoretical thrust per horse-power varies inversely as the velocity of the wake when thrusting against a fixed point.

Now if we consider that the volume of air acted upon is equal to the disc area of the propeller, of a diameter $= D$ multiplied by the velocity of the wake $= V$ as before.

The volume acted upon in unit time

$$= \frac{\pi D^2}{4} \times V,$$

the mass

$$= \frac{\pi D^2}{4} \cdot \frac{\Delta}{g} V,$$

where $\Delta =$ the mass of a cubic metre of air $= 1{\cdot}29$ kg.

$$\text{(Thrust) } P = \frac{\pi D^2}{4} \times \frac{\Delta}{g} \times V \times V = \frac{\pi D^2}{4} \cdot \frac{\Delta}{g} \cdot V^2.$$

The power then required $= T^1$,

$$\text{(H.P.) } T^1 = \frac{1}{150} \cdot \frac{\pi D^2}{4} \cdot \frac{\Delta}{g} \cdot V^3.$$

Working with the above formula we can proceed to calculate the thrust power which can be given by a propeller 2 metres in diameter when propelling air at a velocity of 10 metres per second,

$$\text{(Thrust) } P = \frac{\pi \times 2^2}{4} \times \frac{1{\cdot}29}{9{\cdot}81} \times 10^2 = 41{\cdot}3 \text{ kg.}$$

where $g = 9{\cdot}81$ metres per second per second

$$\text{the H.P.} = T^1 = \frac{1}{150} \times \frac{\pi \times 2^2}{4} \times \frac{1{\cdot}29}{9{\cdot}81} \times 10^3 = 2{\cdot}76.$$

These results are the theoretical values, and are naturally higher than can be obtained in practice with the best propellers, and we will proceed to discover what efficiency can be obtained, and will work out two different methods for arriving at the results.

A certain amount of slip is necessary in order to obtain thrust, as it is inconceivable that when a machine is in motion through the air there should be no wake. If the speed of the point of application were equal to the speed of wake there would be no thrust, but it must be understood that the conditions when the point of application is in motion and the propeller moving through the air are different from those prevailing when the thrust point is fixed.

One propeller tested by M. Boyer-Guillon in Paris had a diameter of 1 metre, and gave a thrust of 15 kg. when consuming 2·713 H.P.

Taking the formula—

$$P = \frac{\pi D^2}{4} \cdot \frac{\Delta}{g} \cdot V^2$$

we have

$$\frac{\pi \times 1^2}{4} \cdot \frac{1{\cdot}29}{9{\cdot}81} \times V^2.$$

If $V = 12$ metres per second, $V^2 = 144$, and

$$T^1 = \frac{1}{150} \times \frac{\pi \times 1^2}{4} \times \frac{1{\cdot}29}{9{\cdot}81} \times 12^3,$$

$$T^1 = 1{\cdot}19 \text{ H.P.}$$

The actual power consumed $= 2{\cdot}713$ H.P. Efficiency $= \frac{1{\cdot}19}{2{\cdot}713} = 44$ per cent. by this method.

This velocity of 12 metres per second was, however, not the correct one, as observations with a Pitot tube showed that eddies were present and that the stream lines diverged from the axial direction. When we work backwards from the horse-power formula we find

$$T^1 = \frac{1}{150} \cdot \frac{\pi D^2}{4} \cdot \frac{\Delta}{g} \cdot V^3$$

we have

$$V^3 = \frac{2{\cdot}713 \times 150 \times 4 \times 9{\cdot}81}{\pi \times 1^2 \times 1{\cdot}29} = 3{,}960$$

whence $V = 15{\cdot}8$ metres per second.

At this speed the thrust would be

$$P = \frac{\pi \times 1^2}{4} \times \frac{1{\cdot}29}{9{\cdot}81} \times 15{\cdot}8^2 = 25{\cdot}75 \text{ kgs.}$$

As the actual measured thrust was 15 kg., the thrust efficiency = E,

$$E = \frac{15}{25{\cdot}73} = 58{\cdot}3 \text{ per cent.}$$

We will proceed to show how this method of calculating the efficiency by means of thrust, and devised by M. Hector Pouleur, is a most accurate one, and that by his method the efficiency of a propeller is practically constant. The same propeller as above worked-out in the same manner gives an efficiency of 57·25 per cent. when thrusting 10 kg. and consuming 1·53 H.P., and the following table shows values for a propeller 2·44 metres diameter:—

Col. 1	2	3	4	5	6	7
Experiment.	**Revs. per Minute.**	**Observed Thrust in kg.**	**H.P. Consumed.**	**Calculated Speed of Wake in Metres per Second.**	**Theoretical Thrust in kg.**	**Efficiency per Cent., Cols. 3 and 6.**
1	217	10	0·76	5·63	19·3	52·0
2	298	20	1·91	7·76	36·8	54·4
3	358	30	3·47	9·47	55·0	54·5
4	410	40	5·40	11·00	74·3	53·9
5	453	50	7·59	12·25	92·0	54·3
6	488	60	9·79	13·10	110·0	54·5

This table proves that, allowing for small experimental errors, the efficiency of the propeller remains constant whatever the speed of revolution, the horse-power consumed, or the thrust developed.

However, the thrust per horse-power diminishes as the thrust increases, as will be seen from the following tables.

As the thrust per horse-power is inversely proportional to the speed of the air the product of the two factors is constant.

Col. 1	2	3	4	5	6
Experiment.	Thrust in kgs.	H.P.	Thrust per H.P. in kgs.	Speed of Wake in Metres per Second.	Product of Cols. 4 and 5.
1	10	0·73	13·67	5·63	77·00
2	20	1·91	10·48	7·76	81·50
3	30	3·47	8·65	9·47	82·00
4	40	5·40	7·42	11·00	81·70
5	50.	7·59	6·60	12·25	81·00
6	60	9·79	6·13.	13·40	82·30

It will be seen that the products shown in the last column are approximately 82, and that this value is exactly 54·6 per cent. of the theoretical value of 150 originally taken as the constant. This value agrees very well with the experimental values for thrust efficiency.

As the thrust per horse-power is inversely proportional to the speed of the wake, and the total thrust is proportional to the square of the speed of the wake, *the thrust per horse-power will be inversely proportional to the square root of the total thrust.*

Col. 1	2	3	4	5
Experiment.	Total Thrust.	Square Root of Col 2.	Thrust per H.P. in kgs.	Product of Cols. 3 and 4.
1	10	3·16	13·67	43·3
2	20	4·47	10·48	46·9
3	30	5·48	8·65	47·4
4	40	6·32	7·42	46·8
5	50	7·07	6·60	46·6
6	60	7·75	6·13	47·5

The Wright and Voisin Propellers Compared.—These two somewhat similar machines will afford a useful comparison as regards propeller efficiency, the Wright machine being fitted with two propellers 8 ft. 6 in. diameter and about 9 ft. 6 in. *effective* pitch, and geared down in this instance in the ratio of 10 to 33 from an engine shaft running at 1,200 to 1,400 revolutions per minute. The Voisin has a single propeller 7 ft. 6 in. diameter with an *effective* pitch of about 3·6 ft. and keyed direct to a motor shaft running at 1,100 revolutions per minute.

The *effective* pitch in the Voisin machine is arrived at by dividing the distance travelled by the number of revolutions of the propeller in a given time, and in the Wright machine this result has to be multiplied by the gear ratio.

The calculation for the Wright machine flying at 58 ft. per second becomes, at 1,200 revolutions per minute—

$$\frac{58 \times 3.3}{20 \times 10} = 9{\cdot}6 \text{ ft.};$$

thus the diameter is 0·88 times the effective pitch.* In the Voisin case the diameter becomes 2·1 times the effective pitch.

Lanchester has found that the efficiencies appropriate to these pitch ratios are: Voisin 54 per cent., Wright 68 per cent., the latter figure being reduced for chain transmission losses become 63 per cent.

The following table shows Lanchester's calculations:—

	Ft.-lb. per Rev. of Engine	Feet Travelled per Rev. of Engine.	Efficiency.	Lbs. Thrust	Maxm. Weight possible.	Tan γ.	Angle of Incidence.
Wright -	708	2·9	63 per cent.	155	1,300	0·12	7°
Voisin -	1,550	3·6	54 per cent.	230	1,720	0·135	7° 40′
Column	1	2	3	4	5	6	7

---

* The pitch ratio is therefore 1·12 for the Wright and 0·475 for the Voisin.

The values in column 1 represent the work given out of each engine per revolution, column 2 the feet the machine traverses per motor revolution. Column 4 is calculated from columns 1, 2, and 3, whilst column 5 gives the weights which would absorb the whole thrust in horizontal flight at the flying speeds of the respective machines, viz., 40 miles per hour, or 58 ft. per second, for the Wright machine, and 45 miles per hour, or 66 ft. per second, for the Voisin machine. It does not necessarily follow that these weights are actually limitations, as improved design and reduced resistance to flight enable this weight to be increased, but they apply to the *particular machines* under consideration.

The mean pitch of the blades is, of course, greater than the effective pitch—in the Wright machine probably by about 15 per cent., as measured from the blades, and in the Voisin machine probably 25 per cent.—so that the mean pitch of each propeller becomes 4.5 ft. for the Voisin and 11 ft. for the Wright.

CHAPTER IX.

MATERIALS OF CONSTRUCTION.

THE principal materials used in the construction of a flying machine are wood, of which the framework consists, fabric of silk or cotton fibre suitably proofed and stretched over the framework, and finally, steel guy wires and their fasteners.

The former material is almost universally adopted in place of bamboo, which was at one time considered to be the ideal material. Some makers, however, prefer to use steel tubing for the framework, but wood has many advantages over steel.

Primarily, wood is easy to work and to replace; breakages may be many, especially in the initial stages of landing, and whereas a steel tube would probably buckle under such a shock, absolute fracture would generally result in a wooden spar.

This is really a point in favour of wood, as it is unlikely that a steel tube could be straightened and repaired, and if this were done it would only be with some difficulty.

On the other hand, a new wooden spar can easily be fitted and the structure made as strong as before.

Wood offers an advantage on account of its comparative stiffness, and although somewhat more bulky than steel weight for weight, the amount of wood in an aeroplane framework is not disproportionate to the size of the machine. Wood spars are frequently made hollow: the advantage of such a form of construction was appreciated by Henson, who shows a hollow section of a spar in his specification in 1843 (Plate IV.).

Hollow wood spars can be made of one-third the weight of a solid spar, strength for strength, as a strut, and their manufacture is specialised in by one or two firms. American spruce of straight grain is best suited for the purpose. The timber is cut lengthwise and the centre cored out, the two halves are then glued together under pressure.

Esnault-Pelterie pins his faith to steel tubes, and the construction of the framework of his machine in this material is a beautiful piece of work.

The tubes are welded together at their joints and triangulation is generously employed in the design.

Such a structure is somewhat heavy, and with the small sustaining areas usually fitted to machines of this type only high speeds can be indulged in. It will be remembered what little success attended these machines at Rheims ; this was probably due to their being unable to reach a sufficiently high starting velocity on the rough and heavy ground.

A speed in the neighbourhood of 40 to 45 miles per hour is required in order to produce sufficient sustentation at starting with a steel tube machine of the R.E.P. type.

The use of wood extends to the main spars, ribs, and outriggers as well as to the chassis of an aeroplane, and each portion requires attachment to the other. Wood lends itself readily to this purpose and may easily be detached for transport. Thin wood panels are sometimes fixed to the body of the machine to reduce skin friction, and wood is generally the material from which propellers are made. In this latter case as many as six independent timbers are sometimes glued together and the blades shaped from the resulting block. Canvas is occasionally glued all over the tips of the blades to bind the whole together in the event of a fracture occurring.

The chief requirements of the timber itself are that it should be light, stiff, and strong, straight in the grain and free from knots. In addition, certain portions of the framework require to be rigid and others flexible, and the correct timber must be selected for each respective part.

Messrs Short Brothers use nothing but spruce in their machines, this wood is lighter and stronger than ash, used by MM. Voisin Frères, but it is frequently blemished by knots, and it is somewhat difficult to obtain sound spars as long as 30 ft. Lengths of 12 ft. are usually the maximum obtainable, and as the main spars of flying machines are of considerably greater length, the question of timber is an important one, and must have some influence upon the design of the machine.

Silver spruce is very stiff for its weight as well as tough, and for aeroplane construction, particularly details of the planes, it is a very useful material. Ash, too, is mainly characterised by its flexibility and its "whip," it is therefore suited to parts requiring bending rather than for rigid supports; it is, however, not so strong for its weight as spruce. We find it somewhat difficult to calculate exactly the stresses upon the timbers of a main plane, and trial and error methods have been adopted up to the present. The point is that failure is usually due to contact with the ground or some stationary object, and a tough flexible timber usually suffers least under such circumstances.

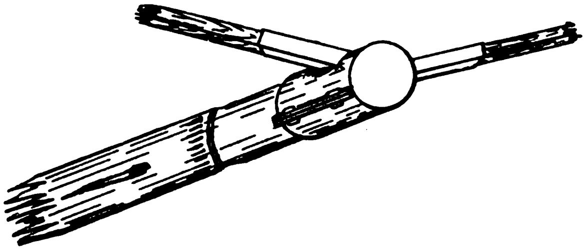

FIG. 54.—Method of Attaching Struts to a Bamboo Spar.

Bamboo has been tried on several occasions: Mr Cody has used it, and the main frame of M. Santos Dumont's (No. 20) "Demoiselle" consists of three main spars of this material, yet in the future machines of the Demoiselle type bamboo is to be discarded in favour of steel.

The main planes on this machine are made upon bamboo ribs attached to main spars of ash, light bamboo corner stays are also fitted.

A bamboo spar needs no shaping, and conversely it cannot be shaped as desired, it is also unreliable and is apt to split, necessitating binding wires between the nodes; it is very difficult to construct suitable joints and fastenings between the various spars and struts, which facts neutralise any apparent advantages of bamboo as a material of construction.

In addition to the main spars and struts, the ribs of the main planes are constructed of wood, usually ash. These ribs may first be bent under steam to the required shape, and strips of a section of ⅝ in. by ⅜ in. are readily shaped for this purpose. The exact or most probable curvatures for these ribs are discussed in Chapter II.

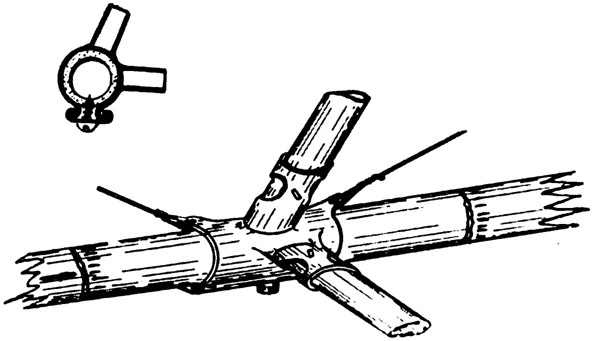

FIG. 55.—Method of Attaching Struts and Guy Wires to a Bamboo Spar.

Steel piano wires are largely used as tension members, and are of various sizes for withstanding stresses in different portions of the structure. Wires are invariably much stronger in tension than the original material from which they are made, the act of drawing the metal through the dies imparts this extra property to it. As an instance, a No. 26 steel wire, having a cross sectional area of 0·002 sq. in., breaks at about 800 lb. in tension, which works out at about 125 tons per square inch. No. 28 gauge steel piano wire breaks at 520 lb. and weighs about 1·75 lb. per 100 yds. The larger wire weighs about 2·25 lb. per 100 yds.

The ends of such wires require careful fixing, as they will draw through the most elaborate eye rather than break, even though the loose end of the wire be turned round the taut end many times as in the twisted eye fixing (Fig. 61). Stretching screws must be firmly attached to the wires for the purpose of keeping them taut, as explained later on, and great care must be taken in the method of attachment.

In monoplane construction stranded wire cable is often used in place of single steel wires, and in the Blériot machine cables of this type are used to brace the wings to the superstructure above, and to control the warping below the surfaces.

The principal load is carried by flat steel strips, two being attached to each wing, their lower ends are fixed to the front framework of the machine just above the running wheels (Fig. 68).

The planes or decks of an aeroplane are usually double surfaced, the two surfaces having a different curvature. This necessitates two rib strips separated by wooden distance pieces or webs for each composite rib. The ribs are fixed to the main spars some 9 in. from their leading edge and 12 in. from their trailing edge, the leading edge being given a bluff entry, and the trailing edge being sharp and usually flexible. The spars pass between the two strips, forming one rib, and are thus totally enclosed between the two surfaces.

In some machines, such as the Wright, the front main spar is carried at the leading edge of the main planes, thus enabling the front row of struts to be fixed between the leading edges of these planes.

When this is the case, the planes themselves have a bluff entry which conforms with stream-line requirements, and this arrangement will often be found in biplane practice.

Single surfaced machines, as the Farman, have the spars above the surfaces covered in order to reduce skin friction. The front main spar is, therefore, contained in a pocket formed by returning the fabric from the underside over the top of this spar, it being sewn back some few inches behind the leading edge. The other spars are enclosed by strips of fabric sewn over them in such a manner as to give an easy entry and trail, an air pocket of triangular cross section being left both in front of and behind each spar.

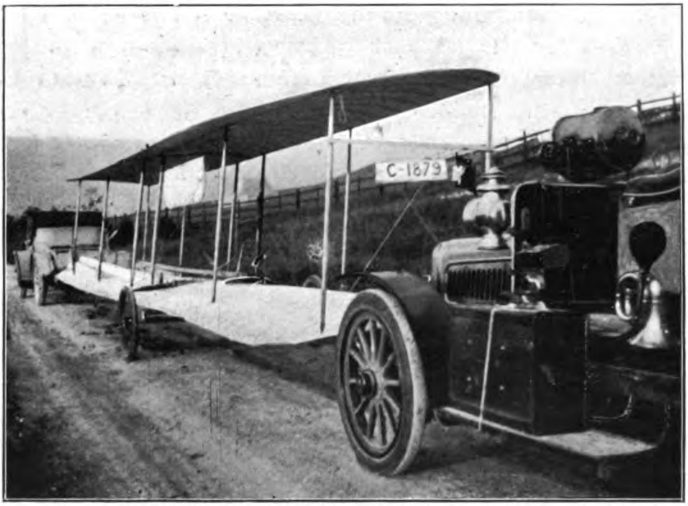

Fig. 56.—Method of Transporting a Wright Glider from the Works to the Flying Ground. The Arrangement of the Struts is clearly shown.

The Esnault-Pelterie machine is almost entirely enclosed with fabric, and there are no exposed stay wires, such gear being contained between the upper and lower surfaces of the main planes. Several methods are adopted for securing the fabric to the underside of the ribs ;

the use of thin flexible strips of wood nailed on or of large headed nails alone may lead to rotting of the fabric owing to oxidation of the nails, unless copper nails are employed. Probably the most satisfactory fixing is by sewing long fabric slings to the lower surface on either side of the ribs, these slings of course passing across the ribs from one side to the other.

Outriggers and tails are constructed of a wooden framework, and such a framework should be of ample strength, as in the act of alighting severe shocks and stresses are apt to come upon these portions of the machine. There is no doubt that the safety of the aviator depends more upon the reliability of his outrigger than upon anything else, and failure of this will cause a precipitate descent. The size and position of a tail is a very difficult thing to determine, and the size of its members can only be decided upon by experience.

Fabric.—The main planes or decks, the rudders, and sometimes the frames of aeroplanes are covered or "surfaced" with a closely woven and proofed material which, in addition to being reasonably air-tight and of small skin resistance, must not stretch and must be strong. The whole of the sustentation provided by the air has to be transmitted to the framework of the machine through the medium of this fabric.

In addition to strength, toughness is an essential property, and a material which will not easily tear should be employed. Suitable fabrics for aeroplanes are not always those which give the best results for balloon work, as gas-tightness is not of great importance.

There are several materials on the market, made of either silk or cotton thread and proofed with either rubber or celluloid, and these are made in several weights and strengths according to the particular design of machine and method of support.

Great importance must be attached to the maintenance of the true shape of the surfaces in actual working conditions, and this can only be achieved either by ample support afforded by the ribs, or by utilising a strong fabric stretched taut. The Continental Tyre and Rubber Company were the first manufacturers of these fabrics upon a large scale, and their fabrics are made in rolls 42 in. wide.

Their marks, 52 II. and 52 III., have been largely used in the construction of all the best known French machines, and have given the greatest satisfaction owing to their light weight and extraordinary durability.

It must be borne in mind that fabric is liable to rot, particularly when in contact with steel, on account of the corrosion of that metal. MM. Farman, Blériot, and Delagrange use the qualities mentioned above, but those marked 100*a* and 100*b*, although slightly more expensive, are preferable to the 56 II. and 56 III., as their durability is greater and their extensibility considerably less, and they are less affected by climatic conditions.

CONTINENTAL FABRICS OF AEROPLANES.

Quality Mark.	Approximate Weight in Ounces per Sq. Yd.		Tensile Strength in Lb.				Price per Sq. Yd.	
			Warp.		Weft.			
			Total.	Per In.	Total.	Per In.	s.	d.
56 II. -	Single proofed -	4	2,400	57	2,100	50	4	3
56 III. -	Double ,, -	4	2,400	57	2,100	50	4	3
100*a* -	Single ,, -	4½	2,370	56	2,550	61	4	9
100*b* -	Double ,, -	4½	2,370	56	2,550	61	4	9
109 -	Single ,, -	4½	1,800	43	2,200	53	2	9
110 -	Double ,, -	4½	1,800	43	2,200	53	2	9
111 -	Single ,, -	4½	1,800	43	2,200	53	3	3

The Scottish Aeroplane Fabric Company, as well as the Michelin Company, also manufacture fabrics for this purpose; the former term theirs Vulcanised Silk, and a table of their fabrics, which are made in widths of 36 in., is given on the next page.

SCOTTISH AEROPLANE FABRIC COMPANY'S VULCANISED SILK.

No.	Weight in Ounces per Sq. Yd.	Tensile Strength in Lb. per Inch Width.	
		Warp.	Weft.
7½	2¾	38	26
8½	2⅞	40	28
10	3⅛	44	30
12	3¼	56	34
1,065	4	106	56

DUNLOP (BRITISH) FABRIC.

No.	Proofed.	Width.	Price per Sq. Yd.		Approximate Weight in Oz. per Sq. Yd.	Tensile Strength of Warp.
		Per In.	s.	d.		Lb.
1	Single	39	4	2	4·25	2,200
1	Double	39	4	8	4·5	2,200
3	Single	36	5	6	4·25	1,940
3	Double	36	6	0	4·5	1,940
7	Single	44	7	0	3·75	2,350
7	Double	44	7	6	4·0	2,350
13	Single	44	7	0	3·25	1,250
13	Double	44	7	6	4·00	1,250
16	Single	42	6	2	3·75	2,100
16	Double	42	6	8	4·00	2,100

The following tables, prepared by Mr W. H. Thorpe, A.M.I.C.E., are of great utility, as they not only give the direct stresses capable of being withstood by various materials but also what he terms the "proportionate resilience" and the resilience per pound weight of the material.

A few explanatory notes are needed and are here given, with due acknowledgment to Mr Thorpe, and by permission of the *Aero*, in which paper they originally appeared.

The specimens are generally of square section except where otherwise stated.

Bending.—Column 2 gives the modulus of transverse rupture or the resistance to cross breaking, bending stresses consisting of tension on one side and compression on the other side of the centre of gravity of the section.

Column 3 is the proportional stress where the elastic limit occurs to the ultimate breaking stress.

Column 4 shows the modulus of elasticity of the material or the stress required to stretch a specimen to twice its original length, assuming it remained elastic the whole time, in the same manner as it behaves at stresses below the elastic limit.

Column 6 is the span at which a specimen will be stressed up to its elastic limit due to its own weight. The section of the beam is given by Mr Thorpe as "of standard proportions," and we must assume this to mean square, as that section is generally the basis taken.

Column 7 gives the proportionate resilience of the various materials and is the number of inch-pounds of work which may be stored up in a material without causing permanent set. When $f =$ the safe stress allowed, this value for a rectangular beam loaded at the centre is $\frac{f^2}{18E}$ where E is the modulus of elasticity.

This column gives comparative values for the resilience of a specimen of unit length at whatever size the specimen may be to give a strength equal to that of ash. The value of 4.69 is an exact figure giving the number of inch-pounds of work which may be taken up by 1 cub. in. of ash beam without injury.

Column 8 gives the resilience per pound weight of the material.

Column 9 the limiting circumferential whirling speed for rods of uniform section, and is a tensile measure.

Referring to the tension and compression tables the first few columns give the same properties as before.

Column 6 shows the lengths of material which would of their own weight stress the material up to the elastic limit.

Columns 7 and 8 give the same values as before.

TABLE I.—BENDING.

Sections Square and Solid.

Material.	Ultimate Stress.	Ratio of Elastic Limit to Col. 2.	E = Modulus of Elasticity.	Weight per Cubic Foot.	Limiting Span.	Proportionate Resilience.	Resilience per Lb. Weight.	Limiting Whirling Velocity.
1	2	3	4	5	6	7	8	9
	lb. per sq. in.	per cent.	lb.	lb.	feet.		inch lb.	feet per second.
Ash - - -	14,300	80	1,550,000	47	3,900	4·69	172·0	1,642
American elm -	14,400	80	1,700,000	46	4,025	4·32	162·8	1,847
Larch - - -	9,600	80	1,100,000	34	3,615	3·88	155·3	1,443
Honduras mahogany	11,500	80	1,600,000	35	4,206	3·40	145·1	2,062
American hickory -	16,000	80	2,400,000	51	4,018	3·47	126·4	1,792
Pear - - -	9,500	80	1,000,000	44	2,764	4·21	126·0	1,446
Georgia yellow pine -	12,600	80	2,070,000	38	4,242	2·97	124·1	1,982
Lombardy poplar -	6,000	80	770,000	24	3,193	2·89	119·5	1,493
American white pine - - -	7,900	80	1,390,000	24	4,213	2·37	114·9	1,926
Spruce fir (deal) -	11,000	80	1,700,000	39	3,607	3·01	112·1	1,538
Birch - - -	11,500	80	1,650,000	45	3,276	3·28	109·0	1,576
Oak - - -	12,500	80	1,600,000	56	2,864	3·78	107·1	1,505
American yellow poplar - -	10,000	80	1,400,000	44	2,905	3·63	99·8	1,482
Mild steel - -	60,000	60	30,000,000	490	1,175	1·12	8·5	827
Wrought iron - -	54,000	60	26,000,000	480	1,080	1·12	8·1	763
Cast iron - -	36,000	70	18,000,000	450	896	1·15	7·5	537
Magnalium (cast, 4 per cent. M.) -	...	50	10,200,000	160	...	...	...	1,002
Aluminium (cast, 7 per cent. C.) -	...	60	11,100,000	180	...	...	...	807
Glass - - -	10,000	90	8,000,000	192	750	·66	5·0	365
Sections Round and Hollow.								
Bamboo ($t=\frac{1}{8}$d.) -	22,500	80	3,200,000	55	6,147	3·07	207·0	2,300
Ash ($t=\frac{1}{8}$d.) - -	14,300	80	1,550,000	47	4,567	3·50	202·0	1,642
Steel tube ($t=\frac{1}{30}$d.)	100,000	80	32,000,000	490	3,680	1·59	55·2	1,202

TABLE II.—TENSION.

Material.	Ultimate Stress.	Ratio of Elastic Limit to Column 2.	E = Modulus of Elasticity.	Weight per Cub. Ft.	Maximum Tensile or Compressive Length.	Proportionate Resilience.	Resilience per Lb. Weight.
1	2	3	4	5	6	7	8
	lb. per sq. in.	per cent.	lb.	lb.	ft.		inch lb.
Indiarubber - -	330	80	Varies	58	...	...	22,000
Silk - - -	52,000	80	1,300,000	62	100,000	218·0	18,550
Bamboo - - -	39,000	80	3,200,000	55	81,700	66·0	4,778
Honduras mahogany	20,000	80	1,600,000	35	65,800	68·0	3,948
Georgia yellow pine	20,000	80	2,070,000	38	60,600	53·0	2,811
Ash - - -	17,000	80	1,550,000	47	41,700	60·0	2,194
Piano wire - -	280,000	70	32,000,000	500	56,400	41·0	2,074
Spruce fir - -	12,400	80	1,700,000	39	36,600	40·0	1,280
Magnalium - -	34,500	50	10,200,000	160	15,500	11·5	158
Mild steel - -	60,000	60	30.000,000	490	10,600	8·1	76
Aluminium alloy -	21,000	60	11,100,000	180	10,000	7·7	69

TABLE III.—COMPRESSION.

1	2	3	4	5	6	7	8
	lb. per sq. in.	per cent.	lb.	lb.	ft.		inch lb.
Ash - - -	9,500	80	1,550,000	47	23,300	18·6	685
Honduras mahogany	8,000	80	1,600,000	35	26,300	15·2	632
Spruce fir - -	8,500	80	1,700,000	39	25,100	15·2	602
Georgia yellow pine	8,000	80	2,070,000	38	24,300	11·8	450
Mild steel - -	40,000	95	30,000,000	490	11,160	4·8	85

CHAPTER X.

DETAILS OF MANUFACTURE.

NO matter what class of machine one may consider, the question of the design of the details is all-important—in fact many machines entirely owe their success to the good design and perfect manufacture of their details, rather than to the general principles embodied in the apparatus as a whole.

The machines which are dealt with in this book essentially depend upon details, as their general principles have been known for many years. Certain of the details, too, were described accurately by Henson in his specification of A.D. 1843, and others have been adapted from kindred appliances such as sailing yachts (if we may term them as such). In an aeroplane certain rigidity and form of surface must be maintained in order to produce maximum lifting effect with minimum skin resistance, followed as it is with the production of eddies. This latter means expenditure of energy and consequent waste of power.

The head resistance of various types of machines varies somewhat considerably, and this is in a great measure owing to the various angles of incidence employed.

The necessity for increasing the angle of incidence in certain machines becomes apparent in order to increase the sustentation per unit of area when the speed remains low. It was pointed out that in comparing two machines, a monoplane of certain surface area with a biplane of double the area of sustentation, the weights of the two machines being the same, the speed of the monoplane would necessarily have to be greater than that of the biplane, in order that the machine should fly.

This, of course, is on the assumption that the angle of incidence of the planes is the same in each case.

If we compare the Wright machine, which sustains only 2·0 lb. per sq. foot at a speed of 34 miles per hour, with Blériot XII., which machine sustains 5·2 lb. per sq. foot at only 38 miles per hour, when the engine in the former case is of 30 H.P., and in the latter 35 H.P., we cannot fail to be somewhat puzzled.* (See page 178.)

This enigma is further complicated when we note that the two machines are so very different both in construction and angle of incidence, and yet we find that the coefficient of traction is practically the same, viz., 17·6 per cent. in the former and 18·3 per cent. in the latter machine.

In arriving at these figures the Wright machine is reckoned as carrying one passenger and the Blériot two, that is with the engine running at its maximum output.

The head resistance of the machine as a whole must be reduced as far as possible, and here again it is the details which count. Farman expended a great deal of time with his original Voisin machines in perfecting details, and this work was eventually rewarded by successful flight. The strength of an aeroplane as a mechanical structure depends on the details of fixing the main spars, ribs and struts, and to the methods employed for retaining the guys taut. When a number of different parts consisting of different materials, and even of the same materials of varying shape and section, are employed, each part must do its proper share of the work.

In other words, the stresses throughout the structure must be capable of adjustment to suit each individual member. A composite structure such as we have in an aeroplane depends upon the efficiency of each member of which it is composed for its stability as a whole. The failure of any member in tension or compression will throw

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* The different angle of incidence in these two machines accounts for the widely different sustentation (see Table in the Appendix), but one machine in this case is undoubtedly more efficient than the other.

undue stresses upon all the other component parts and may result in immediate failure.

When the framework of a biplane is considered, the principal structure is the box girder formation of the main planes and struts. This girder is subjected to loading in several directions: there is the loading as a beam with the weight concentrated in the centre and an evenly distributed support, or considered conversely a central support and an evenly distributed load, as it is immaterial which we consider, the top or bottom of the structure.

This occurs when the machine is supported in the air, and in addition there is an evenly distributed bending moment in a direction at right angles to this, owing to the thrust of the propeller considered as a force acting at the centre. This force is resisted by an evenly distributed pressure along the whole length of the machine due to head resistance or drift plus skin resistance. Then we have a reversal of stress when the machine is at rest upon the ground where the centre of support is at the centre of the machine, and there is a small evenly distributed load acting in exactly the opposite direction to the lift in flight. This small load is due to the weight of the structure itself.

The stresses are thus somewhat complicated and are reversed in some portions of the structure.

If we wish to avoid reversals of stress in engineering practice we can put initial stresses on the structure slightly in excess of any reversed stress which might occur. This is done in the case of the tangential spokes of a bicycle wheel. Here we put an initial tension on the spokes greater in magnitude than the compression which would otherwise come upon them when they are at the position between the wheel hub and the ground.

In the biplane we fit guy wires coupled up in series with stretching screws, so that any desired tension may be put upon them.

Whether a great tension is employed or not is a matter of individual practice, but the structure can be so

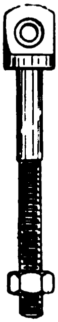


FIG. 57. Eye Bolt Form of Wire Stretcher.

arranged that these steel guy wires can take all the tension, and the struts consequently take all the compression stresses. Examples of some of these stretching screws frequently employed are shown in Figs. 57, 58, and 59. The ends of the struts may be fixed in aluminium sockets as shown in Fig. 60. These sockets retain the ends of the struts in their correct positions upon the main spars of the machine and in addition often form terminals for attachment of the steel guy wires as shown in Fig. 61. In the Wright machine, owing to the flexibility of the rear of the main planes, the struts are fixed by hooks and eyelets so that a slight universal motion is permitted; the eyelets also form attachment points for the guys.

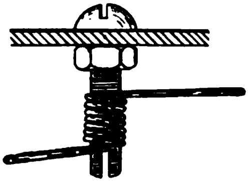


FIG. 58.—Simple Form of Wire Stretcher.

The details of spar attachment in the Blériot monoplanes is most interesting. When one strut meets a main spar it butts against it, and a long bolt of small diameter bent to **U** section is inserted through a hole near the end of the abutting spar. The ends of the **U** bolt are passed through two holes in the long main spar and nuts are screwed on to the ends, thus drawing the two spars together. When a second strut abuts at right angles to the first one, another **U** bolt is fitted in the same manner, the ends of the two are so arranged that they do not foul one another. The tension of the guy wires, which are looped round the **U** stretchers, actually retains the struts and spars in contact as the bolts themselves are free to move in tenoned slots.

FIG. 59. A Wire Stretching Screw.

Perhaps the average reader has not considered the stresses which come into play in a monoplane of the Blériot XI. type when in flight. Suppose the wings were unstayed by guys, they would then act as cantilevers, and would be subjected to the greatest bending moment where they are attached to the fusilage. No appreciable bending, however, occurs here in practice, and no provision is made for resisting such stresses, practically the whole of the lift of the wings being transmitted to the fusilage by two flat steel tension bands fixed between the front main spar of either wing and the lower part of the chassis, these bands being 15 mm. broad by 1·5 mm. thick, as shown in the figures of the machines. The lift from the rear main spar is transmitted by the *gauchissement* flexible cables to the lower steel **A** frame attached to the chassis below the aviator's seat.

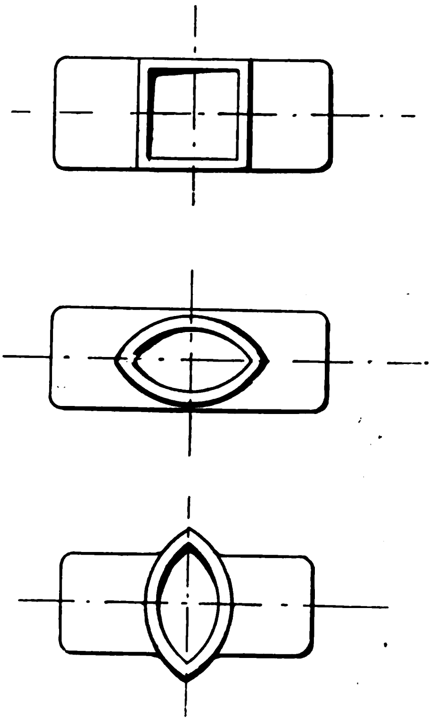


FIG. 60.—Types of Sockets for Receiving the Ends of Struts.

In addition, however, to the lifting stresses we have a certain proportion of direct lift and direct drift producing a shearing stress in the end of the front main spars where they fit into their sockets, and the two rear main spars tend to close in towards one another due to the drift produced by the incidence of the main planes and their head resistance. Such tendencies are resisted by placing a strut between the rear main spar of either wing, otherwise the fusilage would collapse owing to the lateral pressure of the wings upon it.

The lateral pressure alluded to is increased on account of the obliquity of the guy wires and strips.

The system of triangulation adopted in modern aeroplanes is that originally described by Henson, and a light and stiff structural formation results. From the end of each vertical strut in a biplane three wires are taken, one to the diagonally opposite end of each strut alongside it, and one to the diagonally opposite end of the strut at the rear or in front of it as the case may be.

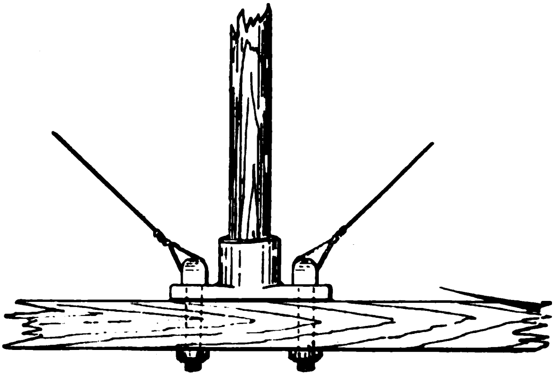


FIG. 61.—Method of Attaching a Strut to a Boom and of Securing the Ends of the Guy Wires.

Where these struts are at the rear of a warping element in a biplane the diagonals are not firmly secured but are the wires which operate the warping movement.

Instead of them being fixed firmly to an eye a piece of chain is interposed in the length of the wire adjacent to the strut and this chain runs round a pulley or through a tube attached to the framework, but as the wire is practically continuous from end to end of the machine, the length of reduction on one side of the centre is equally a length of extension on the other side of the centre, thus no slackness occurs when the warping takes place. Wires are liable to stretch from time to time, so that the stretching screws require occasional tightening up to prevent any slackness. The section and shape of the spars varies according to the work to be done.

A member in compression should have a larger section at the middle of its length than at its ends, and in order to reduce weight these members are occasionally made hollow in the manner described in the previous chapter. A hollow section is very efficient in compression, as a compression stress invariably produces bending in a long member. Bending is most efficiently resisted by material away from the centre

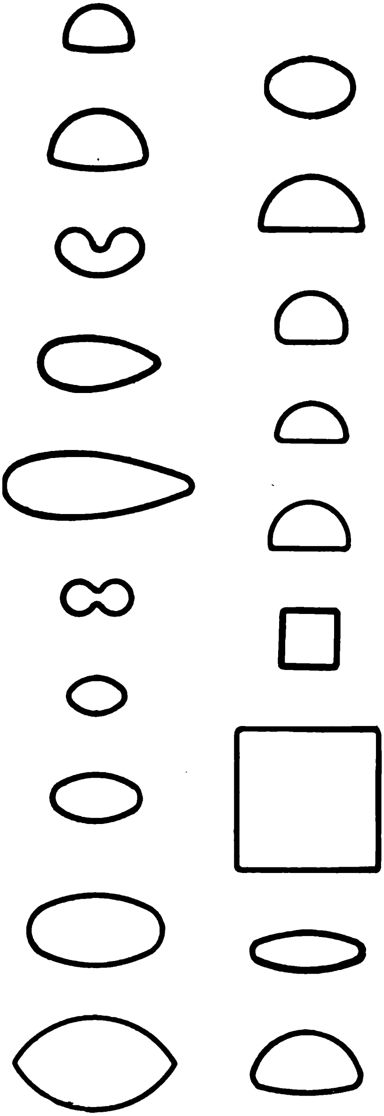


FIG. 62.—Sections of Struts used in Aeroplane Construction.

of the section when that material is distributed in the proper direction.

Sections of spars and struts are shown in Fig. 62. These may be either of wood or of metal tubes.

There are other structures under stress, such as the outriggers. The magnitude of the stresses here are difficult to compute, as they are usually produced by landing shocks.

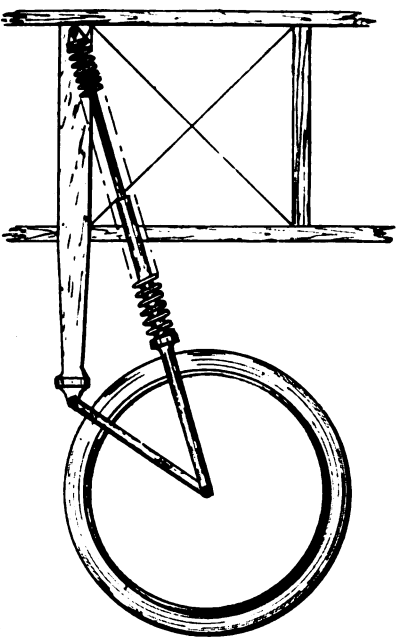


FIG. 63.—The Rear Wheel Suspension, Type Blériot XI.

Conformity of the surfacing material to the correct curve is of great importance, and to obtain this, the material is initially stretched tight, occasionally by lacing, but where ordinary pins are used, no provision is made for tightening up the material. The only alternative is to employ a surfacing material which will not stretch appreciably under varying climatic conditions, and to use a sufficient number of ribs.

Details of landing and running gear have been described in connection with some of the leading machines; a favourite method of spring support is similar to that employed for the recoil mechanism of guns. Such an arrangement is adopted by M. Esnault-Pelterie amongst others in his monoplane. Pneumatic suspension, however, is rapidly coming to the front for this work, and probably will be adopted on account of its lightness and great possible range of action. Spring suspensions are fitted below the tail of some machines in addition to those under the main planes, and the device of M. Blériot is shown in Fig. 63.

This arrangement is at the rear of his machine, and somewhat resembles his main indiarubber suspension with the exception that coil springs replace that material.

The question of an efficient suspension is one of great importance owing to the rough nature of the ground usually available for starting purposes. The shocks due to irregularities of the ground surface should on no account be transmitted to such a delicate structure as that which usually composes the framework of an aeroplane.

A large working range of the wheels in a vertical direction is therefore essential. The wheels should be capable of movement in any direction, as in the act of landing the machine is liable to be carried in a lateral direction by a gust of wind, no risk of putting a side strain on the wheels should be therefore taken.

Another important detail is the control gear, and this should be sufficiently keen and effective, not only for fancy flying, but to enable the aviator to recover his stability rapidly or to evade an object which he may encounter unawares.

CHAPTER XI.

SUCCESSFUL MONOPLANES.

THE ANTOINETTE—ESNAULT-PELTERIE—BLÉRIOT XI.—SANTOS DUMONT'S "DEMOISELLE."

HAVING considered the individual features which in combination may produce a successful flying machine, we will consider in detail a few of the better known machines. A number of plates are given at the end of this book, being reproductions of scale drawings made by one of the author's draughtsmen.

The author is indebted to the proprietors of *Flight* for their permission to utilise certain of their drawings and dimensions as a basis upon which to work.

Antoinette IV. (Fig. 64) is chiefly notable as being the machine upon which M. Latham made his first attempt at cross-Channel flight and with which he made several record flights previous to that attempt. Antoinette IV. was by far the largest monoplane in existence at the time, as will be seen by inspection of Plate VI. at the end of this book, which represents Antoinette VII., a somewhat similar machine. The main sustaining plane consists of a pair of wings of trapezoidal form built up on lattice girders of the usual aerofoil shape, and one notices how the general principle resembles that of Henson's machine shown in Plates I. to IV.

The main wings are double surfaced, and the sustaining area of each wing is 25 sq. metres, being 50 sq. metres in all, and weighing 1 kg. per square metre without the fabric, the angle of incidence is 4°. The wings are stayed by aluminium stays and fixed to the main framework of the machine at their larger end. In construction of this kind based upon the triangle and pyramid the materials do not flex appreciably when in tension or compression.

The body of the machine is boat shaped and covered with a varnished fabric to reduce skin friction to a minimum.

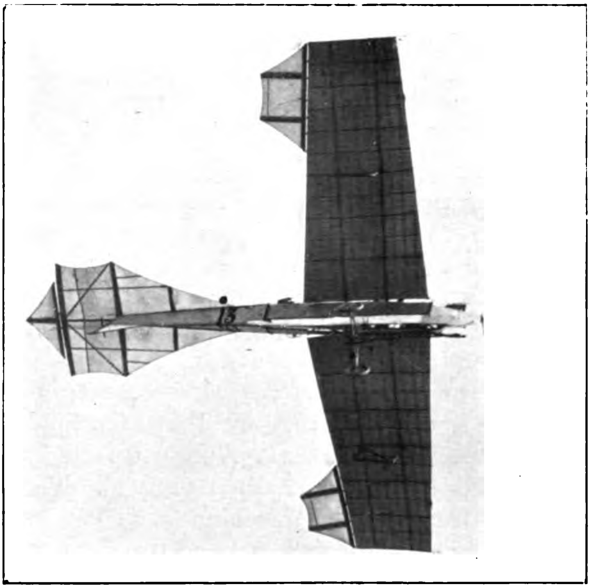


FIG. 64.—Antoinette IV.

The tail carries horizontal planes as well as vertical ones, and a vertical fin along the top, and in addition there is a dipping rudder or elevator made in two pieces, one on each side of the rear vertical plane. In the later models this is made in one piece. The direction rudder is also carried upon the tail and is a vertical plane placed over the two dipping planes. At the rear extremities of the two main planes small movable fins or *ailerons* are fitted in order to obtain lateral stability and to assist in turning. These are controlled by one mechanism which lowers one when raising the other. Such an arrangement of *ailerons* produces a more pronounced effect than warping the planes as in the Esnault-Pelterie. The action of these is explained in Chapter XV. on "The Art of Flying."

In the construction of Antoinette V. and the later models these *ailerons* have been dispensed with and the warping system adopted, as will be seen in Plate VI. at the end.

The control of the machine is by means of a lever on the right which operates the dipping planes, whilst two other levers at the left hand of the aviator control the *ailerons* at the ends of the main wings and the steering rudder. These two latter levers can be either operated separately or together with one hand.

The machine when on the ground is supported by a centre wheel and a pair of runners in the front. As the speed of the machine increases along the ground, the pressure upon these decreases until the machine finally rises. The motor is a 50 H.P. Antoinette having eight cylinders, and described in detail on page 38. The motor is carried in front of the machine and is very easily removable, and is direct connected to a two-bladed tractor propeller.

Propeller.—The Antoinette propeller is of a special construction composed of two nickel steel arms forged with clips of the same metal which embrace the shaft.

Aluminium blades are fixed to these arms by a number of copper rivets.

Any number of blades may be used but two only are usually fitted. The pitch of the blades can be varied to suit the angle of incidence of the main planes ; if this angle is smaller and the flying speed consequently higher, the pitch should be greater, and *vice versa.* The propeller is clipped direct to the motor shaft without intermediate gearing or clutch. The pitch of the propeller fitted to Antoinette IV. is 1 m. 30 cm., and its diameter 2 m. 20 cm. and its normal rate of revolution is 1,100 per minute.

The cooling system adopted in the Antoinette machine is as original as it is interesting. The object of the designer being to reduce weight to a minimum, only a small quantity of 12 litres of water is carried. The water gravitates to the cylinder jackets where it is converted into steam, thus carrying with it latent heat of evaporation, in addition to the sensible heat causing its rise of temperature to boiling point. The steam is then condensed in a large radio-condenser in the form of two nests of tubes one on either side of the body of the machine. These nests of tubes form a thin panel on either side, being extensions of the cedar wood panels forming the bows. The total weight of the tubes is only 12 kg., and they afforded a total cooling surface of 12 sq. metres. Their duty is to condense 1 litre of water per minute which is evaporated in the engine jackets.

The overall dimensions of Antoinette IV. are: length 11 m. 50 cm., span 12 m. 80 cm., and weight 250 kg.

Antoinette V. is a somewhat similar machine but is not fitted with *ailerons;* it has a propeller 2.7 metres in diameter.

Antoinette VII. (Fig. 65 and Plate VI.) is the machine on which Latham made his second cross-Channel attempt, and is similar to the one shown in Plate VI. at the end. The Antoinette aeroplane is conspicuous on account of the dihedral angle at which the wings are set, and the thickness of the wings from upper to lower surface. Between the top and bottom rib member a lattice work of wood is fitted in order to increase the strength of the construction. Each wing is pointed at its entrant as well as at its trailing edge.

The great span of these wings, 46 ft., necessitates the use of guy wires attached to the upper and lower ends of vertical hollow posts, two being fitted in the centre of each wing. These wires are also attached to the top of a mast standing up in the centre of the chassis at the front, those wires fixed to the front of the wings being rigidly fastened whilst the rear guy wire runs over a pulley. A large amount of timber bracing is inserted between the surfaces

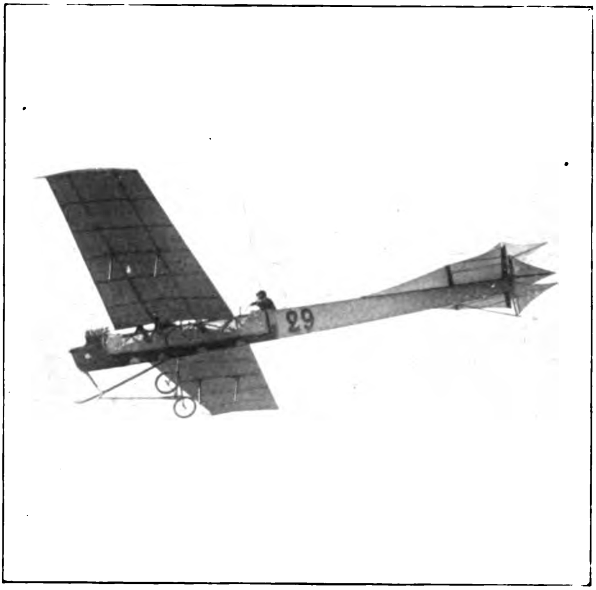


FIG. 65.—Antoinette VII.

of the wings, the ribs being placed 18 in. apart, and supplemented by simple ribs of an open form to support the fabric, their spacing varies from 2 in. to 4 in. The body of the No. VII. is of boat-shaped form covered with cedar panelling in front and fabric at the rear, and two small wheels attached to an axle form the necessary support upon the ground. The medium absorbing the landing shocks is an air compression cylinder consisting of two concentric tubes, one of which is an extension of the centre vertical mast.

One of these tubes forms the body of the pump and the other the plunger, the weight of the machine compresses the air in the arrangement an amount according to the magnitude of the shock. A riding sleeve slides on the guide tube, and has attached to it wooden struts which locate the axle by means of steel forks fixed to the ends of these struts. An ash skid is fitted at either end of the machine—that at the front is to prevent the propeller from fouling the ground when landing.

The tail planes are designed to obviate the elevator from interfering with the rudder, and with this end in view the rudder planes, two in number, are made triangular. Forward of the upper rudder plane a long triangular fin extends to the vicinity of the aviator's seat.

The control gear is somewhat different in this machine to that in No. IV., as it is operated by two hand wheels and a foot pedal. These wheels are rotatable about a horizontal axis, and are placed one on each side of the aviator. The right-hand wheel operates the elevator whilst the left-hand wheel warps the wings.

The foot pedal actuates the vertical rudders, pressing the right foot steers the machine to the right, and *vice versa.*

Provision is made for engine control by two supplementary hand wheels.

The warping control is effected by means of wires, one from each wing being attached to a central chain passing round a chain wheel fixed to the stationary tube member of the shock absorber below the chassis, which has fixed to it a double ended lever. The control wires from the operating hand wheel drum are fixed one to either end of this lever.

The main dimensions of Antoinette VII. are: span 46 ft., chord 10 ft. at the centre, and 6 ft. 8 in. at the tips, overall length 40 ft. Total area of main planes 365 sq. ft.; weight of machine without aviator 1,040 lb.

Esnault-Pelterie, No. 2 (*bis*) (Fig. 66).—The designer and maker of this machine and its engine has adopted sound engineering practice in many of its important principles. Although he has been for many years engaged in the problem of flight, the success which he deserves can scarcely be said to have been awarded to him.

The R.E.P. (Plate VII.) is essentially a high speed machine, and although its construction, as far as the chassis is concerned, is very rigid, its main planes are extremely flexible. The chassis, as has already been stated, is of steel tubular construction, and is supported on the ground by one principal wheel fixed at the end of a strong recoil mechanism.

FIG. 66.—Esnault-Pelterie Monoplane, Type R.E.P. 2.

This consists of an oleo-pneumatic brake capable of absorbing 2,520 ft.-lb. of work, though its weight is under 13 lb. The action of a system such as this is proportional to the square of the speed of the fall, and is very rapid in working.

In addition to the centre wheel in front a small wheel is fitted beneath the tail, also one small wheel under each wing tip. When at rest upon the ground three wheels touch, that is the two centre ones, which are in alignment, and one wing wheel fitted in a different plane. This necessitates canting over the flyer on one side or the other until balance is secured when running along the ground. The two wings forming the supporting surfaces are very thick from upper to lower surface, and contain between the two layers of fabric wooden ribs fixed to composite main spars consisting of wood, aluminium, and steel. At the inner end these spars are attached to the chassis, but one-quarter of the total lifting effect is transmitted from each wing tip by means of a shroud.

The two shrouds are fixed at their inner end to the lower end of a vertical controlling rod passing through the chassis in both directions, to the lower end of which are fixed the elevating and warping shrouds. The wings have a total surface of 155 sq. ft., and the weight of the machine which they support is 924 lb. It will be seen that a lift of 5·93 lb. per square foot must be produced, and this should be accomplished at a speed of 37·2 miles per hour. The supplementary surfaces consist of a dipping rudder or elevator placed at the rear of the tail, and a vertical direction rudder beneath it. Two large vertical fins are carried, one above and the other below the chassis, and the whole machine is encased with fabric. The engine is placed in front and directly connected to a four-bladed metal propeller of 6 ft. 6 in. diameter.

The control is by two vertical levers one at either hand of the aviator; that on the right controls the steering rudder, and is moved in the direction the aeroplane is desired to take. The left-hand lever has an universal motion, and is a continuation of the control pillar before referred to.

Forward and backward motion of the lever operate the elevator, and transverse motion warps the wings; the whole motion is arranged to afford a subconscious system of control. The aviator grasps the left-hand lever, and his body automatically sways in the direction he wishes the machine to take.

A foot operated throttle is provided for controlling the engine speed, and a second pedal enables the engine to be started from the aviator's seat.

FIG. 67.—The Author and a Blériot XI. Monoplane.

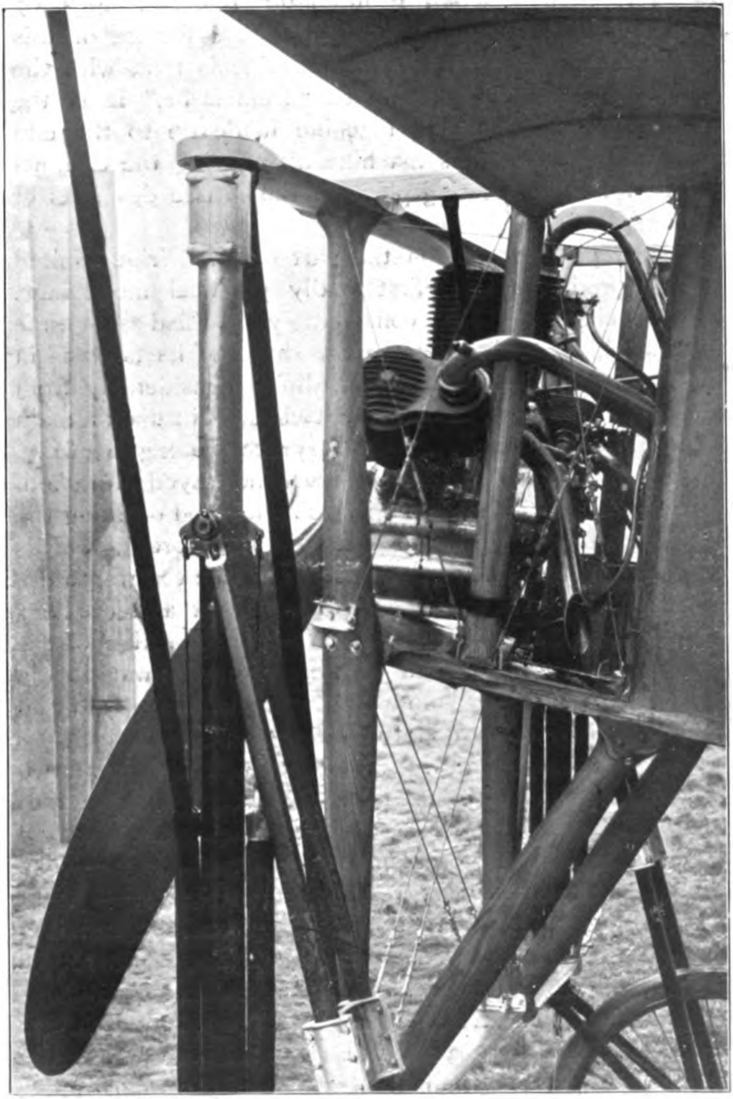


FIG. 68.—Engine Mounting and Front Chassis, Blériot XI. Monoplane.

Blériot Short Span Monoplane, No. XI. (Figs. 67 and 68, and Plate VIII.).—The special feature of this most successful and historical machine is that, with the exception of Santos Dumont's "Demoiselle," it is the smallest successful flying machine made up to the end of the year 1909. This machine after flying the Channel has now found a resting-place in the Musée des Arts et Mètiers, Paris.

Great perseverance on the part of M. Blériot resulted in his producing the first really practical monoplane. This machine has been considerably modified from time to time, chiefly with regard to the shape of its tail, and in the later machines this portion differs considerably from the earlier types. The machine itself is built upon a main lattice framework made of ash and spruce of box girder form, the members being strutted with ash and stayed with piano wires and covered with fabric. The method of fixing the struts to the longitudinal spars is noteworthy, and is carried out by means of U-shaped bolts, the centre passing through a slot near the end of the strut and the legs through two holes in the spar. The front section of the chassis is square, the rear portion tapering away in the form of a boat. The piano-wire guys are each separate, and some are provided with a stretching screw (see page 130).

Main Planes.—These planes are built up about two main spars, the inward ends of the leading pair fit into the two ends of a cross steel bracing tube, 42 mm. internal diameter, this tube is attached to the main frame. The wings or planes are very readily removable, as the front main spars project inwardly some 2 in. and are a sliding fit into the sockets. The rear main spars, which are of rectangular section, project inwardly a few inches only and are bolted to two vertical struts by a single bolt each, one on either side of the main frame. The tail is carried by the lower principal longitudinal members of the main frame, and is fastened to the same with aluminium clips of channel section. These clips partially embrace the rectangular ash beams, and necessitate, therefore, only light bolts to complete the attachment. The bracket extensions of these clips carry the main transverse bar of the tail which is a steel tube, and so arranged that the tube works as the fulcrum of a hinge about which the tail pivots. The trailing edge of the tail consists of a metal strip held by a number of distance tubes, the surface is swept forward as a fin on either side of the fusilage.

In the 1909 Blériot model the tail is divided into three sections, the centre portion or stabiliser is about half the total span, and its angle of incidence can be set before the machine leaves the ground.

For this purpose a drilled metal quadrant is attached to the trailing edge of the stabiliser, its upward end is located by means of a small bolt passing through this quadrant and through a small lug attached to the rear of the chassis of the machine. At either end of the stabiliser a small elevating plane is located, these two work in conjunction, and are operated by wires attached to vertical levers on the elevator fulcrum.

The main spars upon which the wings are built are of solid rectangular section of ash 3 in. deep by ¾ in. wide. At intervals of 13 in. apart these two spars are joined by curved ribs, some of which are only ¼ in. thick, whilst others are made of strips of aluminium reinforced in front by a strip of wood. The main rib at the inner extremity of each wing is of wood of a built-up channel section. A curved strip of aluminium is also fixed along the leading edge of each wing below the surfacing fabric.

The wings are double surfaced with Continental fabric, and at the maximum thickness are 3½ in. deep, the front edge is about 1½ in. thick, but the trailing edge, however, is quite sharp. The maximum amount of camber on the under or pressure surface is at one-third of the distance from the leading edge; this amounts to 85 mms. in the ordinary type and 65 mms. in the high-speed type of wings. Each wing is set at a dihedral angle of 5° to the horizontal, the angle of incidence is 7½° in the ordinary type and 6° in the high-speed machines flying at 90 kilometres an hour.

The extremities of the wings are rounded off as shown in Fig. 67. The lifting effect of the planes is transmitted to the chassis by four flat steel strips 15 mms. broad by 1·5 mms. thick, two being attached to each front main spar, in positions shown in Fig. 69. The lower ends of these strips are fixed to the lower part of the front of the chassis.

The rear main spars are interconnected by two flexible cables, which form the *gauchissement* control, the outer cable actually operating the control whilst the inner one runs round a pulley wheel freely. The total span of the wings is 28 ft., the chord is 6 ft. 6in., and the aspect ratio is only 4·65.

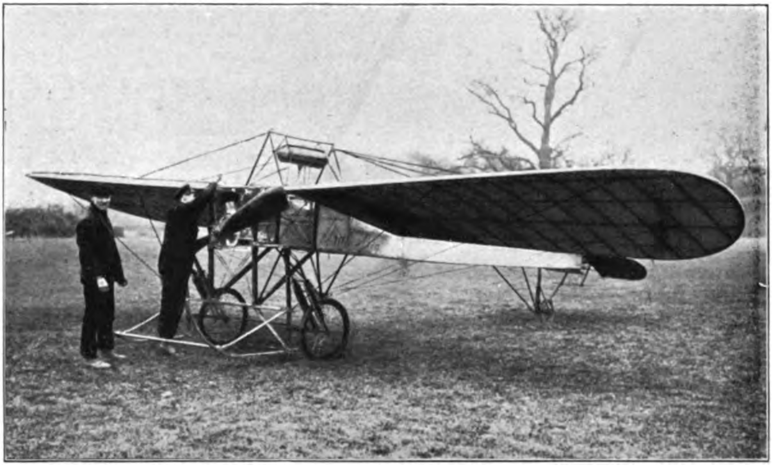
The area of support of the main planes is 150 sq. ft., and of the tail 33 sq. ft. The weight of the machine with aviator is from 600 to 700 lb., according to the engine used.

The supplementary surfaces consist of a monoplane tail with pivoted extremities and a rudder. The total span of the tail is 11 ft. 9 in. and it is 2 ft. 10 in. wide in a fore and aft direction, being about a third the span of the main wings and having an area about one-quarter as great. The pivoted tips are nearly square, and at the rear of them is situated the vertical rudder with an area of 4·5 sq. ft.

The construction of the tail is carried out in the same general manner as that of the main wings, except that the transverse spar is a steel tube. Only the central portion of the tail, as previously explained, can be permanently adjusted before flight, the tips being operated at will during flight.

Chassis.—The fore part of the machine is supported upon a pair of large bicycle wheels mounted upon telescopic castors. These consist of a pair of steel tubes braced together by two wooden beams, upon one of which the front end of the machine rests, the upper beam being merely a strut between the two steel tubular columns. The wheel hubs are stayed independently to loose collars, which ride up and down upon these steel columns, and are anchored to the lower ends of the same by means of very strong elastic bands which form the suspension at the front end of the machine (see Fig. 68). Springs are fitted inside the columns which return the wheels to their normal position by means of wire attachments after they have been deflected to one side or the other when running along the ground. The rear part of the machine rests upon a single wheel just in front of the tail, as shown in Fig. 63.

Control.—The aviator sits on the main frame near the centre of gravity of the machine, which is situated slightly forward of the trailing edge of the main planes, the engine being placed in front of him, and in front of the leading edge. The aviator rests his back upon a leather strap or seat, and his feet are placed upon a pivoted crossbar by means of which the rudder is operated.



Aero photo.

FIG. 69.—Blériot Type XI. Monoplane, "Little Boy."

A vertical lever terminating in a small hand wheel in front of the pilot's seat operates the *gauchissement* or warping of the planes, and this lever also controls the pivoted elevators by means of wires. This lever has a curious cup-shaped fitting or bell upon its lower end, to which the four controlling wires are attached, and it is operated by the left hand, leaving the right hand free to control the ignition levers of the engine, and also as occasion requires to increase the air pressure upon the lubricating tank by means of a hand pump.

The *gauchissement* is obtained by lateral displacement of the control lever, whilst the elevators are operated by a longitudinal movement, thus causing the angle of incidence of the machine to the horizontal to be altered.

The motor fitted to this machine is a three-cylinder 100 mm. by 150 mm. stroke air-cooled Anzani radial type described in Chapter V.; an E.N.V. or a Darracq engine is now fitted to many machines of this type. A few high-speed type XI. machines have been fitted with 50 H.P. Gnome engines, and Darracq engines are now seldom fitted by Blériot. The propeller is a composite wooden one by Chauvière, and is 6 ft. 8 in. in diameter, with two blades.

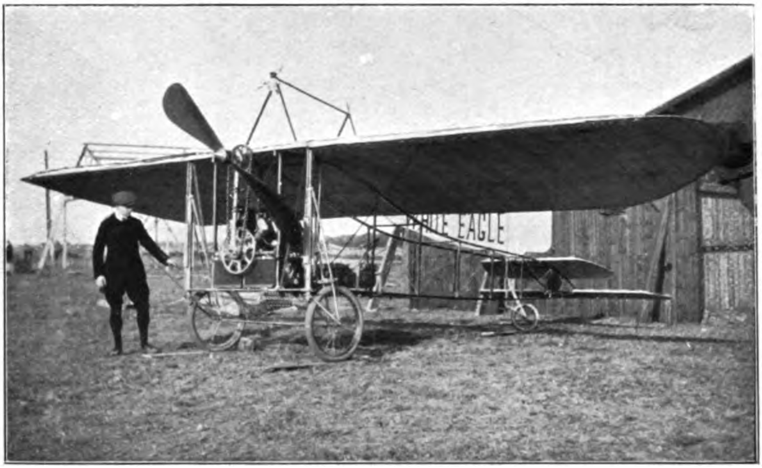


FIG. 70.—Mr C. Grahame-White's Monoplane, Type Blériot XII.

Blériot IX. differed slightly from this machine, having a span of 9 metres and an area of 26 sq. metres, and its lateral stability was obtained by *ailerons* situated at the extremities of the main planes, movable about their transverse axes. Such *ailerons* can be moved in a contrary direction by means of the controlling lever in order to displace the machine laterally, as when turning, or in levelling it again after a turn has been made, and this worked in conjunction with the vertical rudder. The controlling lever fitted to the Blériot machines is the subject of a patent of M. Blériot's.

Santos Dumont's "Demoiselle" (Plate IX.).—This machine, otherwise known as Santos XX., is the smallest practical machine to have attained flight, and on 16th September 1909 its constructor made a remarkable cross-country flight from St Cyr to Buc, a distance of about 17 km., which he covered in fifteen minutes, and then returned. He rose from the ground in the remarkably short time of six and one-fifth seconds. It is a notable fact, however, that nobody except the inventor had at the time of writing succeeded in flying this aeroplane.

The *Chassis* is constructed of three main bamboos about 2 in. diameter, two at the bottom and one at the top, braced together into a triangular cross sectional frame by steel struts of oval section. This frame is 16 ft. 5 in. long to the front, and carries the main planes on the higher level, and the two small wheels below. The main chassis is divided at the rear of the main planes; the bamboos here fit into brass sockets, so that the machine can readily be taken apart for transport. It will be noticed that the lower members of the chassis are quite close to the ground, and that the aviator's seat, which consists simply of a piece of canvas stretched between the two lower bamboos, is beneath the main planes and the engine, and level with the axle of the supporting wheels.

Such an engine position above the aviator's head involves risk of grave danger as landing shocks are apt to dislodge the engine itself from the chassis, and in falling this would strike the aviator.

Main Planes.—The principal spars upon which these are supported are of ash but not of an even section throughout their length. They are 2 in. wide by 1 in. deep where they are connected to the chassis and tapered towards their extremities to a bare inch in depth and 2 in. in width. These spars are set at a dihedral angle to one another, the front spar being 9 in. behind the leading edge of the plane and the rear one 12 in. forward of the trailing edge.

The body of the planes is built up with bamboo ribs fixed beneath the two main spars, the surface is double and made of silk fabric.

·The shape of the planes is such that the angle of greatest incidence is towards the centre of the machine, the angle diminishing towards the tips; the maximum camber of 4 in. is more towards the centre of the plane than is usual. The span of the main planes is 18 ft., the chord 6 ft. 5 in., the total area of main plane being 115 sq. ft. The aspect ratio of 2·76 is abnormally small.

The leading and trailing edges of the main planes are quite sharp owing to the use of wires attached to the ends of the ribs. All the controlling wires are below the main planes, and the radiator tubes, some hundred in number, are fixed immediately below the planes towards the centre of the machine and these tubes run the full length of the chord. All the wire diagonals are between the surfaces, and a line of sewing is run between each of the neighbouring ribs. Tubular rods connect the front main spars to the chassis near their centre and form their chief support.

Tail.—The tail moves as a whole and is pivoted on an universal joint at the rear of the chassis. A vertical member fitted 3 ft. from the rear of the chassis carries the wires which operate the elevator portion of the tail, the lower end of this vertical member is set round at right angles to form a small rear runner.

The arrangement of the tail in one piece obviates the necessity for using divided planes as in some other machines to allow of independent movement.

Both the tail surfaces are flat, there being no camber in the elevators, and they are stretched upon bamboo ribs. These surfaces are of a peculiar shape as shown in the accompanying drawing.

Engine and Propeller.—The engine is of the twin cylinder opposed type by the Darracq Company, and described in Chapter VI. MM. Duthiel and Chalmers, who have for some years past supplied engines to M. Santos Dumont, are now making both the engine and the aeroplane commercially. No flywheel is fitted to the engine, the propeller being keyed directly to the crankshaft.

The engine is supported upon the upper bamboo of the chassis and upon the front transverse spars of the main planes.

The propeller has two blades and is 6 ft. 6 in. diameter, and revolves in front of the aviator's line of sight. The centre of the propeller is 4 ft. 2 in. from the ground level.

Control.—The elevating lever is fixed at the right-hand side of the aviator. This operates the tail by means of a tension wire fixed to the top of the tail; the lower edge is connected by a wire and spring to the hand lever, the spring keeping the wire always taut and allowing the plane to be affected by gusts to some extent.

Lateral motion of the rudder is governed by a hand wheel at the left of the aviator, wires being attached to the lateral extremities of the tail for this purpose. The *gauchissement* is controlled by a lever pressed against the aviator's back, which enables him to warp the wings by subconscious motion, leaning to one side causes the wing on the other side to flex downward, and thus increases the lift of that wing. It will be noticed that the *gauchissement* and rudder control are independent in this machine, and the wires actuating the former run from the lever diagonally upward to the trailing extremities of the main planes.

The total weight of the machine without the aviator is 242 lb., of which the engine weighs 110 lb.

CHAPTER XII.

THE WRIGHT AND VOISIN MACHINES COMPARED.

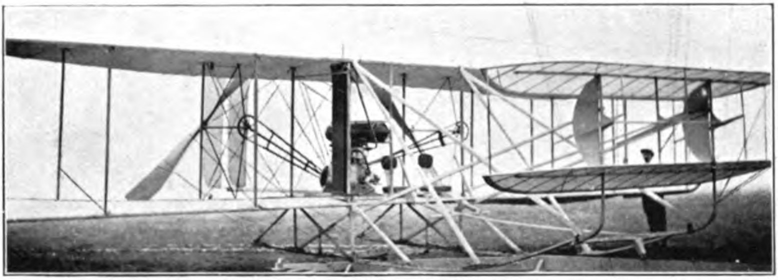
TOO much credit cannot be given to the Wright brothers for their untiring work and original investigations into the problem of flight. They were stimulated by the gliding experiments of Lilienthal, Pilcher, Chanute, and Herring, the latter two being associated with the Wrights in their work at one time. The investigations of Maxim and Langley also provided data upon which to work, but these data all required verification. The length and detail of all these earlier experiments will not be dealt with here, nor will mention be made as to the evolution of the present type of machine. Whether the Wright type of machine is in a final and satisfactory form or not, is still a matter of doubt to many minds, but the fact remains that it can and does fly in spite of its supposed instability. Stability is not everything, as instance the bicycle and the tricycle—the former is an unstable machine, but who would not prefer riding the former to the latter?

A comparison of the Wright and Voisin machines will be a convenient and instructive method of obtaining a clearer view upon two apparently somewhat similar types. Messrs Voisin have constructed a large number of machines of the rigid type, confining their early attentions to the box kite form, with side curtains.

Latterly these curtains have been dispensed with, and the machine which Farman has redesigned has a somewhat similar appearance to the Wright machine with the exception that it has a tail and *ailerons* attached to the trailing edges of the main planes. Mr F. W. Lanchester read an interesting paper upon these two machines before the Aeronautical Society at the end of the year 1908, and we cannot do better than consider some of the points he raises.

The later Wright machine (Fig 71) weighs complete with an aviator of average weight 1,100 lb., and has a total supporting surface of about 650 sq. ft. Its span is 41 ft., and the chord 6 ft. 6 in., giving 530 sq. ft. in the main planes.

Lanchester has taken an earlier model for comparison whose dimensions were 40 ft. span by 6 ft. chord, and he allowed 500 sq. ft. as the total sustaining area.



Aero photo.

FIG. 71.—Mr M'Clean's "Wright" Biplane.

The ordinary velocity of flight is 40 miles per hour or 58 ft. per second.

The plan of the main planes is nearly rectangular, the leading corners being slightly rounded, and the trailing corners rather more so. The main planes are built up on two spars of American spruce, the front spar being fixed at the entrant edge, and about 2 in. in thickness. This spar has a series of aluminium sockets attached to it which hold the struts between the upper and lower main planes. All the struts except the three rear ones at the extremities of each wing are attached by means of these sockets.

The second transverse spar is situated at a distance of 4 ft. 3 in. to the rear of the front spar in each plane, and the nineteen struts are distributed between these two pairs of spars. The outer three on each trailing end of the wings are attached as described in Chapter X. by means of hooks and eyes to permit of a small movement.

The ribs have a total length of 6 ft. 6 in., those forming the engine supports at the centre of the machine being stiff and solid. The trailing ends of the ribs are connected together by means of a steel cable.

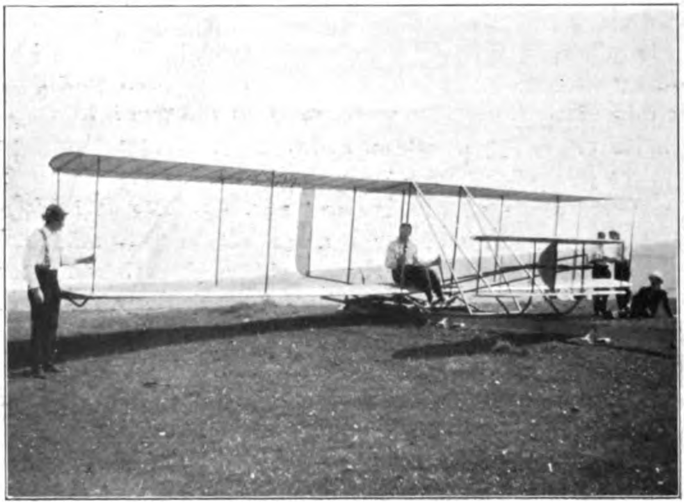
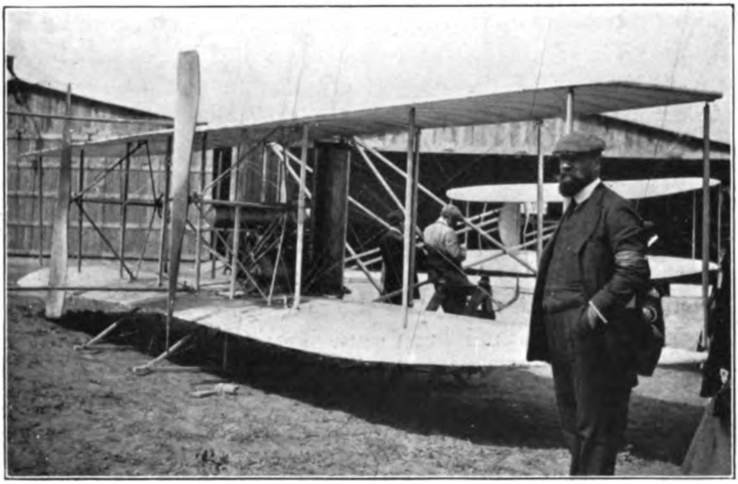


FIG. 72.—General View of the Wright-Clarke Glider.

The planes are double surfaced, the fabric being nailed to the front spars, and sewn to the ribs by means of pocket strips. Diagonal wire bracing is also fitted between the upper and lower layers of the covering fabric.

The auxiliary surfaces consist of a double horizontal elevator of the superimposed type, 14 ft. 10 in. from tip to tip, having a chord of 2 ft. 5 in. and a gap of 2 ft. 7 in., and it is placed about 10 ft. in front of the machine, held in an outrigger, and the movement is so arranged that the curvature of the surfaces is increased when the elevating planes are moved out of their normal positions. This is arranged by fixing the fulcrum of the operating levers so that the forward ends of the levers which are attached to the leading edge of the elevators move through a much smaller arc than the rear ends of the levers attached to the trailing edges of the elevators. Thus the rear edges of the elevators are flexed downwards, and increase the curvature of the planes when they are set to raise the front of the machine in the air. Between these two elevator surfaces is fixed a pair of small vertical half-moon shaped surfaces 6 ft. apart to assist in maintaining a straight direction, and to facilitate turning. This arrangement is shown in Fig. 72, representing Mr Alec Ogilvie on his Wright glider, which is a smaller edition of the actual flyer.



Aero photo.

FIG. 73.—Wright Biplane at Rheims, showing the Propellers.

A double vertical steering rudder is fixed on an outrigger 8 ft. 6 in. behind the main planes. These two surfaces are 5 ft. 10 in. in height, and 2 ft. in width, and are situated 19 in. apart; they are attached by cross struts and wires, and move in unison.

The total area of these auxiliary surfaces is about 150 sq. ft.

The Wright machine is propelled by two wooden screw propellers (Fig. 73), 8 ft. 3 in. diameter, which revolve at a speed of 450 revolutions per minute in opposite directions; larger propellers up to 9 ft. 2 in. diameter have, however, been fitted. These are driven by an open and a crossed chain from the rear of the engine crankshaft, and are geared down in the ratio of 9 to 33 in the modern machines; Lanchester took these ratios as 10 to 33 in his calculations.

The propeller shafts are held in brackets supported from the rear of the main frames, and are 11 ft. 6 in. apart, and an adjustable stay is fixed for tightening each chain. The gliding angle of the machine is about 7°.

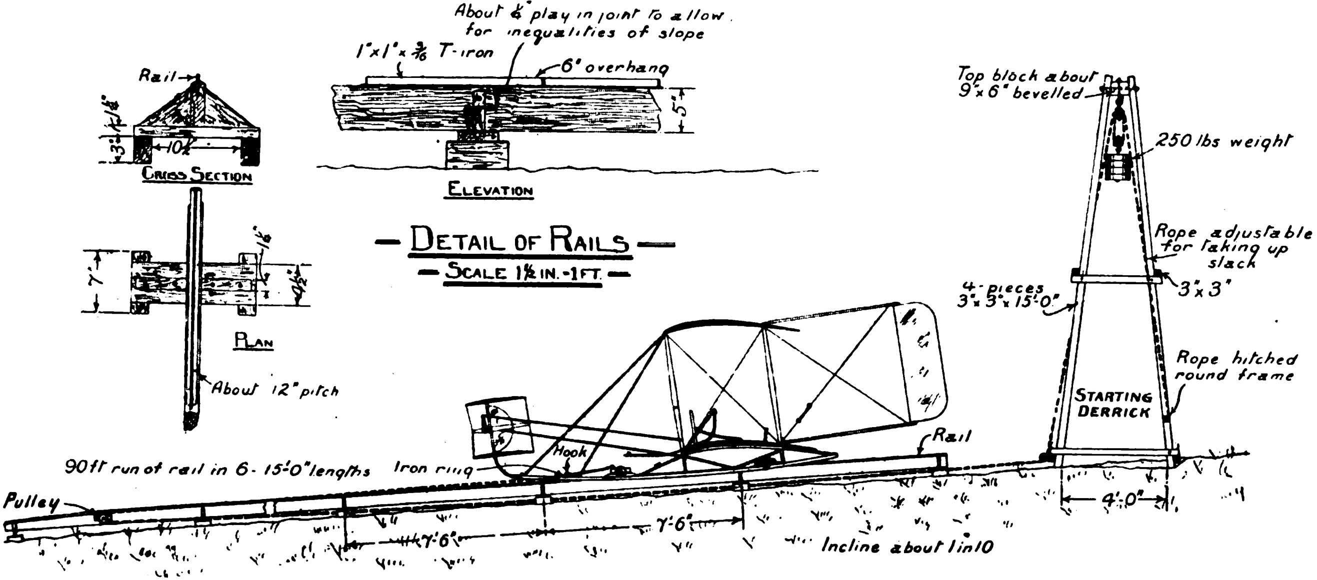
Messrs Voisin had been experimenting for many years before their first machine became known through the medium of Farman and Delagrange.

The machine was modified in many ways by Farman, who took every precaution to reduce wind resistance by covering portions with fabric.

The Voisin machine is stated to weigh with the aviator 1,540 lb., and has a total supporting surface of 535 sq. ft., this being the combined areas of the supporting surfaces of the main planes and the tail, but there are reasons for supposing that the intensity of pressure on the main planes is greater than that on the tail, probably owing to eddy currents of air in which the tail operates. The ordinary maximum velocity of flight is 45 miles per hour, or 66 ft. per second.

The area of the side curtains is approximately 255 sq. ft., and they are each nearly square, the main surfaces

PLATE V.



– SKETCH SHOWING MR. OGILVIE'S METHOD OF LAUNCHING HIS WRIGHT-CLARKE GLIDER. —

FIG. 74.

are 10 metres span by 2 metres chord, and have an aspect ratio of 5.

The early Voisin machine is propelled by a single screw propeller 7 ft. 6 in. diameter, with an *effective* pitch of 3 ft., and is keyed direct to the motor shaft. The actual pitch of the propeller is much greater than 3 ft., the particular type under discussion had a very great slip.

Several types of motors have been fitted to the Voisin machine, including the E.N.V., Itala, Gnome, and Antoinette, the latter being of 49 H.P. at 1,100 revolutions per minute, and weighing 265 lb. The gliding angle of the machine was originally 11°, but improvements in design, such as reduction of wind resistance, have enabled this angle to be reduced to 9°.

Weight.—With regard to the weights of the two machines, the Voisin is about 40 per cent. the heavier; this may be, to a great extent, due to the fact that the Voisin machine is fitted with a chassis having wheels attached to enable it to run along the ground and start from any point, whereas the Wright machine has large skids and two small central wheels which enable it to start only from a rail or occasionally from smooth grass. The total weight of the chassis of the Voisin machine is about 1 cwt., and probably exceeds the weight of the undercarriage of the Wright machine by 60 or 70 lb.

The weight of the aviator and sundries in each case is about 200 lb.

Lanchester's theory was that for machines of equally good design the resistance to flight of two machines of equal weight is practically independent of the velocity of flight, therefore the horse-power required will vary directly as the velocity of flight.

The Voisin machine should consequently be fitted with a more powerful engine, both on account of its greater weight and its greater speed of flight.

Assuming that there is a mean pressure of 72 lb. per sq. in. in the engine cylinders as referred to the output on the *brake*, we have at the speeds corresponding to the declared horse-power of the Wright engine, and the Antoinette engine:—

	Bore.	Stroke.	Revolutions.	Horse-Power.
	inches.	inches.		
Wright	4·25	4·0	1,200	24·7
Voisin	4·35	4·15	1,100	49·2

If these figures are obtained in practice the Wright machine has 1 B.H.P. per 45 lb. sustained, which at the same rate should give the Voisin 34 B.H.P., and allowing an extra 10 per cent. for the greater speed of the Voisin, this latter machine would require 38·5 B.H.P.

The actual power, as we have seen, is 49·2, and the difference either is accounted for by inefficiency of propulsion, but more probably by an excess of power supplied to enable the machine to rise without the aid of a pylon.

There is no doubt about the fact that an excess of power is present in both the machines, as additional weight has been carried in the form of a passenger. The Wright machine is provided with a passenger's seat located in the centre between the two main planes just forward of the centre of gravity of the machine. In this arrangement the distribution of weight is unaffected, as far as stability is concerned, whether the passenger be carried or not. An addition of a weight of say 200 lb. means approximately 20 per cent. extra weight to be carried, and this in turn requires either increased engine power or sustaining surface. The latter being a constant quantity, it is evident that a reserve of power is present. Owing to the fact that no throttle is fitted to the Wright engine, what really takes place is that the speed of flight of the machine is and must be lower when a passenger is carried than when otherwise, showing that even when the extra weight is supported the engine power is sufficient to propel the machine at a soaring speed at least. There is another aspect of this reserve of power, and that is the capability of the machine to ascend. Mr Lanchester did not think that the early Wright machine showed much capability in this respect, but Count de Lambert and the Wright brothers at least have demonstrated the fact that high altitudes can soon be reached. Wilbur Wright states that with his machine weighing 1,000 lb., and having a gliding angle of 7°, a thrust of 140 lb. is required, and at 58 ft. per second velocity of flight the thrust horse-power becomes 14·5, the B.H.P. of the motor being 24, and if this is as he states 40 per cent. in excess of the B.H.P. actually required, 17·1 B.H.P. is exerted by the engine. On continuing the argument this shows an efficiency of the screw propellers, and transmission of 85 per cent., which is obviously too high. Probably 70 per cent. would be nearer the mark. It may, however, be that the *thrust* horse-power is 15 to 16, and that the reserve of 40 per cent. includes losses in propulsion.

The comparative efficiencies of the propellers are dealt with in Chapters VII. and VIII. on Propellers.

The principal points of difference in the main planes of the two machines are the flexibility of those of the Wright machine, which forms the subject of one of their patents, and the rigidity of the Voisin planes. The mechanism which controls this flexibility is directly controlled by the right-hand lever moving either to left or right, its fore and aft movement operating the steering rudder. The two movements are intimately connected, and for this reason a single lever-controlling device is desirable.

Supposing, for instance, the rudder be turned in any one direction, the outer wing in performing its flight round an arc will travel faster than the inner wing, and tend to rise.

A certain amount of rise or banking is necessary in order to counteract centrifugal force tending to make the centre of gravity of the machine continue in a straight path. This banking may be carried to excess in an extended turning, and it becomes necessary, therefore, to reduce the lift of the outer wing and increase that of the inner one, and incidentally to put a slight "drag" on the inner wing—the action is explained in Chapter XV.

In the Wright machine this is accomplished by reducing the angle of incidence of the outer ends of the upper and lower planes, and increasing that angle on the inner ends. The method of construction can be seen in the figures, and consists of wire connections diagonally attached in such a manner that the tension on one side draws the rear outer strut downwards on that side, and a cross connecting wire to the other wing raises the rear outer strut of that wing a corresponding amount.

The flexure of wing tips is also employed to restore lateral stability after unequal pressure on the two wings has tilted the machine from the horizontal in straight flight. This *gauchissement* can clearly be seen in action in Fig. 87 of Mr Ogilvie's glider. The elevator is manipùlated by a lever at the left hand of the aviator.

The Voisin machine is provided with side curtains to provide lateral thrust surfaces which only come into play when resisting centrifugal force. A steering rudder is placed inside the box tail, whilst a single elevating plane is fitted in front of the machine on an outrigger.

The Voisin Biplane, 1909 type, has already been referred to, and a description of its more essential details, together with a study of Plate X., founded upon the original dimensioned drawing appearing in *Flight*, will be both useful and instructive.

The Voisin machine was one of the very first European machines to demonstrate the possibility of a flying machine, and its leading characteristics are as follows:—The main feature of the machine is a box form tail carried on a light outrigger about 13 ft. at the rear of the main planes. The

"Bird of Passage," originally the property of Mr Moore Brabazon, was fitted with a single propeller directly connected to the engine shaft, and an elevator in front separated by a distance of 4 ft. 4 in. from the leading edge of the main planes, this distance being much less than that found in the Wright machine. It will be noticed that neither the wings warp nor are *ailerons* fitted, so that the lateral stability must be acquired by other means explained in Chapter XV.

Another important difference is the chassis, which supports the wheels and the engine in a steel framework.

Main Planes.—These are of the superposed type, having a span of 32 ft. 11 in. and a chord of 6 ft. 9 in., giving a total area of 445 sq. ft. and an aspect ratio of 4·9. The surfacing is single, and Continental fabric is used and fixed beneath the ribs, the main spars and ribs being encased in pockets. The main spars, 1½ in. wide by ¾ in. thick, are fixed, one on the leading edge and the other about 5 ft. at the rear. It will be seen that a trailing edge of 1 ft. 9 in. thus overhangs the rear main spar.

Ash ribs of 5/16 in. by ¾ in. section lie across the main planes 1 ft. 3 in. apart in order to define their true shape, and they have a camber as follows, measuring from the leading edge :—

Distance -	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	6 ft. 9 in.
Camber -	3⅛ in.	4⅛ in.	3¾ in.	2¾ in.	1⅜ in.	⅝ in.	0 in.

The two main planes are separated by eight pairs of struts 6 ft. 8 in. long and 1½ in. by 2 in. section, those at the extremities of the wings being placed farther apart than those at the centre, and the ribs over the struts are stronger than the intermediate ribs. Diagonal wire bracing is stretched across the various panels, both lateral and longitudinal, thus giving a stiffness to the whole machine.

The amount of this wire bracing is very considerable in the Voisin machine, perhaps more so than in any other.

Tail.—This member, which is of the biplane box form, has a pair of superposed cambered planes similar in construction to the main planes of the machine, though the gap between them is smaller. Wire bracing is carried out as before, the span of the tail planes is 7 ft. 11 in., and its chord is the same as that of the main planes, thus giving a total tail lifting area of 107 sq. ft., that is, nearly a quarter of the area of the main planes.

The *Rudder* is mounted upon a vertical hinge fixed between the rear main spars of the tail, and it is rectangular in form and consists of a single plane 4 ft. 2 in. in height by 4 ft. long, and has an area of 16·5 sq. ft.

The rudder plane projects 1 ft. 3 in. beyond the box formation of the tail, and it is operated by means of wires, and has a flexible trailing edge.

The *Elevators*, two in number, have a combined area of 45 sq. ft., each being 6 ft. 11 in. span by 3 ft. 3 in. wide. They are situated in a lower relative position than that generally adopted, being almost on a level with the lower main plane. The elevators are double surfaced, a hinge tubular rod passing right through the ribs at about one-third the length of their chord from the leading edge. This rod is held by a forward continuation of the chassis which projects between the two halves of the elevator. Attached to the hinge rod in the centre are two wooden levers, and between them a bar passes, to which is fixed one end of a connecting rod. The other end of this connecting rod is fixed to the steering wheel spindle in such a manner that the elevator is moved when the steering wheel as a whole is pushed away from or pulled towards the aviator. It must be understood that the steering wheel is fixed on an almost horizontal axis, and its spindle slides in a carrier and does not rock about a hinge. Mounted on this spindle is a wooden drum around which the connecting wires to the rudder are coiled. A single hand control is, therefore, all that is provided.

Chassis.—The tubular framework of which the chassis consists is chiefly made of 1¼ in. outside diameter tubes, and holds two swivels to which the running wheels are attached. These are of the wire spoked type and are fitted with pneumatic tyres. Tension springs are attached to the swivelling arrangement to retain the wheels normally in a straight path. The tops of the swivels rest on the ends of helical springs 3 ft. long by 2 in. outside diameter, made of ¾ in. diameter steel, projecting up beyond the lower main plane, the object of the springs being to minimise the shocks received by the wheels in running over rough ground from being transmitted to the machine as a whole. The question of suitable spring suspension is a very important one, and inventors are at work devising a pneumatic system with a large working range to replace springs of this type.

Radius rods are provided, one to each swivel, so that when the spring is compressed the wheel increases its "trail" and the wheel supporting framework is deflected out of the vertical. The outward ends of the radius rods are pinned to the forward extension of the chassis.

Side curtains are fitted both to the main planes and to the tail, in the former instance they are four in number, and in the latter, two.

These curtains are made of the ordinary fabric stiffened by ribs and by the diagonal wire bracings. Farman eventually dispensed with these curtains, but their original object is described on page 163. The probability is that their presence affects the air currents, particularly in the vicinity of the rudder, but they may prevent the air under the upper plane leaving it sideways at the tips, and thus therefore increase the efficiency of lift.

Propulsion.—The single propeller running at a high speed is driven by an engine of 50 H.P., finally an E.N.V. of the eight-cylinder V type being decided upon.

The two-bladed steel propeller is of the clip or adjustable pitch type, with large square ended blades. Some observations on this propeller are made in the comparison with the Wright machine.

WEIGHTS OF THE "BIRD OF PASSAGE."

	Lb.
Main planes	180
Chassis	250
Tail	108
Rudder	10
Elevator	32
Engine	320
Radiator and water	80
Aviator	170
Total	1,150

CHAPTER XIII.

THE FARMAN MACHINE.

PLATE XI.

HENRY FARMAN'S name has been prominent amongst those of successful aviators, and particularly as having been associated with Voisin Frères, and as the winner of the Deutsch-Archdeacon prize for the first circular kilometre flight.

This was achieved on a Voisin biplane, but Farman carried out from time to time numerous modifications with this type of machine until eventually he has designed a machine of his own somewhat on Voisin lines. His machine has been particularly successful at the latter end of 1909, both in his hands and those of M. Paulhan, and fitted with a Gnome engine some beautiful and remarkable flights have been made. In general appearance this machine is light and stable, its most noticeable difference from the Voisin machine is the absence of side curtains both in the main planes and the tail. The provision of skids in addition to four supporting wheels beneath the main planes is an innovation, and the great advantage of such an arrangement in landing is obvious. Paulhan has, however, such remarkable control over the machine that although descending from a height through a dangerous-looking angle, his final impact with the ground is so slight as to scarcely warrant the use of the term at all.

Main Planes.—These are of the superposed type, having a span of 32 ft. 6 in., and a chord of 6 ft. 4 in., their aspect ratio being therefore 4·1. These planes are separated by eight pairs of ash struts, 6 ft. 4 in. long, four pairs being close together in the centre section where the weight is situated. The framework of the planes is of the usual type, being made up of two transverse main spars, 4 ft. 9 in. apart, and attached together by longitudinal ribs, flush at the leading edge, and projecting at the trailing edge beyond the rear transverse spar. The planes are single surfaced only, but the spars and ribs are enclosed in fabric pockets. It will be seen that the flexible trailing edge is 1 ft. 7 in. broad, and each plane has an *aileron* fitted of that breadth, and of a length equal to that of about one-fifth of the total span. When in flight these *ailerons* lie in the same line with the trailing edge, and can scarcely be detected, but when stationary they hang down vertically like hinged flaps. Owing to the position of the propeller at the rear of the main planes, and revolving about a centre only slightly above the level of the lower plane, this plane is cut away to give the necessary clearance at the centre.

The framework supporting the tail is made of four ash spars of rectangular section attached to the transverse main spars; they converge slightly at the rear, and are separated by vertical struts held in aluminium sockets. No lateral distance struts are provided, but wire diagonal bracing is freely used here, as also between the main planes. These four spars are carried forward parallel in plan view, but converging to an angle in side elevation, and terminating in a cross member, about which the elevating plane is hinged. At the rear a biplane tail member is fitted, built up in a similar manner to the main planes, but of 7 ft. span.

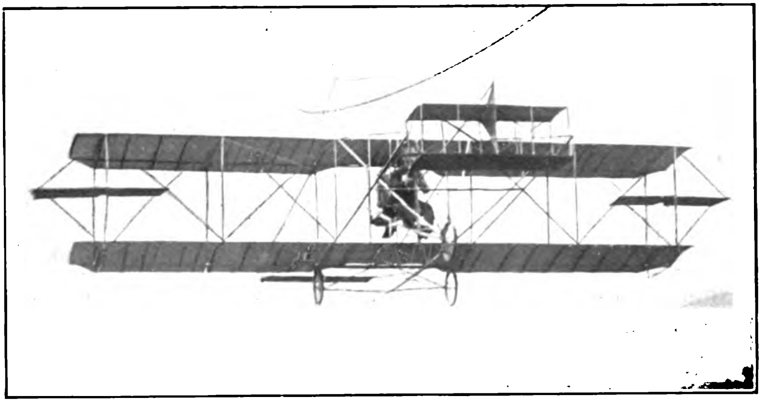
The two vertical rudders are hinged between the rear spars of the tail, and work simultaneously. They are rectangular in form, and project a short distance beyond the tail. Through the centre of each rudder plane a short strut projects in both directions normal to the surface, and their ends serve as fixing points for bracing wires, one of which is attached to a corner of each plane, and a complete triangulation is for~~med.~~ These wires are also carried across from the rear two corners of one rudder plane to those of the other.

The control wires which operate these rudder planes are carried across a short lever fixed normally to the surface of each plane at the centre of its hinged edge, and pass across the centre struts fixed to the rudder planes, and round the rear edges, to which they are attached, the connection being also carried across between the two rudders.

The elevator plane has a span of 15 ft., and is hinged as before stated, and constructed in three sections to clear the members forming the outrigger; the forward portion, however, is continuous. The controlling wires are attached to a normal strut attached to the rear transverse member of the framework, one at the upper and one at the lower end of the strut. The wires are connected at their other end to a lever placed at the aviator's right hand, which lever also actuates the wires controlling the balancing *ailerons*. The connections are arranged to allow of subconscious control; a backward pull of the lever increases the angle of incidence of the elevator. The lateral stability is effected by movement of the same lever to right or left—thus moving to the right lowers the *ailerons* on the left, causing that side of the machine to rise. It will be noticed that although the same idea is carried out as in the Wright machine, the connection of elevator and *ailerons* to one lever is adopted, whereas in the Wright machine it is the rudder that is connected to this universal lever. Perhaps in many respects the rudder and the *ailerons* are more intimately associated, as the movement of the rudder is bound to affect the lateral stability, and a suitable motion of the controlling lever in a diagonal or elliptical path actuates both simultaneously. The Farman machine has foot-operated rudders, a pivoted foot rest being so connected up that a depression of the right foot steers the machine to the right, and *vice versa*.

The skids already referred to are each suspended from a short axle carrying a pair of wheels. The suspension is by a stout rubber band, and the skids are located at right angles to the axles by distance rods. Normally, the weight of the machine, which is supported upon the skids, is transmitted through the rubber bands to the axles and wheels and thence to the ground. An excess of load or shock stretches these bands, and the skids themselves come into direct contact with the ground.

The propeller is by Chauvière, of the two-bladed type, 8 ft. 6 in. diameter.



Aero photo.

FIG. 75.—Curtiss Biplane.

Curtiss Biplane.—This machine was somewhat of a dark horse at the Rheims meeting, but its great success in speed contests, both there and later in America, at once arrest attention. The machine much resembles the Wright.

The main planes are fitted with twenty-two ribs, each made of three-ply wood ; both upper and lower planes are detachable at about half the length from the tip to the centre, and the planes themselves are single surfaced. The fabric is attached to the ribs by flat cords and fastened with brass nails ; the surfaces are divided each into seven sections, three in the centre and two on either side. The woodwork is of American spruce, and braced together with steel stranded cable. The cables are soldered together wherever they cross one another; the supports for the elevator and the rudder are fixed to bamboo stays fitted with cable bracings. The lateral stability is obtained by the use of *ailerons* situated about half-way between the upper and lower planes, and at their outward extremities, and are operated by the back of the aviator's seat by means of natural movement of his body.

The Curtiss engine has four cylinders 3¾ in. by 3¾ in. stroke, giving 35 H.P. at 1,100 revolutions per minute, and a maximum of about 50 H.P., and weighs about 200 lb.

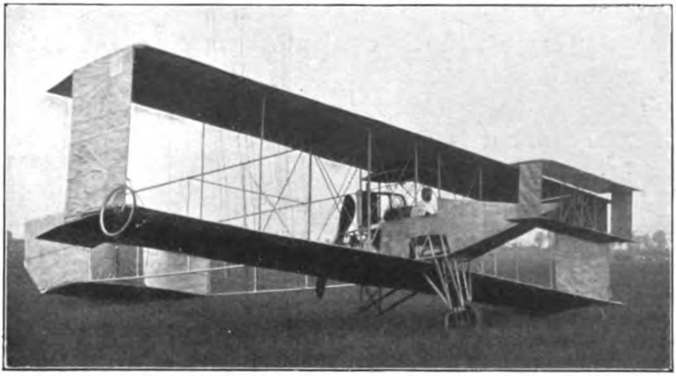
Maurice Farman has produced a machine to his own design and with which he has had considerable success. This cellular biplane resembles Fig. 76, and is somewhat similar to two other well-known types.

The span of the main planes is 32 ft. 6 in., and its total supporting area 540 sq. ft. A chassis somewhat similar to that of the Voisin machine is fitted and covered with fabric forming a cockpit in which the aviator sits. The elevator is placed well forward, and is controlled by circular motion of the steering wheel which also acts upon the rudder, the latter being between the box tail curtains.

A lateral movement of the wheel operates the rudder by means of a cable. The main wings are warped at their rear tips in the manner of the Wright machine, a lever at the aviator's left hand performing the necessary control. Both the control mechanisms are arranged so that in the case of *gauchissement*, or elevating, the gear remains as placed by the aviator until he moves it at will.

The new Maurice Farman machine will be fitted with an under carriage embodying the use of skids in conjunction with the wheels; it will be noticed that the suspension contains spring buffers, and also provision for lateral displacement of the wheels to some extent.

Cody Machine.—One is apt to be sceptical about Mr Cody and his machine, but at the same time great credit should be given to him for the untiring work he has put into the subject. He has achieved some excellent flights at Farnham, but somehow when the public eye has been upon him, failure has attended his efforts. Lack of sufficient funds was perhaps one of the chief drawbacks which he encountered, but dogged perseverance on his part has been rewarded by several successful flights.



Aero photo.

FIG. 76.—Mr Howard Wright's Biplane. This machine is somewhat similar to the Maurice Farman machine, except that the latter has a monoplane elevator in two sections and a different suspension, its framework also is wooden instead of tubular.

Enthusiasm, however, seems to be the dominating feature of his character, and it is a pity that its reward should have been so disappointing. The most remarkable feature of the Cody machine is its size and weight—these two may be thought to be a disadvantage, and that is true when considered from the point of view of the still air flyer. There are some of us who think that the future development of flying machines will be a high speed and comparatively heavy machine, so perhaps the Cody flyer may be a move in the right direction. The weight of this machine is attributable to the very substantial construction of the framework timbers, of large size are used and well triangulated.

The Chassis projects well in front of the leading edge of the main planes, and carries three wheels in tricycle form. The machine is properly carried upon the two rear wheels, the leading one being for emergencies, and to retain the machine in a level position when stationary. One of Cody's innovations is a stout wooden tail formed like a large hockey stick, to take the shocks when alighting, and he attributes great importance to this adjunct.

The machine is somewhat of the Wright form in that it has no tail, but is fitted with an elevator in front held on a bamboo outrigger.

Main Planes.—These are arranged in the usual biplane superposed fashion, but they are slightly arched. The span of the planes is 52 ft., and they have a chord of 7 ft. 6 in., giving an aspect ratio of 6·94. The gap between the planes at the centre is 9 ft., and they are separated by struts and diagonals in the usual way. The aviator's seat is quite in front of the leading edge of the main planes, and in front of the engine.

The planes are double surfaced, but their arching is not uniform throughout, being flatter at the tips.

The Elevator, which is in front, is of considerable length, and divided into two at the centre. Each half can be separately manipulated, thus forming *ailerons* to control the lateral stability of the machine.

These elevators are of the single plane type, and arched in the same manner as the main planes. In addition to the elevators, supplementary surfaces may be fitted in a vertical plane at the rear of the main planes to improve the steering qualities of the machine, and to act in conjunction with the—

Rudder.—This is at the rear of the machine, and of the single vertical type, held between a pair of rear spars 9 ft. apart, and stiffened by diagonal bracing.

The control of the rudder as well as the elevators is obtained by movement of a steering wheel with a pivoted joint and a lever attached. Movement of the aviator's body is naturally transmitted to the wheel, which thus performs the necessary operations. Control rods are attached to the elevator mechanism in front, one to either plane. The machine has a very large area, there being 780 sq. ft. in the main planes alone. An eight-cylinder E.N.V. engine of 80 H.P. was fitted, driving two propellers by means of chains.

The propellers are placed between the planes and near to the leading edge. They revolve in opposite directions, and are geared down from the engine shaft.

Mr Cody prefers a shape of blade which is broad towards the root and narrow at the tip, similar to those he designed for the War Office dirigible; he is not very keen about chain drives owing to the supposed liability of the chains to break. With slow speed propellers the author does not think the risk great, as should the engine suddenly stop, the inertia, a slow speed propeller, would not generally be sufficient to cause the modern well-made chains to suffer any such risk.

EXHIBITS OF MONOPLANES AT THE FIRST AERONAUTICAL SALON, PARIS, DECEMBER 1908.

Machine.	Exhibitor.	Span in Metres.	Surface, Sq. Metres	Weight, Kg.	Engine, H.P.
Ader's Avion (No. 3)	Arts et Mètiers Museum	16	·56	258	40 Steam.
R.E.P. (No. 2 *bis*)	R. Esnault-Pelterie	9·6	15·7	360	35 7 cyl. R.E.P.
Blériot (No. IX.)	Société Blériot	9	24	410	50 16 cyl. Antoinette.
,, (No. XI.)	,, ,,	7	13	160	35 7 cyl. R.E.P.
Antoinette	Sté. Antoinette	12	40	500	50 8 cyl. Antoinette.
La Demoiselle	Santos Dumont	5·5	9	67	2 cyl.
Pischoff	Pischoff & Koechlin	...	23	...	17 2 cyl.
Vendôme (No. 2)	R. Vendôme	9	26	305	50 3 cyl. Anzani.
Clement Bayard	Clement Bayard	12·5	23	400	50 7 cyl. B.C.

EXHIBITS OF BIPLANES AT THE FIRST AERONAUTICAL SALON, PARIS, 1908.

Machine.	Exhibitor.	Span in Metres.	Surface, Sq. Metres	Weight, Kgs.	Engine, H.P.
Wright	Cie. Navigation Aèrienne	12·5	47·5	450	22 4 cyl. B.M.
Farman (No. 1)	Voisin Frères	10·2	52	500	50 8 cyl. Antoinette.
Delagrange	Sté. d'Encouragement	10·5	40	450	50 8 cyl. Antoinette.
Blériot (No. X.)	Blériot	13	65	480	50 8 cyl. Antoinette.
Lejune (No. 1)	Lejune	6·5	23	150	12 3 cyl. Buchet.

TABLE OF FRENCH FLYERS.

The interesting particulars given below are reproduced exactly as they have been published in France.

Flyer.	Type.	Maker.	Propellers.	Supporting Area.	Dimensions.		Engine.			Weight of Flyer without Pilot.	Price in France.
					Length.	Span.	Maker.	Type.	Horse-Power.		
				sq.m.	metres.	metres.				kg.	francs.
Antoinette	Monoplane	Sté. Antoinette	1	35	12	14	Sté. Antoinette	8 cyl.	50	475	25,000
A. V. I. A.	,,	Ateliers Vosgiens	1	14	7	7·50	Dutheil-Chalmers	2 ,,	30	200	8,000
Blériot XI.	,,	Etabliss. Blériot	1	14	7·50	8·60	Anzani	3 ,,	24	210	12,000
,, XII.	,,	,, ,,	1	27	7·60	9·60	E.N.V.	8 ,,	70	450	26,000
Chauvière	Biplane	Penteado	1	20	6·50	10	R.E.P.	7 ,,	35	140	12,000
Clément Bayard	,,	Clément Bayard	1	60	11·65	12	Clément Bayard	4 ,,	43	450	17,000
De Dion-Bouton	Multiplane	De Dion-Bouton	4	62	9	12	De Dion-Bouton	8 ,,	100	700	...
Farman	Biplane	H. Farman	1	40	12	10	Gnome (revolving)	7 ,,	45	450	28,000
Gangler	Monoplane	Gangler	1	27	9·50	11	Gyp	4 ,,	40	295	25,000
Grégoire-Gyp	,,	P. J. Grégoire	1	22	11	10	P. J. Grégoire	4 ,,	40	300	12,500
Hanriot I.	,,	Hanriot	1	24	9·60	9·17	Hanriot	4 ,,	35	335	20,000
,, II.	,,	,,	1	24	9·60	9·17	Buchet	6 ,,	50	400	22,000
Koechlin	,,	Koechlin	1	18	7·50	8	P. J. Grégoire	4 ,,	24	260	14,000
R. E.-P.	,,	R. Esnault-Pelterie	1	21	8·50	10·80	R. Esnault-Pelterie	7 ,,	33	355	30,000
Santos Dumont	,,	Clément Bayard	1	10	6·20	5·50	Clément Bayard	2 ,,	25	110	7,500
Sté. de Construct. d'Appareils Aériens	,,	Sté. de Construct. d'Appareils Aériens	1	20	8	10	Anzani	2 ,,	25	220	12,500
Vendôme	,,	Vendôme et Cie	1	22	11	11	,,	2 ,,	30	270	15,000
Vuitton-Hubert	Hélicoptère	...	3	...	5	6	...	...	120	169	...
Voisin	Biplane	Voisin Frères	1	50	12	11·50	Antoinette or Gnome	...	50	500	25,000
W. L. D.	Monoplane	Loiré et Cie	2	20	8·70	8·70	Buchet	4 cyl.	35	300	12,000
,,	Biplane	,, ,,	2	50	10	10	Renault	8 ,,	60	550	22,000
Wright	,,	Sté. Ariel	2	50	8·50	12·50	Barriquand & Marre	4 ,,	25	400	30,000

COMPARATIVE TABLE OF PROMINENT MACHINES.

Machine.	Area, Square Feet.	Horse-Power.	Weight Lb., with Pilot.	Lb. per Horse-Power.	Lb. per Square Foot Area.	Square Feet per Horse-Power.	Speed with Full Load, m.p.h.	Per Cent. Coefficient of Traction, approx.	Propellers.		
									Number and Make.	Diameter in Feet.	Revolutions per Minute.
Wright - - -	540	30	1,080	36	2·0	21	34	17·6	Two Wright -	8·5	450
Cody - - -	1,000	80	2,170	27·1	2·17	12·5	...	...	Two Special -	...	...
Farman - - -	420	50	1,170	23·4	2·79	8·4	35	21·4	One Chauvière -	8·5	1,200
Voisin - - -	525	50	1,270	25·2	2·42	10·5	...	...	One Voisin -	6·5	1,200
Curtiss - - -	270	50	710	14·2	2·63	...	51	31·6	One Curtiss -	5·85	1,300
Antoinette VII. -	368	50	1,210	24.2	3·29	7·36	42	19·8	One Antoinette -	7·15	1,100
Blériot XI.—Anzani -	147	25	633	26·4	4·30	6·13	36	23·7	One Chauvière -	6·58	1,400
,, XII.—E.N.V.	283	70	1,170	16·7	4·14	4·04	...	...	,, ,, -	8·8	500
,, XII.—E.N.V.	236	35	1,000	35·2	5·2	...	38	18·3	,, ,, -	...	500
Santos Dumont - -	115	30	412	13·7	3·5	4·2	56	29·3	,, ,, -	6·5	1,500

Assumed Weight of Pilot, 170 lb. See also Table in Appendix.

CHAPTER XIV.

PROGRESSIVE MONOPLANE RECORDS UP TO END OF 1908.

Date.	Aviator.	Place.	Distance or Time
14th Oct. 1897	Ader	Satory	300 metres.
5th April 1907	Blériot	Bagatelle	6 seconds.
17th July 1907	Vina	,,	60 metres.
25th ,, ,,	Blériot	Issy	150 ,,
22nd Oct. 1907	Esnault-Pelterie	Buc	30 ,,
27th ,, ,,	,, ,,	,,	150 ,,
18th Nov. 1907	De La Vaulx	St Cyr	60 ,,
6th Dec. 1907	Blériot	Issy	600 ,,
12th Feb. 1908	Gastambide-Mengin	Bagatelle	150 ,,
8th June 1908	Esnault-Pelterie	Buc	1·2 km.
4th July 1908	Blériot	Issy	6 km. = 5 min. 47 sec.
6th ,, ,,	,,	,,	8 min. 45 sec.
21st Aug. 1908	Gastambide-Mengin	,,	1·6 km. = 1 min. 30 sec.
31st Oct. 1908	Blériot	Toury, across country	14 km.

RHEIMS MEETING, AUGUST 1909.

Date.	Aviator.	Achievement.
26th August 1909	Latham (Antoinette)	154 km.
27th ,, ,,	Blériot	40 ,,
29th ,, ,,	Latham (No. 29)	30 km. in 25 min. $18\frac{1}{5}$ sec.
29th ,, ,,	,, (No. 13)	30 km. in 26 min. $32\frac{2}{5}$ sec.
28th ,, ,,	Blériot (speed record)	10 km. in 7 min. $47\frac{4}{5}$ sec.
26th ,, ,,	Latham	10 km. in 8 min. $32\frac{3}{5}$ sec.
Gordon Bennett race	Blériot (2nd place)	15 min. $56\frac{1}{5}$ sec.
,, ,, ,,	Latham (3rd place)	17 min. 32 sec.
Altitude prize	,, (1st place)	155 metres (508 feet).
150 metre speed record	,, (No. 29)	2 hrs. 13 min. $9\frac{3}{5}$ sec.

PROGRESSIVE BIPLANE RECORDS UP TO END OF 1908.

Date.	Aviator.	Place.	Distance or Time.
1906.			
14th Sept.	Santos Dumont	Bagatelle	8 metres.
13th Nov.	,, ,,	,,	220 ,,
1907.			
30th Mar.	Delagrange	Bagatelle	200 metres.
15th Oct.	Farman	Issy	285 ,,
26th ,,	,,	,,	771 ,,
17th Nov.	Santos Dumont	,,	200 ,,
17th Dec.	Pischoff	,,	500 ,,
1908.			
13th Jan.	Farman	Issy	1·5 km.
12th Mar.	Bell	New York	315 ft.
10th April	Delagrange	Issy	2·5 km.
27th May	,,	Rome	9 km.
30th ,,	,,	,,	12·5 km.
22nd June	,,	Milan	17 km.
4th July	Graham Bell	New York	1,100 yds.
6th ,,	Farman	Ghent	19·17 km.
8th Aug.	Wilbur Wright	Hunaudières	1 min. 45 sec.
11th ,,	,, ,,	,,	3 min 43 sec.
19th ,,	Capt. Ferber	Issy	256 metres.
3rd Sept.	,, ,,	Auvours	10 min. 40 sec.
5th ,,	Wilbur Wright	,,	19 min. 48 sec.
6th ,,	Delagrange	Issy	24·7 km.
9th ,,	Orville Wright	Fort Meyer, U.S.A.	1 hr. 2 min. 30 sec.
12th ,,	,, ,,	,, ,,	1 hr. 15 min. 20 sec.
21st ,,	Wilbur Wright	Auvours	1 hr. 31 min. 25 sec.
29th ,,	Farman	Chalons	39 km.
30th ,,	,,	,,	41 km.
18th Dec.	Wilbur Wright	Le Mans	1 hr. 54 min. 22 sec.

The Wright brothers had made a very large number of flights in America previous to their appearance in France, but the author is not in possession of the details of these.

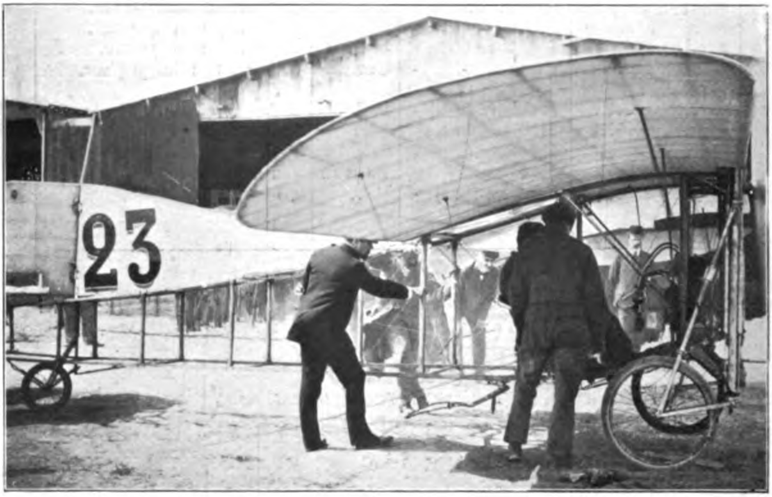
BIPLANE RECORDS AT RHEIMS, 1909.

Date.	Aviator.	Machine.	Achievement.
27th August -	H. Farman -	...	180 km., 3 hrs. 4 min. 56 sec.
25th ,, -	Paulhan - -	Farman	131 km., 2 hrs. 40 min.
26th ,, -	De Lambert -	Wright	116 km., 1 hr. 51 min.
27th ,, -	Tissandier -	,,	110 km., 1 hr. 47 min.
29th ,, -	Curtiss (Speed prize)	Curtiss	30 km., 23 min. 29 sec.
22nd ,, -	Tissandier (3rd)	Wright	30 km., 28 min. 59 sec.
29th ,, -	Curtiss (2nd) -	Curtiss	10 km., 7 min. $49\frac{2}{5}$ sec.
22nd ,, -	Lefebvre (4th)	Wright	10 km., 8 min. 59 sec.
Gordon Bennett race	Curtiss - -	Curtiss	20 km., 15 min. $50\frac{3}{5}$ sec.
,, ,,	Lefebvre (4th) -	Wright	20 km., 20 min. $47\frac{3}{5}$ sec.
Passenger prize	H. Farman (1st)	Farman	2 passengers, 10 min. 39 sec.
,, ,,	Lefebvre (3rd) -	Wright	1 passenger, 10 min. 39 sec.
Height ,,	H. Farman (2nd)	Farman	110 metres.
,, ,,	Paulhan (3rd) -	,,	90 ,,

These records are of particular interest in view of the enormous advance which was made in length of flight, feats of daring, and height attained during the short duration of the meeting. Such results can only be attributed to the keen rivalry between the aviators. It may be definitely stated that the Rheims meeting has given a very great stimulus to the art of aerial flight, firstly by demonstrating the fact that flight is not "the height of impossibility" as Mr Rolls has pointed out, and secondly, that it is a practical sport.

The results of the meeting are a great landmark in the science and sport of aviation, and as such are set down here. Since that meeting, as we all know, still more remarkable feats have been performed, as instance the daring displays of Latham at Blackpool and in France, also the notable flight of Count de Lambert across Paris and round the Eiffel Tower, during which flight he is credited with attaining an altitude of 350 metres, and the subsequent exploits of Paulhan and Curtiss in America.

Amongst British aviators four at least have already attained success, not including Mr Cody. First by a few days, Mr J. T. C. Moore-Brabazon succeeded in winning the *Daily Mail* £1,000 prize for a flight of a circular mile on 30th October on an all-British built machine. Mr Moore-Brabazon had already had considerable experience with his Voisin machine, shown at the first Olympia aero show, in addition to other machines in France; he, however, was anxious to fly a British machine, and his opportunities had been delayed whilst the machine was in course of construction. Messrs Short Brothers, who are the constructors in this country of the Wright biplanes, built the aeroplane, the engine being a 50-60 H.P. Green with cylinders 140 mm. bore by 140 mm. stroke, weighing without flywheel and magneto about 250 lb. Closely following upon this achievement the Hon. C. S. Rolls made some excellent flights on his Wright machine, also



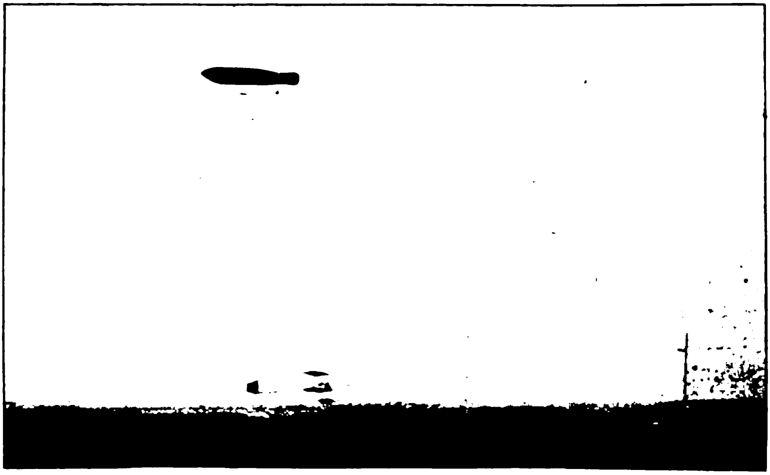
Aero photo.

FIG. 77.—Tuning up a Blériot Type XII. at Rheims.

at Shellbeach, covering a double circle of a mile and a half altogether two days after the previously recorded performance.

The same week-end Messrs Ogilvie and Searight took delivery of their Wright machine at the Shellbeach factory, and the author had the pleasure of assisting in the transport of this machine by road to their hangar near Rye.

Within a fortnight of that date the machine had been assembled and tested, and Mr Alec Ogilvie had made several flights, in a circular course of ten minutes' duration, over the beach.



Aero photo.

FIG. 78.—Renard Airship and Farman Biplane at Rheims, 1909.

Mr Claude Grahame-White, at the Blériot school, Pau, soon achieved success as an aviator, and made some extended flights on a Blériot XII. model, and subsequently both at Brooklands and Hendon demonstrated with a Blériot XI. that he was a master of the monoplane. He obtained the pilot aviator's certificate of the French Aero Club as a result of his performances.

RECORDS AND PROGRESS OF 1909.

Just previous to the New Year of 1909 Wilbur Wright made his official record for the Michelin cup in France. On 18*th December* 1908 he flew a total distance of 99·8 km., a world's record to that time, in 1 hour 54 min. 53⅖ sec.

At the beginning of *January*, Herr Grade on his monoplane flew short distances up to 400 metres at speeds of from 30 to 40 km. per hour.

Mr Moore-Brabazon also made a flight of 5 km. on a Voisin machine.

Mr Cody also made short flights, the greatest distance covered being 250 yds., the flight ending in disaster to his machine.

Blériot made a flight of 200 metres on his short span monoplane.

February.—On the 14*th* Farman flew a distance of 5 km. with a passenger.

Two days afterwards Guffroy, on an R.E.P. monoplane at Buc, flew 800 metres at a speed of 80 km. an hour.

On the 16*th*, also, Blériot increased his flight to 600 metres on Blériot XI., the short span machine, at Issy, and Demanest flew 400 metres at Chalons on an Antoinette monoplane.

The 18*th* saw Wilbur Wright, accompanied by Count de Lambert as a passenger, fly at an average speed of 70 km. an hour for four attempts at the measured kilometre.

On the 24*th* Mr Moore-Brabazon covered a circular kilometre at Issy on a Voisin biplane, and also in America the "Silver Dart" biplane flew ¾ mile in a straight line.

8*th March.*—On this day the "Silver Dart" flew 8 miles in 11 min. 15 sec., and on the following day Santos Dumont made a trip on his "Demoiselle" of 500 metres.

Goupy, on a biplane constructed by Blériot, flew 200 metres at Buc, and Blériot himself flew 1½ km. on his No. XI. machine.

The "Silver Dart" continued to make progress, and on the 11th flew 19 miles at Baddeck, Nova Scotia.

April.—In the early part of this month Latham flew at Chalons on Antoinette IV. over a kilometre. Wilbur Wright also made flights at Rome.

On the *8th* Santos Dumont flew 2½ km. across country at a height of from 60 to 70 ft. on the " Demoiselle."

19th.—Latham flew 1½ km. on Antoinette IV., and on the following day De Caters made three flights at Chalons on a Voisin machine, of about 1 km. each, and Rougier on a Voisin machine also made similar flights of rather less distance.

A record speed of 72 km. an hour was made by M. Demanest on Antoinette IV. at Chalons on the *29th inst.*

1st May saw Mr Moore-Brabazon transferred to Shellbeach, where his best flight was of 500 yds. distance.

21st.—Rougier was flying at Juvisy on this date and made eleven circuits of the course, in all about 30 km., on a Voisin machine. On this day, also, Demanest flew for 13 min. 23 sec. on the Antoinette machine.

On the following day Latham was out with Antoinette IV., and made a flight lasting 37 min. 37 sec. at a speed of 72 km. an hour, thus making a new monoplane record.

The same day and the following day Guffroy was busy at Buc, and finally made a flight of 8 km. with the R.E.P. No. 2 (*bis*) machine.

29th and *30th* were days of the Juvisy meeting, where a prize of 1,000 francs was won by the late M. Delagrange on a Voisin machine for his circular kilometre flight, which he made in 1 min. 40⅗ sec.

The late Captain Ferber carried off the 500 metre prize with his Voisin flight.

June.—In this month a prize of £4,000 was awarded jointly to Blériot and M. Gabriel Voisin for their great work in the development of flying machines.

The first remarkable monoplane flight was made on *5th June* 1909 by M. Hubert Latham with Antoinette IV. This flight broke all the French records up to that time for either monoplanes or biplanes, and was made at

Chalons camp. He remained in the air for 1 hour 7 min. 37 sec. at a height of between 15 and 40 metres. The wind was blowing at the rate of 15 km. an hour the whole time, and the rain poured down during the last twenty minutes.

On the following evening M. Latham made another splendid flight, having entered for the Ambroise Goupy prize for a cross-country flight of 5 km. Starting from Chalons camp at 7.52 P.M., he flew straight over the country for 5·9 km. in 4 min. 3$\frac{3}{5}$ sec. at a speed of about 50 km. per hour. He then turned round without coming to earth, and returned to his starting point, another record up to that time.

On *7th June* 1909 Latham made his first flight with a passenger, whom he carried 700 metres, and finally carried Mr Hewartson for 11 min. 57 sec., covering about 6 miles, although the wind was blowing in strong gusts most of the time.

The late Captain Ferber won the Archdeacon cup on the *6th* for his flight of 6·5 km. on a Voisin machine, and on the following day Blériot was out with his large machine No. XII., and carried a passenger for 600 metres at Issy.

Paulhan made his first noteworthy flight on the *9th* at Bar-sur-Aube on a Voisin machine, when he flew for 1 km.

The *12th* was a notable day, as Blériot succeeded in carrying two passengers on a straight flight in his large machine, and Latham made a long flight of 49 km. in 39 min.

Mr Cockburn appeared as an aviator on the *15th*, when he flew for 500 yds. on a Henri Farman machine at Chalons.

Curtiss has a recorded flight on the *17th* in America, where he is credited with a half-mile flight at a speed of 45 miles per hour.

On the *19th* Count de Lambert made a cross-country flight at Juvisy, when he flew for 12 min. 52 sec.

Blériot, Cody, Paulhan, and Farman were all in active practice about this time.

A new-comer in M. Jean Gobron made notable flights at Issy on the *26th* on a Breguet biplane, his principal achievements being flights of 10 and 15 km. at a speed of 70 km. an hour.

July.—Gobron continued his successes, and on the *2nd* carried two passengers for 5 min. in his machine.

On the *4th* Blériot flew the longest distance on that day at Juvisy when he was in the air for 50 min. 8 sec., and thus won Mme. Archdeacon's prize of 1,000 francs.

Captain Ferber also won a prize of 2,500 francs by beating Blériot's time for a 3 km. flight by 12 sec.

M. Roger Sommer, a successful new-comer, made his first flight of 6 km. on his new H. Farman biplane, and on the following day he flew for half an hour.

The *12th* was notable as the day Blériot made a splendid cross-country flight from Mondesir to La Croix-Biquet, 41·2 km. in 44 min.

Two days later Sommer made a cross-country flight from Chalons to Savenay and back.

On the *17th* Curtiss flew for 67·5 min. in America, and Paulhan in his Voisin biplane flew 12 km. at Douai; also Orville Wright flew for 12 min. in America, and again on the *20th* he flew for 1 hour 21 min., covering during that time about 50 miles.

The *18th* was a day of competitive flying at Douai, and Paulhan went for height and speed records. In the former he was successful in beating Wilbur Wright's record of 360 ft. by attaining a height of 490 ft. In the speed contest with Blériot he was beaten in the kilometre, his time being 1 min. 37 sec. to Blériot's 1 min. 9 sec.

Latham made his first cross-Channel attempt on the *19th*, when he traversed 6 to 8 miles, starting from Sangatte. The same day Paulhan flew from Douai to Arras, 13 miles, and then on another 6 km.

Cody was out on Laffan's Plain on the *21st*, and flew 4 miles, and the next day Paulhan covered 70 km. in 1 hour 17 min. 19 sec., with a Voisin biplane at Douai, and Orville Wright is also credited with a speed of 54½ miles per hour, at Fort Meyer, U.S.A., attained on the *22nd.*

Blériot made his historical cross-Channel flight on *25th July* from Les Baraques to Dover, a distance of 31 miles in 37 min. and thus won the *Daily Mail* £1,000 prize, and many other awards. Two days later Latham made his second Channel attempt, when he failed just before reaching Dover.

The *27th* was the date of the Vichy aviation meeting, when the following were winners of events:—

Tissandier covered 20 km. in 22 min. 55 sec., in his Wright machine; he also did the circuit of 1⅔ km. in the best time of 1 min. 52 sec., and totalled the greatest time in the air during the meeting of 1 hour 23 min.

Paulhan won a prize for his flight of 2·5 km. in 5 min. 1 sec., including twice crossing the River Allier.

On the *28th* Sommer put up a new record for time, remaining in flight for 1 hour 23 min. 30 sec., on a Farman machine, thus beating H. Farman's own record by half a minute.

1st August.—Sommer improved upon this by flying for 1 hour 50 min. on his Farman machine, and he made a cross-country journey of 9 miles in 12 min. on the next day. Again on the *4th* his duration of flight increased to 2 hours 10 min.

The late M. Lefebvre made a flight of 18 min. duration in Holland on his Wright machine on the *4th.*

De Caters and Bunau Varilla also flew on the following day for about a quarter of an hour, each on Voisin machines.

On the *7th* Paulhan was at Dunkirk, and made a flight of 1 hour 32 min. 45 sec.

Sommer on the same day made an unofficial duration record of 2 hours 27 min. 15 sec., thus beating Wilbur Wright's record of 2 hours 20 min. 23 sec.

M. Jean Gobron remained in the air for 30 min. on that day.

22nd to *28th* was the Rheims aviation week (see other table).

Cody made a flight of 8 miles across country on the *28th*, and flew for 1 hour 3 min. on *1st September*, rising to a height of 300 ft.

Aero photo.

FIG. 79.—M. Lefebvre standing on his Wright Biplane just before his Fatal Accident.

7th September was a sad day in the annals of aviation, as M. Lefebvre, who had shown such remarkable skill at Rheims, was fatally injured by a fall in his Wright machine at Juvisy.

13th.—Santos Dumont flew across country in the

"Demoiselle" from St Cyr to Buc, 5 miles in 5 min., and returned the next day.

18*th*.—Orville Wright carried a passenger in his machine for 1 hour 35 min. 47 sec.

Paulhan was at Ostend on that day, and won a prize of 25,000 francs for the hour flight.

Santos Dumont beat Curtiss' record for rising in the shortest distance, when he got off the ground after 70 metres' run, beating the previous distance of 80 metres.

Captain Ferber was fatally injured on the *22nd* by a fall in his Voisin machine at Boulogne. He was one of the earliest experimenters, and had spent many years in investigation of aeronautical matters. He flew under the name of "de Rue."

2nd October.—The Crown Prince of Germany was taken for a short flight by Orville Wright at Berlin. Mr Wright afterwards reached an altitude of 1,500 ft. in his machine.

The Doncaster meeting was held from 15*th to* 23*rd October*, and the Blackpool meeting from 18*th to* 23*rd October*. The latter meeting is chiefly marked by the daring flight of Latham in a gale of wind. These two, the first aviation meetings in England, were much marred by bad weather.

The 18*th* was marked by a splendid flight by Count de Lambert in his Wright machine, when he started from Juvisy, and flew over Paris, encircling the Eiffel Tower, and returning to the starting point.

On the 20*th* Maurice Farman made a flight on a new machine built to his own design, when he covered a 12-mile circuit in the vicinity of Buc, remaining in the air for 55 min.

The first lady aviator, Baroness La Roche, made a flight at Chalons in a Voisin machine on the *22nd*.

On the 27*th* H. Farman made a duration flight of 4 hours 17 min. 35 sec. at Chalons, covering a distance of 137 miles.

30th.—The *Daily Mail* £1,000 prize for the first circular mile flight by a British subject on an all-British machine was won by Mr Moore-Brabazon at Shellbeach. On the same day Paulhan made some splendid flights at Brooklands, one of an hour's duration, when he attained heights of 600 and 720 ft. The following Monday he flew 95 miles in 2 hours 49 min. 20 sec.

1st November.—The Hon. C. S. Rolls won the Salomons 100 guinea cup for a circular flight at Shellbeach.

Paulhan made a high flight of 977 ft. at Sandown Park on the *6th.*

Aero photo.

FIG. 80.—Comte de Lambert's "Wright" Biplane before and after an Accident.

Henry Farman made a new French passenger record on *1st November* at Chalons, his flight lasting 1 hour 16 min. 35 sec., and followed up this achievement two days later by a duration record of 4 hours 17 min. 35 sec., covering 150 miles in all, which remained unbeaten at the end of the year, thus entitling him to receive the Michelin cup.

Maurice Farman made a cross-country flight on his machine on the same day, and was in the air three-quarters of an hour in the vicinity of Buc.

Herr Grade was rewarded with success, and incidentally the Lanz prize of £2,000, after a long spell of patient work. 30*th October* was the actual date of the flight, when he covered a figure-of-8 course round two posts placed 1 km. apart. His monoplane is of entirely German make, and on the 31*st October* he made several flights lasting just under 5 min. each.

Hon. C. S. Rolls, on 4*th November*, won the first Aero Club £50 prize for a circular mile flight at Shellbeach on his Wright machine.

Mr A. Ogilvie, on his Wright machine, made his first successful flight on the 10*th November*, at Camber, near Rye.

Lieut. Engelhardt, one of the German pilots of a Wright machine, made a trip lasting 1 hour 53 min. at Bornstedt on the 5*th*, and only came down on account of his petrol supply being finished.

Mme. de la Roche made a flight on a Voisin biplane fitted with a Wolseley engine, taking as a passenger the Voisin instructor, M. Chateau. She made several circuits of the Chalons camp, and was in the air for 35 min.

The Hon. C. S. Rolls made some long flights on his Wright machine at the end of November. On the 20*th* he made a trip from Shellbeach to Eastchurch, a distance of 5½ miles, and followed this flight by one of 7 miles on the 26*th*.

Latham made a bid for the altitude record on 1*st December*, in spite of a wind of 30 miles an hour blowing. He was in the air for 32 min., and attained a height of 1,500 ft., officially observed as a world's record. Paulhan's 600 metre height was not officially observed.

M. Chateau, the Voisin instructor, has made several good flights with the Wolseley engined Voisin machine in which he accompanied Mme. de la Roche. On 27*th November* his longest flight was 49 min. 35 sec.

Herr Grade improved his performances by flights on 23*rd November*, lasting up to 5 min. each, and at one time he rose to a height of 140 metres.

During the early part of December British aviators obtained more satisfactory results.

Mr A. V. Roe at last succeeded in leaving the ground at Wembley on his triplane. At Eastchurch Mr Rolls made a journey of 20 min. duration, and Mr Ogilvie at Rye made several flights of 15 min. in his Wright machine.

A fatal accident occurred to M. Fernandez on *6th December* at Nice. He was flying a biplane of his own design, shown at the recent Paris Salon. The machine suddenly stopped in the air and fell from a considerable height, throwing out the aviator, who was instantly killed.

Aero photo.

FIG. 81.—Mr A. V. Roe's Triplane at Wembley.

Mr Neale made a flight on the *5th* the length of the Brooklands straight on a Blériot machine; he had previously made several short flights. He attained a height of about 15 ft. and landed quite easily.

On *9th* and *13th December* Mr Claude Grahame-White made several good flights on his large two-passenger Blériot monoplane at Pau. He was able, owing to ample engine power, to control the machine from the first He flew round the track five times on the 13*th*, rising to a height of 30 metres. The next day he made an officially observed flight twice round the course at a height of 70 metres.

M. J. de Lesseps made a remarkable flight for a beginner at Issy on 16*th December*, lasting 1 hour 30 min. 28 sec., it being only his fourteenth time out with his Blériot monoplane; this was a record flight for a machine of this type at Issy. He covered 7 km. in 12 min. the previous day. On the 21*st* he attempted a cross-country flight of 100 km., but after covering 6½ km. he had trouble with his engine and made a rapid descent.

Paulhan, on the 15*th*, made a remarkable weight lifting performance with a new Henri Farman biplane. Although the machine is smaller than his older machine he carried two passengers, weighing together 330 lb., also 10 gallons of petrol.

Molon, on the 19*th*, near Havre, made a number of flights on a Blériot monoplane, totalling a distance of 60 km. across country.

Koechlin, at Juvisy, showed marked improvement with a monoplane of his own design on the 16*th*, when he flew round the course ten times.

Mdlle. Marvingt is the first woman to pilot a monoplane. On a Hanriot machine at Rheims she made a successful flight on the 14*th*.

M. Metrot, a new-comer, has had much success with a Voisin biplane at Algiers. He made a cross-country trip on the 15*th* as far as Bilda, 3 km. distant, and making a wide sweep at a height of 150 metres, returned to his shed after a total flight of 20 km. He had previously raced and beaten an express train for a distance of 7 km.

Hon. C. S. Rolls made his best flight during the year on the 30*th inst.*, when he started from Eastchurch, Kent, and with one stoppage covered in all about 48 miles. He was flying for about an hour. Later in the day he made a second flight on his Wright machine, carrying a passenger, for about 20 min.

Mr M'Clean made his first cross-country flight of about 4 miles on the same day. An illustration of his Wright machine is shown in Fig. 71.

Several aviators made attempts to wrest the Michelin cup chances from Farman during the last week of the year, and though several notable performances were made, Farman's distance record remained unbeaten, and thus left him entitled to receive the cup he so well deserves. The late M. Delagrange made the boldest challenge on a Blériot monoplane when he covered 125 miles in 2 hours 32 min., representing an average speed of 50 miles per hour, a truly noble performance and a sight well worth seeing.

The world of sport suffered a severe loss by the fatal accident which terminated the brilliant performances of this daring aviator a few days later—he had fitted a 50 H.P. Gnome engine to his Blériot machine and was thus able to attain a high speed of flight. During one of his performances the sides of the fusilage collapsed owing to the absence of the cross strut between the rear main spars of his lifting planes, the machine fell to the ground with fatal result.

The fatal accident to Le Blon at St Sebastian on 2nd April 1910 was occasioned by a fall of the same machine on which Delagrange was killed. Le Blon's flights at the Doncaster meeting in October 1909 were his chief public performances.

On the last day of the year Maurice Farman made a cross-country flight from Châtres to Orleans (47 miles) in 50 min.; thus ended a series of the most remarkable conquests ever made by man over Nature, and it may be that the year 1909 will go down to posterity as the beginning of a new era in the art of aviation.

CHAPTER XV.

THE ART OF FLYING.

IF flight is ever the height of impossibility at the present time, it is simply because the correct method of attacking the problem is not realised. One cannot learn to ride a bicycle on land, or to swim in the water, simply by a theoretical study of the laws of balancing, or of stream-line form. Practice is the only road to success, and more is this true in the case of flight than in many other sports.

Take boxing, for instance, or wrestling. Great knowledge is required as to the efficacy of certain grips or stresses upon the human system produced by specific acts on the part of the athlete. Some knowledge of the human anatomy is required, and the weak points of the same, so that advantage may be taken of any position in order to score a point.

In the sport of aviation, however, although mastery of the air is only attained by very few, several of these successful aviators do not claim any special knowledge of the science of aeronautics, and it is practice and perseverance which have led them on to obtain this mastery of the art of aerial navigation.

Practice, however, is more unattainable in this art than in any other, because it cannot really be accomplished until the machine is actually in the air. The periods of early practice are limited, therefore, to a second or two at a time, and in the early stages a flight of one minute, as the reward of a month's hard work and endeavour, would appear to be somewhere about an average attainment. When we look back to the early work of the Wright brothers, we find that during a period of several years the total time they spent in the air could be counted in minutes only. The 1902 season, in which they made their most successful glides, enabled their proficiency to be increased to such an extent that glides lasting as long as twenty-six seconds were accomplished, and during their most satisfactory period of six days as many as 375 glides of various distances were accomplished. There is no doubt that the best method of obtaining practice is by gliding, and both Messrs Rolls and Ogilvie in this country put in some very good work with gliders.

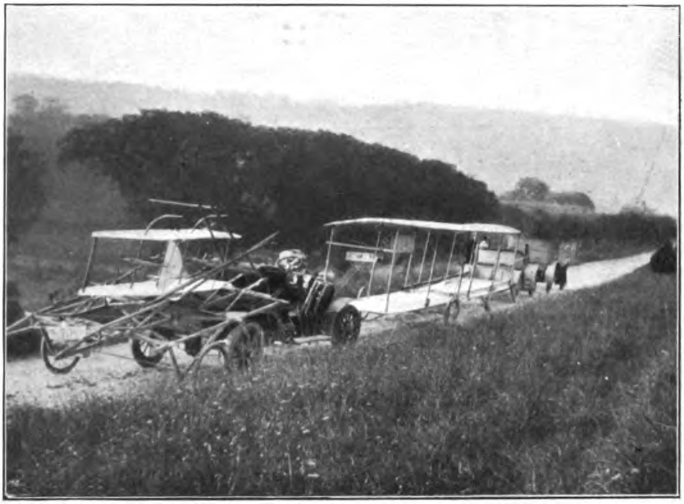


FIG. 82.—The Glider was Conveyed Seventy Miles in the Early Morning—Arrival at the Flying Ground—the Author's Car towing the Outrigger and Supplementary Planes.

Mr Ogilvie's glider was made by T. W. K. Clarke, of Kingston, to the designs of the Wright brothers, by their special permission, and a number of views of this glider are given in this book, showing the early stages of the gliding experiments.

It is difficult to imagine the extraordinary loss of one's sense of will power during the early attempts at flight. Mr Rolls has described the initial sensations as those received in driving a motor car which is skidding in all directions at once. In addition, however, to the ordinary tendencies to movement, there are the third and fourth directions, *i.e.*, upwards and downwards, and the human brain is not normally made to think in these extra two directions. Thinking, therefore, is too slow; the transmission of ideas from the brain to the limbs has not been tuned up to the great pitch required for manipulating an aeroplane. What is it, therefore, that impels the limbs to perform their proper functions in order to keep the machine on an even and straight course? We have only one word which describes that power, and that is "instinct," or put in another form, it is "subconscious movement." We now see why the control of so many machines is arranged so that this

FIG. 83.—Special Temporary Hangar for Biplane Glider. This Machine has a Span of 33 ft.

subconscious movement on the part of the aviator directly operates the balancing mechanism. There is no time to think, especially in the early stages. Not only is there no time to think, but memory disappears. You may ask, "What did you do then?" The aviator does not know, and unless the observer notices the movement of the hands, or takes photographs, no record is obtained as to what was the false movement which caused the machine to slew round or come to the ground. The control of the hands, too, is a difficult matter, as a spar may unconsciously be clutched in mistake for an operating lever, or the elevator be raised to such a degree that the machine climbs up in the air, loses its velocity, and falls back on its tail.

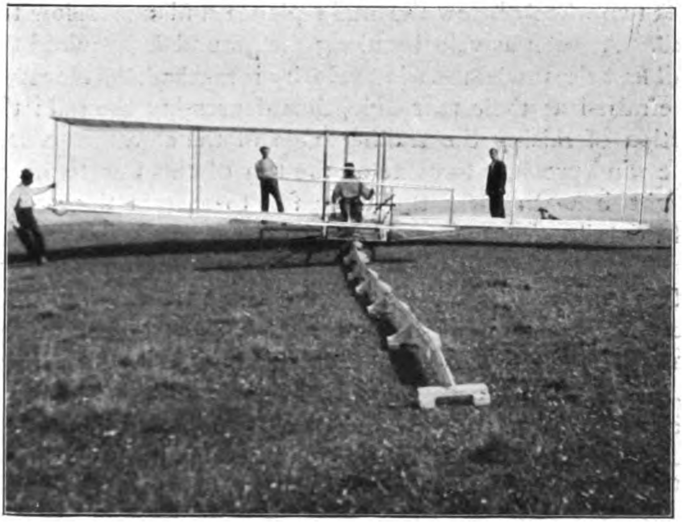


FIG. 84.—Biplane Glider and Starting Rail.

This is a very usual performance in the early stages and one to be carefully guarded against, it is analogous to putting a motor car at a stiff hill when in the top gear before the driver has learned to change gear downwards.

It is worse than that, because a flying machine cannot fly backwards.

When a machine rises from the ground, preferably towards the wind, whether it be from a rail or not, its path of flight should be a gradual upward inclination, but this is most difficult to accomplish owing to the keenness of the elevator, the tendency always being to give the elevator too great an angle of incidence.

Take the case of a monoplane first, the machine perhaps has two wheels below the main planes and one below the tail. As soon as velocity along the ground is acquired the tail first rises; when soaring velocity is reached, the elevators are raised at their rear edge, thus depressing the tail; the action of raising the trailing edge of the elevators causes the wind pressure to come on the top of them or to be so slight beneath them that they fail to sustain the weight of the tail.

The effect of this is to increase the angle of incidence of the main planes, which in turn rise in the air, the tail continuing to run on its wheel for a short distance until the whole machine is supported by the air. In the Wright type of biplane the elevator being in front is kept level, thus keeping the fore part of the machine down until the critical velocity is reached, *i.e.*, when the machine leaves the end of the rail (when a starting weight is used) or just before that point when starting by the propellers alone. At this moment the front edge of the elevator is raised and the trailing edge consequently lowered a very small amount, thus causing the machine to mount in the air.

Now the difficult point comes in. At this stage perhaps the maximum velocity of flight has not yet been reached, and care should be taken that the rising angle is small, otherwise the power of the engine, which may not have yet reached its maximum, would not be sufficient to cause the machine to ascend an inclined path at the soaring speed. If the speed of flight is reduced by the increased resistance the whole machine will slide back in the air. Suppose

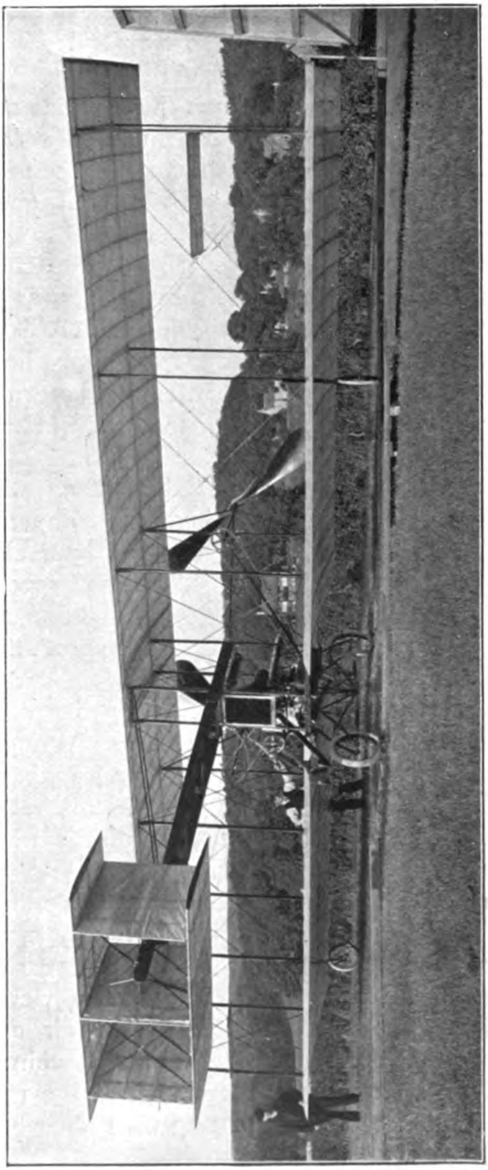


FIG. 85.—Barnwell Biplane ready for a Trial, which ended in Disaster after a Flight of 80 yds.

that the machine has just left the rail and the elevator is put up at too great an angle, the rear end of the skids might drag along the ground, and if they do not break off, would cause so much resistance that the machine could not attain its normal soaring speed. When starting the Voisin machine, which has a large tail, another consideration comes in. The tail being comparatively light tends to lift before the main planes, and if allowed to do so the whole machine may turn up on its nose. In order to counteract this tendency the elevator must be raised so as to keep sufficient pressure underneath it; the moment of this pressure about the centre of gravity of the machine must be at least equal to that of the pressure under the tail planes about the centre of gravity of the machine, or the tail will rise unduly in the air.

Mr Moore-Brabazon describes the feeling when the machine leaves the ground as being almost imperceptible, and that whereas a speed of 30 miles an hour along the ground appears to be very great, that same speed, when clear of the ground, seems quite a gentle motion, and that when no objects are near to indicate the speed, the sense of motion is almost lost.

The difficulty as to approximating the degree of relative motion is a very real one, and a persevering aviator resorted to the precaution of attaching a hanging ribbon from his elevator so that he might ascertain readily his direction of motion relatively to that of the wind. He found this a most useful indicator.

Another consideration must be borne in mind when learning to pilot a monoplane of the Blériot type, and that is the effect of engine torque. As the engine rotates in a right handed direction from the point of view of the pilot, the left wing tends to rise in the air owing to the depression of the right side of the machine. The aeroplane when in motion tends to turn to the right, and this must be counteracted by putting the rudder hard over to the left.

The aeroplane answers comparatively slowly to its control, with the exception perhaps of the Wright machine which has no tail, all control movements must, therefore, be very gentle as the behaviour of an aeroplane is more like that of a boat than of a motor car. The action of the elevator has been described and is perhaps the most difficult of the controls to manipulate, in that it requires the exercise of a new sense. The rudder, however, is a more familiar type of control, and in action is similar to the rudder of a boat.

Regulation of the centre of pressure is obtained, as far as longitudinal direction is concerned, by use of the elevator, but laterally by *ailerons* or warping of the planes. In the Voisin machines, where neither of these provisions is made, the rudder has to be utilised so that the velocity of the air under the falling side can be increased by turning the machine.

The static balance of the machine should be carefully tried before commencing to fly, and particularly that of the biplane of the Wright type, in which the engine is placed beside the aviator. When provision is made for carrying a passenger, his seat is placed on the centre line of the machine, so that his presence or absence does not materially affect the question of lateral balance. As men are not all of the same weight, in cases where the aviator only partly balances the engine about the centre line, if his weight is insufficient for the purpose, weights should be placed on the wing tip at the lightest end until true balance is secured, otherwise a permanent *gauchissement* is required at that side in order to keep the machine on an even keel.

CENTRE OF GRAVITY AND CENTRE OF PRESSURE.

In aeroplanes fitted with tails the centre of gravity is usually in the vicinity of the trailing edge of the main planes, and, of course, should be on the centre line of the machine. The centre of gravity of the aviator on a monoplane should approximately coincide with that of the machine, if this is not the case the stabiliser or elevator must be permanently set to produce longitudinal balance. Much downward set or increase of angle of incidence of this tail member will create undue resistance to flight, and should be avoided where possible by putting the weight further forward. The centre of pressure should coincide with the centre of gravity, and balance will result (see p. 15).

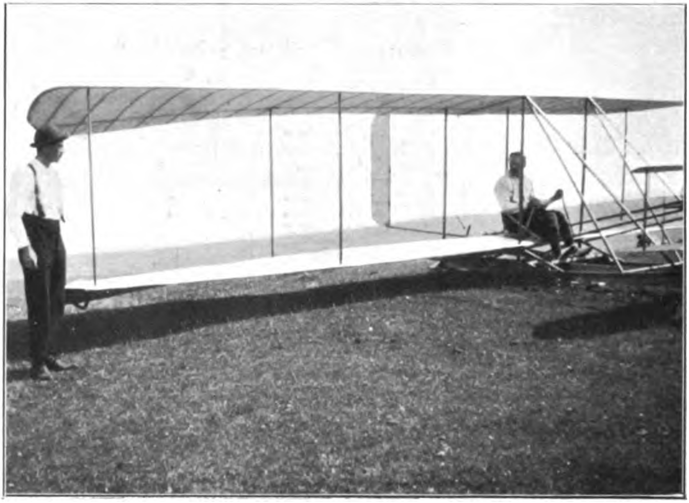


FIG. 86.—Biplane Glider showing *Gauchissement.* The Author and Mr A. Ogilvie testing the Balance.

Now although the centre of gravity remains approximately constant, the centre of pressure is continually varying and is never constant for many seconds. The centre of pressure upon an aerocurve constructed to Phillips' design is about one-third of the length of the chord from the leading edge of the plane under normal conditions, *i.e.*, when the angle of incidence is about 8° between the direction of motion of the plane and that of the air.

Immediately this angle is increased the centre of pressure moves towards the rear, and *vice versa* when the angle is decreased up to a critical value, so that either the centre of gravity must be moved to coincide with this new position or the centre of pressure must be artificially restored by the use of supplementary damping planes or elevators, moving in a contrary direction. A forward movement of the centre of pressure tends to lower the tail of the machine, when the intensity of the pressure is unchanged, and to counterbalance this a rear elevator must have its angle of incidence increased in order to increase the lift at the rear of the machine, or it will slide down backwards.

The alternative to be adopted in the case of temporary lack of engine power is to decrease the angle of the elevator and allow the aeroplane to swoop downwards and thus gain momentum. The increase of speed will then probably be sufficient to enable the machine to continue in horizontal flight, when the centre of pressure is again restored to its normal position.

Gauchissement.—An increase of lift imparted to one wing of the machine is produced by increasing the angle of incidence of the whole or part of the wing or by an increase of pressure under that wing, and will tend to cause that side of the machine to rise, and the other side to lower, the result being that the machine will be liable to slide through the air diagonally. In the majority of aeroplanes there are no curtains or fins to counteract this movement, and lateral stability must be restored by artificially increasing the lift of the depressed wing. This can be done by *gauchissement* or lowering the trailing edge of the depressed wing, increasing its lift, and simultaneously raising the trailing edge of the other wing, thus decreasing the angle of incidence of the latter, and reducing its lifting effect. This applies to flight on a straight course whatever the cause tending to upset the lateral stability. It will be seen, therefore, that the centre of gravity remains constant, and the centre of pressure must be manipulated to restore stability. This manipulation is much more rapid and positive than the alteration of the centre of gravity by movement of the aviator's body resorted to in the early gliding experiments of pioneer aviators.

Turning.—When turning is desired the same train of thought must be followed, but it is obvious that when a turn is actually commenced by means of the rudder, the outer wing moves at a greater velocity relative to the air than the inner wing. Owing to this increased velocity, the lift of the outer wing becomes greater than that of the inner wing; the former, therefore, tends to rise, and the latter to fall. If this is not corrected, the machine as a whole will bank up excessively and in the limit will slide down on the air in a diagonal direction. This is a very perilous condition for the aviator, and must be guarded against, by manipulating the *gauchissement* so as to increase the lift on the inner wing of a biplane. (NOTE.—Great care must

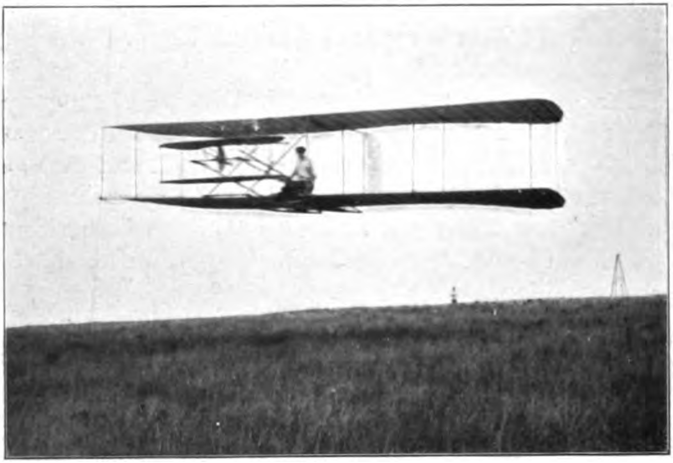


FIG. 87.—Mr Ogilvie in Flight on his Glider, notice the *Gauchissement.* The Starting Pylon is seen in the Distance.

be exercised with a monoplane, as warping the inner wing tends to drag the whole machine downwards, and not to raise the inner wing. Several bad accidents have occurred owing to monoplanes refusing to respond to the warping of the inner wing when making a turn. In such machines the rudder must be judiciously used to bring the machine up on an even keel if such a condition is required.)

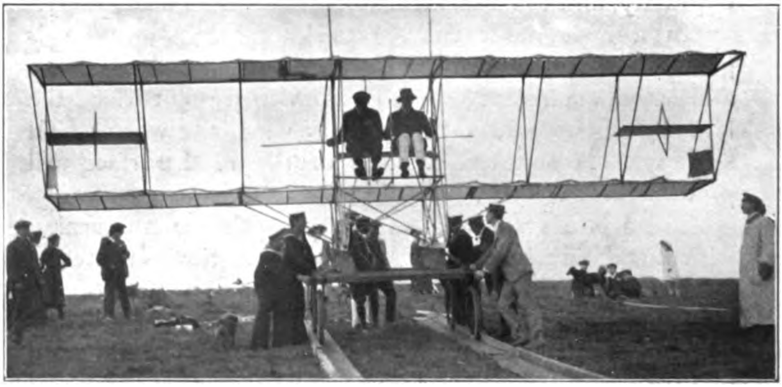
Owing to the absence of side curtains or fins in many instances, lateral resistance must be obtained, otherwise in the act of turning, the machine, if kept on an even keel, will tend to skid through the air and turn about its centre of gravity, and to emphasise this, we will take an analogy.

In a boat the resistance to lateral displacement is great, as compared with that in a longitudinal direction, and so with a motor car, though on a greasy surface the lateral resistance may be small, as when the wheels skid sideways. A suitable banking of the road surface will prevent this skidding.

There is a great deal of misconception as to turning with a machine in which there are no vertical surfaces or fins, and many authorities maintain that banking of the machine is *only* the direct effect of the turn. It is obvious that in order to make a turn, some force must be imparted to the machine to counteract the effect of the centrifugal force upon the machine as a whole, and as the sidewise projection of the machine is only of small area a component force must be introduced. This can only be done by previously banking up the machine on the outer wing, so that the pressure of air under the main planes can counteract the tendency to lateral displacement. The force now acting under the planes is in a diagonal direction, and the angle at which it is inclined to the vertical depends on the banking of the planes, it being normal to their greater dimension.

Now this force can be resolved into two forces, one perpendicular, and one horizontal, the magnitude of each being dependent upon the degree of the banking. When the speed of the machine is higher, the amount of banking must be greater in order to increase the value of the horizontal component in proportion to the increase of the value of the centrifugal force at the higher speed, in spite of the fact that the forces acting *under* the plane are also greater due to the higher speed.

As the curve commences, the rudder being put over, the differences of the pressures on the two wings owing to their different flying speeds comes into account as has been already explained, and care must be taken that the banking does not increase abnormally. When the turn is completed, the rudder is straightened and the machine again brought to an even keel by means of *gauchissement* or the *ailerons*.



Aero photo.

FIG. 88.—Naval Glider.

The effect of a reverse of *gauchissement* to prevent excessive banking, lowering the inside wing tip, incidentally puts a slight drag on that wing and assists the action of turning, as does also the provision of small vertical planes between the front elevators of a Wright machine.

In making a turn, say, to the left, the following is the method of procedure. The outside or right-hand wing is first raised by lowering the *aileron* on that side, the rudder is then put over to the left. When the correct banking is acquired, the *aileron* is returned to its normal position, and probably the left *aileron* must be lowered slightly, to increase the lift on the inside wing, owing to its reduced speed. When the turn is completed, the rudder is straightened out and the left *aileron* lowered to return the machine to an even keel.

M. Esnault-Pelterie manages ordinary manœuvring by means of *gauchissement* only and without the use of the rudder. Such a form of control has also been demonstrated by Curtiss in America, who made an exhibition flight with his rudder tied up.

Turning in a Wind.—Two velocities must be borne in mind, that of the machine relatively to the air, and that relatively to the earth. The former is limited at its lower value to the flying speed of the machine, and the latter must be considered on account of the momentum of the machine as a whole. Change of momentum is a matter of horse-power and time, and it is this that is the ruling factor in flying in a wind on a circular course.

Suppose the flying speed of a machine is a minimum of 30 miles an hour relatively to the air, and a wind of 20 miles an hour is blowing. The actual speed of the machine relatively to the earth in flying against the wind will be 10 miles an hour.

If it is desired to turn down wind, the speed of the machine relatively to the earth must be increased from 10 miles an hour to 50 miles an hour relatively to the earth during the turn—and a corresponding change of momentum must be overcome. There are two ways of accomplishing this, either by opening up the throttle to give maximum power or by rising in the air previous to turning and swooping down as the turn is made, thus utilising the acceleration due to gravity to assist the motor. The wind velocity will assist the machine also, as during the turn she will make considerable leeway, a small amount of which must be deducted to counteract the centrifugal force of the machine.

Turning in the contrary direction requires considerable skill, as when flying at 50 miles an hour the tendency on rounding the corner into a 20 mile an hour wind would be for the machine to rise up rapidly in the air. The centrifugal force, too, at these speeds is considerable, causing the machine to make much leeway with the wind during the turn. Turning under these circumstances should be commenced early, particularly if there are objects in the vicinity, and considerable skill should be acquired before an attempt is made to fly in such a wind.

FIG. 89.—Mr Ogilvie makes a Fine Glide.

Early flights should be commenced when the air is practically still, as it will be seen that difficult problems present themselves when a wind is blowing, particularly with heavy machines, and in cases where the engine power is comparatively small.

CHAPTER XVI.

FUTURE DEVELOPMENT.

HE would be a wise man indeed who could predict with any degree of accuracy on what lines the future development of aerial navigation will extend. Such enormous strides have been made in the year 1909, that during the next five or ten years, at the same rate of progress, performances which are almost inconceivable at the present time, may be everyday occurrences then. Authors of imaginative genius have given us food for thought, and some of their conceptions which appeared to be totally impossible at the time they were written have already become accomplished facts. Even the comparatively small practical experience of flying which we now have must have instilled ideas into our minds as to what direction should be sought in the future. The possibilities of aerial navigation, too, become greater the more we study the question.

As regards the development of the flying machine itself, the opinions about to be expressed are only those of the author, and are quite open to contradiction or argument, and are, moreover, in no way given as dogmatic or irrevocable.

Power.—The first consideration is one of power, and I sincerely advocate the adoption of prime movers of considerably higher power than those usually in vogue to-day, these will probably be in duplicate. The great difficulty which the learner experiences is the lack of sufficient power, which makes itself manifest in the inability of the machine to rise from *terra firma.* We find that when a machine attempts to rise too quickly as when its angle of flight is too great, owing probably to a false manipulation of the elevator, the engine power is insufficient to maintain a flying speed. The machine, therefore, falls to the ground, or a second manipulation of the elevator, in time, prevents an actual fall, and reduces the performance to a rapid glide to earth.

Had sufficient power been available at the command of the aviator, this would not have occurred, and a continued flight would have been possible.

Many modern flying machines are fitted with engines so small that they cannot rise from the earth unless the engine is tuned up to give its maximum output. As the internal combustion engine is somewhat fickle in this respect, it becomes apparent why an engine of ample dimensions should be fitted.

Source of Power.—The source of power will be, as at present, a petroleum distillate, probably petrol, as we now know it.

Benzol, or alcohol, may be used in a few instances, or perhaps compounded fuels with these bases. Petrol, however, is the most convenient, it has a large explosive range, and is clean in handling.

Greater precautions against fire risks will have to be taken, and more attention paid to the economy of working.

The consumption of fuel will probably be reduced to below 0·4 pint per B.H.P. per hour, and as the weight of fuel to be carried for extended flights would be considerable, the probability is that arrangements will be made for picking up supplies of fuel in cans without alighting, but more on this point anon.

More attention will be paid to carburation in order to economise fuel, not on the score of expense so much, but on account of the weight of the fuel; devices will be utilised to alter the carburation to suit the varying atmospheric conditions such as temperature, density, and humidity.

Gyroscopic control will probably be introduced and arranged in such a manner that it can be readily disconnected at will.

Ignition will invariably be in duplicate, and I have every reason to believe that at least two magnetos will be employed in conjunction with high tension distributers in duplicate. These magnetos will be either encased in a complete external magnetic field, or other similar arrangements adopted to prevent their affecting the compass which will be carried on every flying machine.

Other instruments will be carried to indicate the speed of the machine relatively to the air and to the land, a special aneroid to determine the height of the machine above sea level which can be set to read directly the height above the surrounding country by a momentary reference to a chart.

An engine or propeller revolution indicator will also be fitted, and probably a gradometer or similar instrument to read the angle of the flight path.

Probably also an instrument will be devised which can readily be set so as to enable the aviator to drop an object on to any desired spot, this will combine readings for altitude and speed of flight relatively to the earth, and make an allowance for any wind velocity.

A convenient form of field glasses will also form part of the equipment of the future flying machine, and a means of universal signalling by day and night will become a *sine qua non.* Special maps will be produced, and the country landmarked, probably the different counties will have special indications in the form of large structures, and it has been proposed that some notation such as that used for the county index marks of motor cars will become generally adopted.

Flying at high altitudes will have to be facilitated by some such means as these, in order that the aviator can locate his position. Balloonists have repeatedly found great difficulty in ascertaining their whereabouts, particularly after descending through a cloud bank.

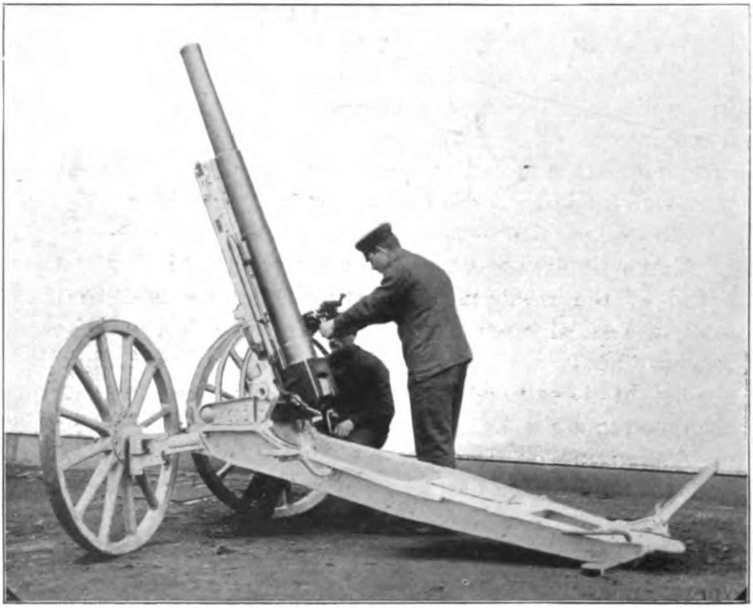


FIG. 90.—6·5 Centimetre German Gun for Attacking Aeroplanes.

Aviators.—We now see how essential it will be for at least two aviators to be accommodated on each machine, especially for cross-country work. It will be the duty of one to manipulate the machine, and that of the other to navigate. The former will have sole command of the controlling mechanism, and the latter will attend to the engine, in addition to his other duties of observation.

I think that more than two men will form the crew of the future flyer, and that passengers will be carried, in the first instance in order to perform special work, such as location of troops and defences, and also to make rough sketches and take photographs of the country.

It is probable that some form of wireless telegraphy will be adopted for military work in conjunction with flying machines, and it would be the duty of a third man to operate these instruments. He may also be required at times to act on the offensive, such as to alight at any desired spot and cut telegraph wires, or destroy a bridge. It is doubtful whether aerial bombardments could be satis-

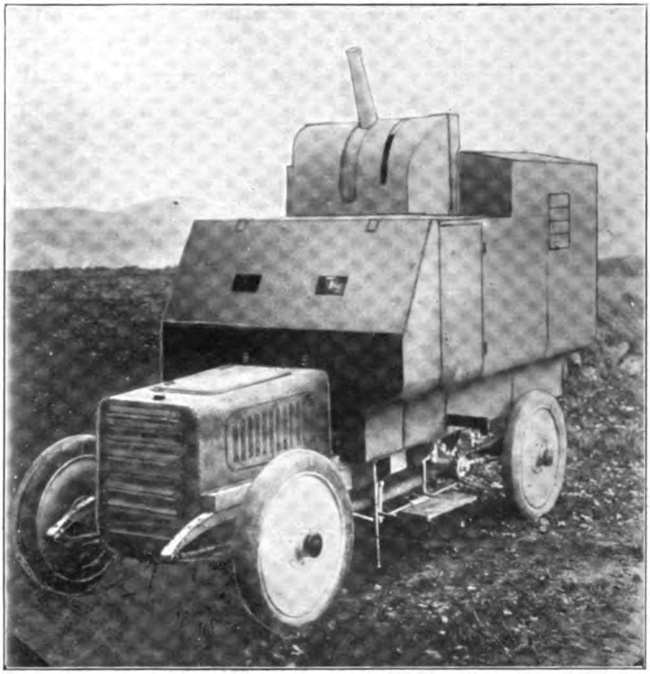


FIG. 91.—German Military Motor Car for fighting Airships and Aeroplanes.

factorily carried out, as the explosive range of a bomb such as could be dropped from a flying machine is usually very small, and confined, therefore, to a small locality. The difficulty of aiming the bomb would be very great when dropped from such a height that the flying machine would be out of danger from either the explosion of the bomb itself or from the guns of the enemy.

The use of the flying machine in warfare has already been anticipated in Germany in a practical manner, and a number of aeroguns have been constructed which have an enormous range; several examples are shown in Figs. 90 to 94.

Future uses of flyers, in addition to those of warfare, will be in the exploration of unknown lands. Where no roads exist, and dense jungles and swamps separate the explorer from his goal, the flying machine offers great possibilities. Difficult mountaineering country can be successfully explored from the region of the atmosphere, and the rate of progress will be beyond our present conception. Work that has in the past taken years to accomplish will be a matter of a few days by the help of the flying machine. The motor car has been of enormous benefit in spreading civilisation and bringing colonists in out-of-the-way parts of the world into touch with one another. What the motor car has done the flying machine will also do, but in a somewhat different manner. I cannot foresee the time when the ordinary man will keep his flying machine as he does his horse, but in certain parts of the world where the weather is more settled than it is in this England of ours, and where the wind blows steadily and not in gusts, flying will become a much simpler matter than it is here to-day.

Engines.—The depreciation of the 1909 flying machine is enormous, the life of the engine is seldom more than 200 miles, in some cases it is a very few miles indeed, and breakdowns or seizures are a constant evil. These are a passing phase; the motor car engine was so once, but now we have these engines running for 50,000 miles with no perceptible wear and tear. The engines now suffer from the craze for lightness, the machine of the future will not suffer from this cause. If the reciprocating engine as now understood still has the mastery of the field, it will be heavier in its working parts, and the lubrication system will

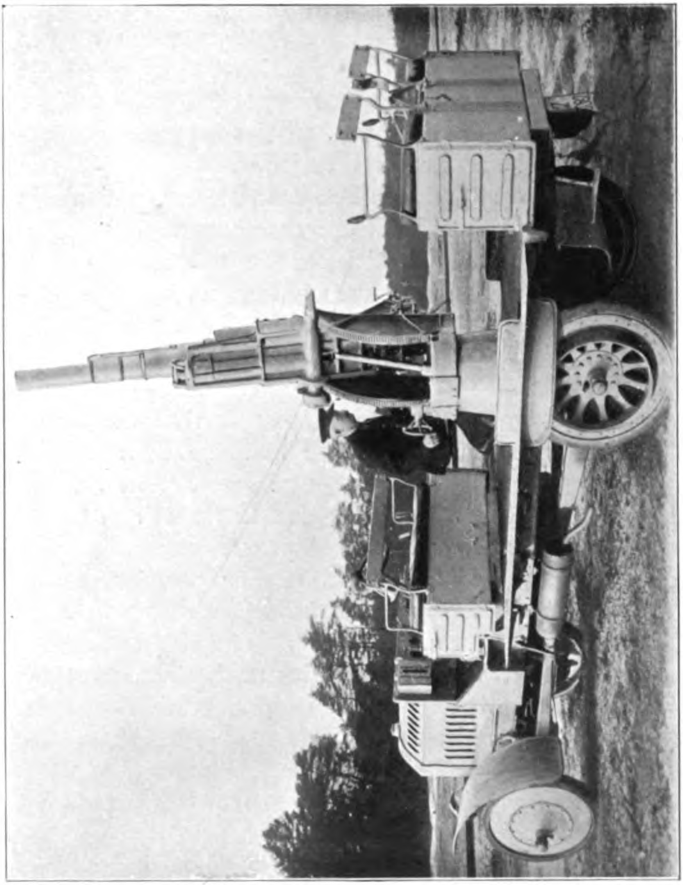


FIG. 92.—7·5 Centimetre German Automatic Gun for Attacking Airships.

be very greatly improved, a more positive system will be adopted than at present. I foresee an entirely different type of engine, which will be rotary, and if not of the piston type, we shall see the internal combustion turbine predominating.

I know that the difficulties are very great, but do not think them insurmountable. Many inventors have been engaged for years upon this subject, and I fully believe that the day is not far distant when the internal combustion turbine will be an accomplished fact.

Its advantages will at once be apparent, and particularly as far as the lubrication difficulties are concerned.

I only wish I could anticipate the advent of a concentrated fuel for use with such a turbine, but the probability of such a useful, desirable adjunct seems remote.

Conclusions.—From the foregoing peeps into the future, one thing is certain, and that is that the future flyer will be a larger and heavier machine than it is at present—it will probably weigh at least three tons, and will be of the form of a flying yacht. It will probably have a boat body, decked in, and proper accommodation will be provided for living and sleeping. A crew of several persons will be carried, who will be able to move about quite conveniently. The machine will fly at a very high speed, such as 150 to 200 miles an hour, as previous reasoning has shown that these speeds are the most practical and economical. For this reason the sustaining surfaces, when in full flight, will be small, but the area of sustaining surfaces will be variable, so that different flying speeds can be accomplished.

A large area will be used for starting, and special starting and alighting grounds will be prepared throughout the civilised countries of the world. These grounds will be fitted up with large starting machines similar to enormous catapults, which will rapidly project the machine into the air with reefed surfaces. The body of a future flyer will be provided with wheels and skids attached to pneumatic suspension gear, so that a machine can be started from a level ground. In addition to starting grounds, depots or towers will be erected for storage of fuel and oil, and the members of aerial leagues will be able to obtain stores by previously signalling. A trailing line will be lowered from the machine and special apparatus will be devised for picking up stores on the same lines as those adopted in railway practice for picking up mails by a passing train.

It may be necessary for the machine to encircle the depot a few times for this purpose, but such manœuvring will be an easy matter when the full area of sustentation is used. This idea can be carried out in a practical manner, and is not a merely mad anticipation.

The sustaining planes will not be made of proofed fabric, but probably of sheet metal, aluminium alloy or steel specially treated to prevent oxidation. These areas will be in the form of sliding panels arranged in the monoplane form. A second surface may be employed, which can be unfurled or unrolled from the deck, and attached to a movable framework of spars in a similar manner to the setting of fresh sails in a ship—the sails, however, will be in a horizontal instead of a vertical plane.

With regard to direct lift from the ground, this would be a very desirable feature if it could be reasonably accomplished, and it may be possible to fit vertical lifting propellers whose action would be to raise the machine to such a height that the machine could then be started to glide back to earth, and thus attain sufficient momentum to enable it to continue in straight flight by means of its ordinary horizontal propellers. If this static control in the air became an accomplished fact, many of the present difficulties before alluded to would disappear. For instance, it is difficult to make observations or take one's bearings at high speeds, the brain does not act quickly enough ;

if the speed could be reduced by the addition of lifting screws, much more favourable conditions could be obtained.

Safety lies in high speeds, as long as we are at the mercy of the elements we must, in order to be safe from their interference, make our conditions superior to theirs. A high wind can only be safely negotiated by a still higher speed of flight.

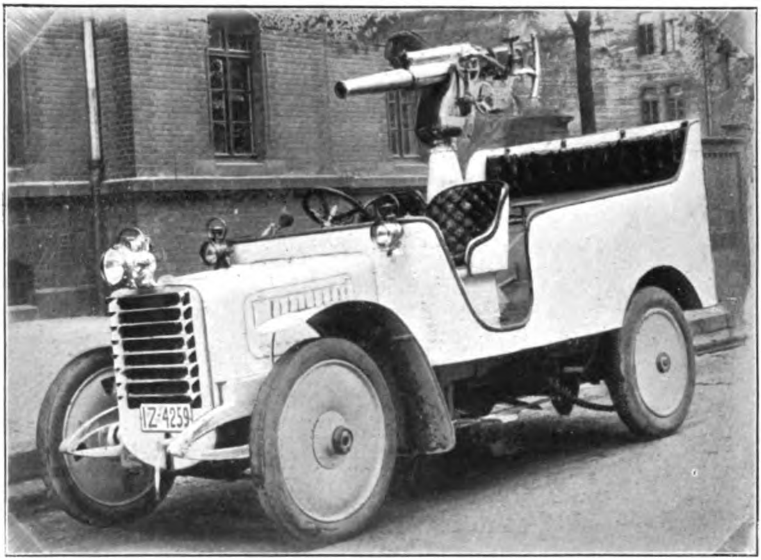


FIG. 93.—German Military Motor Car for Attacking Troops and Airships.

Then there is the effect of lightning, the danger is not great on account of the small capacity of the machine and its occupants. An electrical discharge will in all probability pass to a much larger object. There is, however, the danger of setting fire to the petrol if there happens to be a leakage, but naturally this would be avoided in any event.

Safety in flight of the future machine will be practically

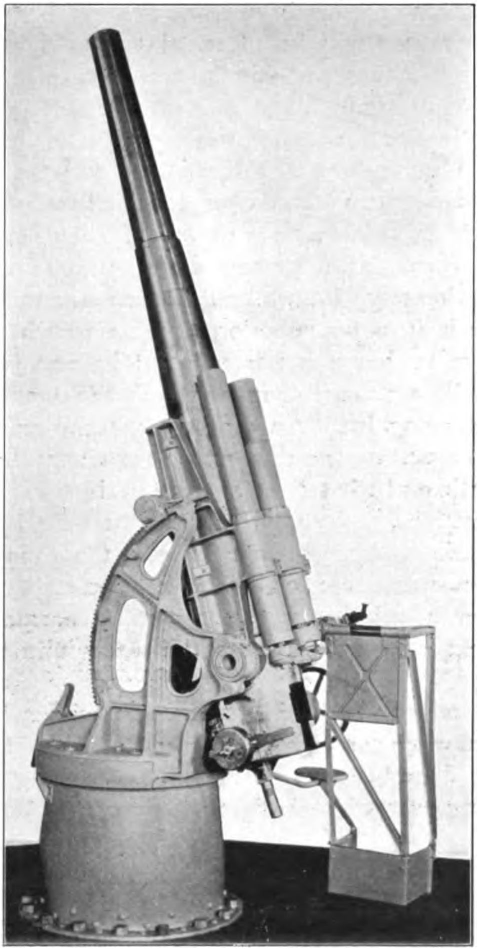


FIG. 94.—German Gun for Attacking Airships, to be Mounted on board Ship or at Frontier Defences.

as great as that of a ship at sea, it will only be in landing that difficulties will occur, and proper places being provided for this purpose, the risks will be minimised.

Uses in war have been briefly touched upon, but the chief importance will be attached to the flying machine for reconnaissances and raids, and carrying dispatches. These machines will fly at any altitude, below the clouds when obtaining information, and above them when escaping from the observations of the enemy. In case of fog the flying machine can skim over the surface of the earth without much risk, and by means of its instruments can penetrate through a fog when the contour of the country is approximately known. A scout mounted on an aeroplane is in a far superior position to when mounted on a horse, he has a better point of observation, and can more rapidly approach or retreat from the enemy with less danger of being hit. An officer commanding troops will be able to ascertain not only where the enemy lies, but also his strength, and what is at his rear. He could also locate his fortifications, and signal to his own base by means of wireless telegraphy. In naval work the flying machine will be unsurpassable, owing to its portability it can be carried on board ship, and should any accident happen it will float on the surface of the water until picked up by a boat.

Its speed of flight will make it an extremely difficult target, and when carrying several men, considerable damage could be done by such a machine dropping explosives when flying over a hostile fleet.

The starting of a high-speed flying machine from the deck of a ship may appear to be a difficult problem, but could be accomplished either by the direct lift method or by projection from a pneumatic tube, the tail of the machine being provided with a piston for this purpose.

CHAPTER XVII.

GLOSSARY OF TERMS EXPLAINED.

IN any new industry the question of terms and the settlement of definite names for certain articles or ideas is of great importance. Confusion only results from want of uniformity in description of the same article by different workers who choose to give different names to the same thing. From the earliest ages every object has had a name, so as new species are discovered or new inventions made, names are applied.

Flight being a science of modern general interest, though of ancient origin, requires standard terms for application to its recognised conceptions and arrangements.

Throughout this little work the author has endeavoured, where possible, to utilise the following terms, which are based in many instances on nautical terms when the parts bear some similitude.

Main Planes, being the supporting surfaces of the main weight of the machine. These are called "decks" by some authorities, this latter term being the nautical similarity. "Main plane" is perhaps a more usually recognised term and fits in well with the popular classification of types such as "monoplane" and "biplane." Superposed planes signify an arrangement of one plane over the other as in the Wright, Voisin, and Farman machines, this being the arrangement adopted in biplane practice. *Monoplanes* usually have their main plane in front, this arrangement, however, causes the smaller governing surfaces to operate in turbulent air. T. W. K. Clarke reverses the order of these planes in his monoplanes, the leading plane being the subsidiary plane and the main plane being at the rear.

It is claimed that the effect of the turbulence of the air is only slight on the larger main plane.

Supplementary planes or surfaces signify all the additional surfaces which are utilised for stabilisation. These generally consist of the elevator, the rudder, the curtains, the fin, and the *ailerons* or balancing planes.

Aerofoil is a more satisfactory term to use than plane for indicating a lifting surface. Main surfaces are not scientifically "plane," and as modern practice employs the arched aerofoils, which are much more efficient, main planes are, strictly speaking, aerofoils.

Elevator is a principal supplementary surface, usually of a miniature form of the main planes. The elevator, as its name implies, is for the purpose of altering the vertical direction of the machine. For this purpose the elevator as a whole is either hinged at one edge or about some axis at right angles to the direction of flight.

The elevator is placed usually in front of the main planes as in the Wright and Farman machines of the biplane type, but monoplane design usually places the elevator at the rear, either combining its motion with that of the tail, about an universal joint, or allowing it to have an independent motion.

The elevator supports part of the weight of the machine, though it is not a definite point whether the weight it bears is in proportion to its area as part of the total sustaining area. When the elevator is in front of the main planes and its angle of incidence is the same as that of the main planes, the probability is that the lifting power of the elevator is in proportion to its area, and the intensity of lifting effect equal to that upon the main planes. When, however, the elevator is at the rear, the turbulence of the air must affect the intensity of pressure on the elevator surface.

The inference is that a front elevator would be more effective than a rear one.

Elevators may be either of one or more planes, there being no fixed rule for this; also in some machines the elevator is divided along its chord, the two halves being independently operated. The idea of this independent control is that manipulation of such an elevator may be utilised to restore lateral displacement of the machine as a whole. The use of the elevator involves a conception on the part of man which is entirely new, that is, his possibility of motion in a vertical direction. This has not previously been attainable in any other instrument of mechanical locomotion, except in the submarine. We cannot be surprised, therefore, that correct manipulation of the elevator is somewhat difficult at first.

Rudder.—One or more rudder planes are invariably fitted to practical flying machines in order to control the direction of flight. These surfaces are set vertically, and are placed at the rear of the machine. Rudders may be either single or duplicate planes, hinged at their forward vertical edge and controlled by wires in the manner employed in marine practice. The distance between the rudders and the main planes must be within certain limits in order to give practical effect to the machine in turning, otherwise there would be a lack of sensitiveness about the control. When duplicate rudders are fitted they are attached so that their movements synchronise.

In some machines, notably the Wright, two small half-moon shaped fixed vertical planes are placed between the elevator planes at the front of the machine, their object being to assist the rudders by giving lateral resistance to the nose of the machine when the rudders at the rear are deflected.

Main Spars are the lateral spars upon which the main planes are built. These are usually two in number per plane or deck, and they act as cantilevers supported at their inmost ends, where they are attached to the chassis either directly in monoplanes and supported by guys, or by means of vertical "struts" and guys in the case of a biplane. These main spars transmit the lifting effort of the main planes to the body or chassis of the machine. When the spars are long, as in cases of machines of wide span, the bending stresses in these spars are relieved by tension wires attached to several points on them, and carried down to either the axle caps or to some lower members of the chassis. This practice is almost universal in wide span monoplanes, whereas in biplanes it is unnecessary, as the construction of the two planes in box girder form allows the tension bracing to be carried out between the main spars which support the upper and lower planes. The bracing is triangulated, and thus great rigidity is obtained, as it is important in biplane construction that the main spars in both upper and lower planes should always remain parallel to one another.* The main spars are usually made of wood, the forward spar in biplanes is generally at the front or entrant edge, and the rear spar some 2 ft. from the trailing edge. Some constructors prefer steel tubes to wood, but the latter material is the most suitable for attachment to the—

Ribs which support the fabric. These are made of ash or spruce, and bent to the correct curves, the lower rib having a smaller camber than the upper one. In all double surfaced planes, and in some single surfaced types, one rib is laid above and the other below the main spars to which they are securely attached. Two or more—

Webs are placed between the ribs, these being small blocks of wood which act as distance pieces. In order to

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* A few biplanes are arranged with arched planes, notably the "Cody" and the "Curtiss."

secure lightness these webs are drilled out in the centre and are fixed at their edges to the main ribs by glue.

The Camber of the ribs is the amount of curvature which is imparted to them in the same way that a motor car spring or a road has camber or curvature.

The amount of camber of the ribs is obtained by measuring the distance of the rib at any point from a straightedge, held to touch its two ends. The camber is not uniform and will be found to be a maximum about one-third of the distance from the leading edge.

Struts are used in biplane construction to maintain an equal distance between the two planes. The length of the struts should not be less than the width or chord of one of the planes. The struts are of oval section wood, and act either in conjunction with or in opposition to the stay wires in transmitting the lift of the upper plane to the lower one and thence to the chassis. Probably the struts near the centre of the machine are really in tension, depending of course upon the tautness of the wire guys. The ends of the struts are attached to the main spars in several ways: in the Wright machine some of them are fitted with steel eyes and are hooked to the spars ; they generally, however, fit into sockets screwed to the main spars.

Outriggers are used to support both the elevator and tail. These are timber constructions consisting of either two, three, or four spars with wooden distance pieces, and guy wires fixed between them. Rigidity is secured by the use of the steel wire diagonals fitted with stretching screws.

When a machine has its elevator placed in front and a tail or rudder behind, the main outrigger spars may be continuous throughout, being parallel or nearly so in plan, but tapering together in elevation both fore and aft.

The front outrigger may also be a continuation of the skids, when these are fitted, or built up from them.

Great importance should be attached to the rigidity of a front outrigger supporting an elevator, as great stresses are liable to come upon it at times, and failure would at once spell disaster. A front outrigger when part of a skid may sustain great shocks from landing and a hidden flaw may at any time develop. Fracture might, therefore, result at a most unexpected moment; tail outriggers are not liable to such great stresses, and may, therefore, be made lighter.

Skids, as their name implies, are in the form of long skates on which the machine can land in safety. In the Wright machine these are the only provisions for landing upon, but in other machines these are supplementary to wheels. They are being somewhat generally adopted in modern practice, on account of their obvious utility, and relieve the wheels of some of the greater shocks.

A skid is sometimes fitted under the tail of a monoplane either alone or as a supplementary precaution.

Chassis or Fusilage.—This is an essential part in some aeroplanes, but in other cases it is dispensed with, depending upon the arrangement for starting the machine from rest.

The chassis is somewhat difficult to define, as in monoplane construction we may designate the chassis as that part of the main framework to which the main planes and tail planes are fitted and which contains the engine and the aviator's seat. The chassis of a monoplane, therefore, comprises the framework to which the planes and mechanism are fitted and the outrigger. Biplanes are built upon a chassis when wheels are employed for starting purposes, it being a short framework supporting the axles and springs, the upper part forming a support for the engine.

The Wright machine has, properly speaking, no chassis, as the engine is supported on heavy timbers attached to the main spars of the lower plane, the skids also being fixed to the same spars.

The chassis may either be of wood or steel work, the latter material is used by M. Esnault-Pelterie, and a beautiful piece of construction is turned out of his factory. Tubes are used with diagonal cross tubes, all welded together at their ends in a most workmanlike manner. The Blériot XI. type of machine has a wooden chassis fitted with sockets into which the main spars fit in such a manner that they are readily detachable. The Voisin machine, also, has a somewhat elaborate chassis or "fusilage" to support the engine and the remainder of the machine. Various chassis details are described under the headings of the several machines.

Ailerons or fins are small supplementary surfaces fitted at the extremities of the main planes, sometimes as continuations of the planes themselves, and at others they are fitted between the main planes in biplanes. The latter method is adopted by Cody and in the Curtiss machine. The *ailerons* in some Antoinette models are triangular in plan, but in other models by the same firm they are rectangular.

The object of these *ailerons* is to increase the air pressure under one or other wing, so that increased lift may be secured, for the same object as warping is resorted to in the Wright machine. The use of *ailerons* is an alternative to any possible infringement of the Wright patents,* and it is claimed by users of *ailerons* that they are more effective in their action than warping the rear tips of the wings. *Ailerons* when inclined at an angle to the direction of motion of the machine put a drag on the wing to which they are attached, and thus assist in slewing the machine round as a whole. As the "drift" on a plane depends upon its angle of incidence, any increase of angle increases the drift, and consequently the drag—it also increases the lift, and it is a combination of these two which produces the required effect. *Ailerons* are operated by the aviator by means of a suitable lever connected to them by wires in such a manner that when one *aileron* is depressed, the other is elevated in proportion.

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* The Wright brothers claim a patent on the use of *ailerons* in addition to the warping of the wings, but the validity of these patents has not yet been upheld in Europe.

When the *ailerons* project beyond the rear tips of the main planes, and also when they are fixed between the planes, these connecting wires are fairly taut, in contrast to the Farman system. In this latter the *ailerons* are really loose sections of the main planes, and hang down vertically when the machine is at rest. The connecting wires at once become slack. This slackness is only taken up when the machine is in flight, and the *ailerons* conform to the stream lines of the air.

Side curtains are seldom now fitted. They were a distinguishing feature of the Voisin machines. These consist of vertical curtains fitted between the main planes, and were four in number, one being situated at each extremity, and one on either side, a distance from the extremities approximately equal to the distance between the two main planes.

The object of these curtains is to give resistance to lateral motion, and to minimise, therefore, risk of sliding down through the air edgewise. These curtains are a fixture, and no control or motion is required. Side curtains are sometimes fitted to a biplane tail, thus producing a box formation.

Keel.—This additional surface is sometimes fitted to a monoplane, the most noteworthy example being in the Esnault-Pelterie. Its function is similar to that of the side curtains. The keel is of the form of a long vertical fin placed in a fore and aft direction along the rear extension of the framework. The Antoinette machine has a smaller keel, but some of the monoplanes dispense with this surface altogether. The keel is also a fixture, but its latter extremity in some cases forms the vertical or steering rudder.

Span is the distance from tip to tip of the main planes in a transverse direction to that of flight. The span of a machine is limited in its maximum dimension only by convenience of design and practical considerations of ease of handling and strength. A machine with a large span becomes very cumbersome, also the effect of gusts or eddies at the end of a long wing produces a greater moment or turning effect than on a short wing in direct proportion to its linear dimensions. When a machine has to be designed in such a manner that its sustentation per unit of area is small, the question of span comes into account, and rather than increase this dimension beyond practical limits, the span is divided by two, and a biplane design results.

The question of span is also one of entering edge dimension, and this is most important, as the length of the entering edge determines to a great extent the efficiency of the lifting surface. This length of edge must bear a direct relation to the load lifted for good design, and at least 1 ft. should be provided for every 4 lb. of weight lifted at speeds of 40 miles per hour or less. At higher speeds this length may be reduced as V^2 increases.

The length of the **entrant edge** loses part of its efficiency at the ends owing to a portion of the air leaving the two ends in a lateral direction. If, therefore, a certain length of edge is provided for and it is found that this must be divided into two, extra length must be given to compensate for the resulting loss of efficiency from this cause. It is probable that a more efficient form of entrant edge would be obtained by making each wing sweep forward towards its centre in the manner that nature has designed the entrant edge of the wings of fast flying birds.

Chord is the length of the plane from leading to trailing edge in a straight line. This dimension is usually limited in its maximum dimension. In the Chauvière machine we find the chord exceeds that usually found, but this is a special design in which the trailing edge is controllable by means of cords. A variable value is given to the chord in this case, as the angle of incidence of the trailing edge can be varied.

Supposing we have a machine with a chord of 2 ft.

only, and an angle of incidence equal to a 1 in 10 slope, at 40 miles per hour the lift will be 2·5 lb. per square foot, the thrust required will then be equal to one-tenth of the weight supported.

If we fix a second and then a third plane at the rear of this with increasing angles of incidence the effects will be increased up to a limit, but beyond this limit nothing is gained, as the stratum of air below the plane will not be affected by any further increase. The only result of still adding surface at the rear will be to increase the skin friction and head resistance.

Surfacing may be either single or double. When the former is employed the fabric is brought round over the leading main spar and sewn back on to itself again. The spar is therefore held in a "pocket." Other spars and ribs are covered with strips of fabric laid over them and sewn on to the main surfacing below, and are thus encased in "pockets" to reduce the air resistance.

Double surfacing consists in sewing and nailing a fabric surface both above and below the whole of the main planes, an air space being left between them. In some monoplanes the petrol tanks are placed between this surfacing, and in others the wire guys are thus protected.

This arrangement makes the main planes buoyant should the machine fall into the water.

Surfacing fabrics have been dealt with in another chapter, but care should be taken to prevent the material from coming in contact with iron or steel, as oxidation will sooner or later result.

Aspect ratio is the ratio of the length of span to that of chord, and may vary considerably. In all modern machines this is more than unity, meaning that the span is greater than the chord. The values of aspect ratios for various machines are given in dealing with these machines in detail. Lanchester terms an aspect ratio greater than unity as "pterygoid" aspect, and that less than unity "apteroid."

Gap is the distance between the two main planes in a biplane—this distance should not be less than the chord of the planes, or the effect of eddies will become more pronounced, and reduce the lifting effect upon the upper plane.

Angle of incidence is the angle which a line drawn from the leading to the trailing edge of the plane makes with the horizontal. The order of this is 8°. The smaller the angle of incidence the greater will be the speed of the machine at which sustentation occurs. Increase of this angle above the normal will cause the machine to rise from the ground, this being caused by manipulation of the elevator, a decrease of the angle produces a contrary motion. When the power acting remains the same, variation of the angle of incidence will produce variation of speed, and is analogous to a motor car ascending or descending a hill; the normal angle will produce horizontal flight when the thrust of the propeller is normal. The value of the angle of incidence defines the "attitude" of the machine.

Gliding angle is, as its name signifies, the minimum angle relatively to the horizontal, at which the machine will glide to earth with the power shut off. Probably the Wright machine has the smallest gliding angle of any of the well-known machines, but values of the gliding angles of various machines are differently quoted by different authorities; about 7° or 8° is the order of this angle's value—it is usually equal to the angle of incidence.

Angle of entry is the angle which the tangent to the leading edge of the plane makes with a line drawn across the chord, *i.e.*, from the leading to the trailing edge of the plane. Values for this angle are given in descriptions of some of the machines.

Trailing Angle is the angle between the tangent to the trailing edge of the plane and the chord or a line drawn from the leading to the trailing edge. This angle is, of course, less than the angle of entry owing to the peculiar shape of an aerocurve whose camber is not the arc of a circle.

The flexible trailing edge usually designed allows of this trailing angle being varied, and it sometimes varies automatically owing to increase of wind pressure caused by gusts.

Gauchissement or warping is applied to the main planes, and produces the same ultimate effect as the use of *ailerons*. *Gauchissement* may be of two kinds, it may affect only the trailing edge or the wing as a whole. In some machines even a further step is taken in pivoting the wings so that they move bodily. The Wright machine is arranged so that the three outer struts at the rear of either wing move vertically and carry the planes with them, the front remaining stationary. The Esnault-Pelterie monoplane is designed so that the greater part of the rear of each wing flexes, an upward movement of one causing a downward movement of the other. The Blériot machine is arranged so that only a small portion of the wing tips flex. Flexibility of this kind is only really practicable in monoplane construction, and to a smaller degree in the Wright type of machine. The Voisin machine, however, is rigid, and in order to attain lateral stability steering has to be employed.

Supposing, for instance, the right side of the machine lowers, steering to the left will increase the velocity of the right wing through the air relatively to that of the left wing. This increase of velocity will be followed by an increase of pressure under the right wing, and cause it to level up to the left wing. This manipulation is naturally not as sensitive as where *gauchissement* is provided.

APPENDIX.

NOTATION.

F = area of an aeroplane surface in square metres.
α = angle made by the surface with the direction of flight.
β = the angle made by the direction of flight with the horizontal.
γ = the angle made by the surface with the direction of the propelling force.
δ = the angle made by the direction of the propelling force with the horizon.

The $\alpha + \beta = \gamma + \delta$.

μ = a special coefficient for an arched (concave) surface.
ζ = a special coefficient for a convex surface.
R^1 = the head resistance in kilogrammes on a plane surface moved perpendicularly against the air.
R = the head resistance in kilogrammes on a plane surface moved obliquely against the air.
g = acceleration of gravity = 9·81 metres per second per second.
v = the velocity of the machine relatively to the air in metres per second.
u = the velocity of the wind relatively to the earth.
C = the velocity of the machine relatively to the earth.
a = the atmospheric pressure.
P = the load.
Q = the weight of the machine in kilogrammes.
G = the lifting power of a surface in kilogrammes.
T = the lifting power of a machine, *i.e.*, $G - Q$.
N = effective horse-power.
η = the efficiency.
n = the number of revolutions per minute of the propeller.

LAW OF RESISTANCE OF THE AIR

(VON LOESSL).

For velocities between zero and 50 metres per second, the head resistance opposing a surface moved perpendicularly against an unlimited air medium, or met perpendicularly by uniformly moving air is given by—

$$R^1 = \frac{\gamma}{g} F v^2 \quad - \quad - \quad - \quad - \quad (1)$$

The pressure on a surface moved obliquely against unlimited air—

$$R = \frac{\gamma}{g} F v^2 \sin \alpha, \quad - \quad - \quad - \quad (2)$$

which may be resolved into its horizontal component (suffix x) and its vertical component (suffix y).

$$\therefore \quad Ry = \frac{\gamma}{g} F v^2 \sin \alpha \cos \alpha \quad - \quad - \quad (3)$$

$$Rx = \frac{\gamma}{g} F v^2 \sin^2 \alpha \quad - \quad - \quad - \quad (4)$$

These four formulæ are very accurate for all angles between 90° and 1°, and are deduced from von Loessl's experiments, which showed that the resistances of small and large surfaces were proportional to their linear dimensions.

If a surface moves forward with an uniform velocity v, it displaces per second a mass of air $Fv = q$, and as this air is forced out sideways an equal quantity of air is displaced at the sides. The total weight of air set in motion is therefore—

$$G = q + q = 2\gamma F v.$$

The energy necessary is—

$$L = \frac{mv^2}{2} = \frac{Gv^2}{2g} = \frac{\gamma}{g} F v^3.$$

Since $L = R^1 v$,

$$\therefore \quad R^1 = \frac{\gamma}{g} F v^2.$$

R represents the normal pressure acting on the surface perpendicularly to the face.

The value of γ, the density of the air, depends on the height above the sea-level, also the temperature and to a slight extent the humidity of the atmosphere.

USEFUL TABLES.

AIR.

Relation Between Volume and Weight.

	Kilogrammes.
1 cub. metre at 0° Cent. and at sea-level weighs - -	1·293
1 „ „ „ 1,000 metres height weighs	1·145
1 „ „ „ 2,000 „ „ „	1·010
1 „ „ „ 3,000 „ „ „	0·892

The density of the air varies with the temperature and height of the barometer.

At temperature $t_0 = 0°$ Cent., and pressure $b_0 = 760$ mm., the density $\gamma_0 = 1·293$ kg. per cub. metre, whilst at other temperatures and pressures t_0 Cent. and b mm.,

$$\gamma = 1·293 \frac{b}{760} \cdot \frac{273}{273 + t}.$$

Values of $\frac{\gamma}{g} = \frac{\gamma}{9.81}$. Values of $\frac{\gamma}{g} = \frac{1}{\dots\dots}$.

Barometric Pressure in mm.	Temperature in Degrees Centigrade.							
	-5	0	+5	+10	+15	+20	+25	+30
770	7·350	7·486	7·627	7·773	7·924	8·080	8·243	8·413
760	7·449	7·585	7·727	7·874	8·027	8·186	8·352	8·525
750	7·549	7·687	7·830	7·979	8·134	8·285	8·464	8·639
740	7·651	7·791	7·936	8·087	8·244	8·408	8·578	8·756
730	7·755	7·897	8·045	8·198	8·357	8·523	8·695	8·875
720	7·862	8·006	8·156	8·311	8·472	8·640	8·815	8·998
710	7·972	8·118	8·271	8·428	8·591	8·761	8·938	9·123
700	8·085	8·234	8·388	8·549	8·714	8·886	9·065	9·253
690	8·202	8·353	8·509	8·672	8·840	9·015	9·196	9·387
680	8·392	8·476	8·634	8·799	8·971	9·148	9·331	9·524

The shape of the surface affects the resistance, and the maximum possible value is given by the formula—

$$R = \frac{\gamma}{g} F v^2.$$

This maximum holds good when the direction of motion is perpendicular to the surface, and when the edges of the surface are raised, or when the forward side of the surface is concave.

The area F must be multiplied by the factor ζ, depending on the shape of the surface.

VALUES OF ζ.

= 1 if surface is concave, or if provided with edges so that the concave side moves forward.
= 0·83 for plane circular surface.
= 0·86 ,, square surface.
= 0·90 ,, equilateral triangle.
= 0·92 ,, isosceles right angled triangle.
= 0·94 ,, right angled triangle whose sides are as 1 : 4.

CONVERSION OF LENGTHS.

Miles	Kilometres.		Miles.	Feet.	Metres.		Feet.
1	1·609	1	0·621	1	0·305	1	3·280
2	3·219	2	1·243	2	0·610	2	6·561
3	4·828	3	1·864	3	0·914	3	9·843
4	6·438	4	2·486	4	1·219	4	13·122
5	8·047	5	3·107	5	1·524	5	16·404
6	9·656	6	3·728	6	1·829	6	19·686
7	11·265	7	4·350	7	2·134	7	22·965
8	12·879	8	4·971	8	2·438	8	26·247
9	14·484	9	5·592	9	2·743	9	29·529
10	16·093	10	6·214	10	3·048	10	32·808
20	32·186	20	12·428	20	6·096	20	65·616
30	48·279	30	18·641	30	9·144	30	98·427
40	64·373	40	24·855	40	12·192	40	131·232
50	80·466	50	31·069	50	15·240	50	164·046
60	96·559	60	37·283	60	18·288	60	196·854
70	112·652	70	43·497	70	21·336	70	229·662
80	128·746	80	49·710	80	24·384	80	262·473
90	144·840	90	55·924	90	27·432	90	295·281
100	160·930	100	62·138	100	30·479	100	328·089

CONVERSION OF WEIGHTS AND MEASURES.

Pounds.	Kilogrammes.		Pounds.	Gallons	Litres.		Gallons.
1	0·457	1	2·20	1	4·54	1	0·22
2	0·907	2	4·41	2	9·09	2	0·44
3	1·361	3	6·61	3	13·63	3	0·66
4	1·814	4	8·82	4	18·17	4	0·88
5	2·268	5	11·02	5	22·72	5	1·10
6	2·722	6	13·23	6	27·26	6	1·32
7	3·175	7	15·43	7	31·80	7	1·54
8	3·629	8	17·64	8	36·35	8	1·76
9	4·082	9	19·84	9	40·89	9	1·98
10	4·536	10	22·05	10	45·43	10	2·20
20	9·072	20	44·09	20	90·87	20	4·40
30	13·608	30	66·14	30	136·30	30	6·60
40	18·144	40	88·18	40	181·74	40	8·80
50	22·679	50	110·23	50	227·17	50	11·0
60	27·215	60	132·28	60	272·61	60	13·2
70	31·752	70	154·32	70	318·04	70	15·4
80	36·288	80	176·37	80	363·48	80	17·6
90	40·823	90	198·42	90	408·91	90	19·80
100	45·359	100	220·46	100	454·35	100	22·01

TABLE OF WIND PRESSURES ON NORMAL SURFACES.

Speed of Wind, Miles per Hour.	Pressure of Wind, Lb. per Square Foot.	Speed of Wind, Miles per Hour.	Pressure of Wind, Lb. per Square Foot.
1	0·003	25	1·875
2	0·012	30	2·700
3	0·027	35	3·675
4	0·048	40	4·800
5	0·075	45	6·075
6	0·108	50	7·500
7	0·147	55	9·075
8	0·192	60	10·800
9	0·243	65	12·675
10	0·300	70	14·700
11	0·363	75	16·875
12	0·432	80	19·200
13	0·507	85	21·675
14	0·588	90	24·300
15	0·675	95	27·075
16	0·768	100	30·000
17	0·867		
18	0·972		
19	1·083		
20	1·200		

TABLE OF FLYING SPEEDS (Approximate Values.)

Miles per Hour.	Feet per Second.	Miles per Hour.	Feet per Second.
20	29·35	42	61·5
21	31	44	64·5
22	32·5	46	67·5
23	33·75	48	70·5
24	35·25	50	73·34
25	36·70	52	76·75
26	38·25	54	79·75
27	39·75	56	82·25
28	41	58	84·75
29	42·5	60	88
30	44	62	90·75
31	45·5	64	94
32	46·75	66	96·75
33	48·5	68	99·5
34	50	70	102·62
35	51·32	75	110
36	52·75	80	117·3
37	54	85	124·6
38	55·75	90	132
39	57·25	95	139·3
40	58·68	100	146·6

PROPERTIES OF ANGLES IN FLIGHT.

Angle in Degrees.	Incline between Lines forming the Angle	Sine of Angle.	Tangent of Angle.
1	1 in 57·2	0·0175	0·01746
2	,, 28·6	0·0349	0·0349
3	,, 19·0	0·0523	0·0524
4	,, 14·3	0·0697	0·0699
5	,, 11·5	0·0871	0·0875
6	,, 9·8	0·1045	0·1050
7	,, 8·2	0·1218	0·1227
8	,, 7·2	0·139	0·140
9	,, 6·41	0·156	0·158
10	,, 5·75	0·174	0·176
11	,, 5·24	0·190	0·194
12	,, 4·81	0·208	0·212
13	,, 4·45	0·225	0·230
14	,, 4·13	0·242	0·249
15	,, 3·86	0·259	0·267
16	,, 3·62	0·276	0·286
17	,, 3·42	0·292	0·305
18	,, 3·23	0·309	0·324
19	,, 3·08	0·325	0·344
20	,, 2·92	0·342	0·364

RELATIONS BETWEEN ANGLE OF INCIDENCE AND WEIGHT LIFTED.

The following interesting and useful table is given by "A Naval Constructor" in *Flight*, and clearly brings out the effect of skin friction and its effect upon the lifting power of a plane.

Theoretically, the relations between lift and drift vary directly as the angle of incidence, and that when this angle is small the relation should be great.

If the value of the coefficient $C = 0·006$ in the equation—

$$P = C\ Fv^2 \sin \gamma,$$

where P is the pressure under the plane normal to the surface,

F = the area of the plane in square metres.

If the value of $f = 0·00001$ in the formula—

$$S = f\ Fv^2,$$

where S = the skin friction.

These being values of the mean constants obtained by several experimenters.

We see from the table that the drift is more affected by the skin friction than the lift, and that the actual lifting power of any plane can be increased by increasing its angle of incidence and supplying the necessary increase of thrust.

Angle of Incidence of Plane in Degrees.	Total Lift in lb. per Sq. Foot at 60 Feet per Sec.	Ratio of Lift to Drift if no Friction.	Ratio of Lift to Drift including Friction.
0·5	0·19	114·6	5·0
1·0	0·38	57·3	8·9
1·5	0·57	38·2	11·1
2·0	0·75	28·7	12·1
3·0	1·13	19·1	11·9
4·0	1·51	14·3	10·6
5·0	1·89	11·5	9·4
6·0	2·26	9·7	8·3
7·0	2·64	8·2	7·4
8·0	3·02	7·2	6·6
9·0	3·40	6·4	6·0
10·0	3·77	5·7	5·5

In actual machines the ratio of lift to drift varies between 5 and 9; if we take a value of say 7·5, the thrust must be $\frac{1}{7 \cdot 5}$, the total weight of the machine.

In a Blériot type XI. the angle of incidence is 7·5° in the ordinary machines, and 6° in the high-speed machines at 90 km. an hour. Taking the former value, the thrust should be at least 80 lb. when in flight, and this is usually 180 to 200 lb. against a fixed point.

THE LAMPLOUGH TWO CYCLE ENGINE.

PLATE XII.

This engine differs from other two-cycle engines in the fact that the charge is pumped into the working chamber by means of an ingenious and novel type of reciprocating pump.

The working chamber unit consists of a pair of cylinders having a common combustion chamber, the two pistons work in unison and are propelled outwards by the single charge at each revolution, the arrangement of the cylinders being similar to that adopted in the well-known Lucas valveless engine. By such an arrangement the fresh charge entering one cylinder at the end of the outward stroke sweeps out the burnt gases effectually, and the length of the passage from the inlet ports to the exhaust ports at the outward end of the neighbouring cylinder is sufficient to prevent the fresh charge from being expelled into the exhaust pipe.

In the Lamplough engine any number of charging and working units are employed, each unit comprising a compressor pump and a twin cylinder, all made in one casting. By this arrangement lengths of piping and passages are avoided, as it is owing to the presence of these in some two-cycle motors with a separate pump that thermal loss results.

It will be noticed from Plate XII. that the crankshaft is held in ball bearings, and that there are no valves of the ordinary type, thus the engine is highly efficient mechanically and silent in working. The novel method of working the sliding sleeve of the compressor can be best understood from an inspection of the figure. The small end of the pump connecting rod has three or four teeth of coarse pitch cut upon it on either side, which engage with two racks, one formed as an extension of each sliding sleeve.

Owing to the obliquity of the rod one or other sleeve is drawn downwards relatively to the piston of the pump, while the other moves in the opposite direction. Thus a very rapid port opening is obtained, the charge is drawn from the carburettor and expelled through the diaphragm valve at the top of the cylinder into the receiver D 2, ready to charge the working chamber when the piston descends and uncovers the port A 2.

The lubrication of the sliding sleeves and cylinder walls is effected by the introduction of lubricating oil directly into the carburettor mixing chamber, a sight feed with a regulating screw is attached so that the flow of oil which is forced through it can be adjusted exactly.

Oil is also pumped to the working parts of the motor and falls to the bottom of the crank case, is filtered and pumped back again.

The adoption of small cylinders such as 2-inch diameter, fitted in four groups to the 30 H.P. engine, is a wise one for many reasons. A 2-inch cylinder is probably more efficient than any other size, also the twin arrangement permits of ample radiation surface.

The cylinders and all working parts are ground to the true shape with the greatest care, and all the materials are of the best of their kind.

This engine should have great possibilities, and for aviation work a simple air-cooled engine is much to be desired. The compact arrangement and freedom from pipes and water-joints are points in its favour, especially for the use of novices. A bad landing on the ground will not seriously derange an air-cooled engine, whilst it might place a water-cooled one out of action.

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