THE AEROPLANE

AN ELEMENTARY TEXT-BOOK OF THE PRINCIPLES OF DYNAMIC FLIGHT

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THE AEROPLANE

BIRD FLIGHT AS THE BASIS OF HUMAN FLIGHT

By OTTO LILIENTHAL

Translated by A. W. ISENTHAL from the Second Edition of the Original

With Illustrations

This is an English version of a book which is considered a classic by recent writers on Aviation, as it contains a record of the important experiments made by the author and his brother on the relations between the form of the wing and the wind.

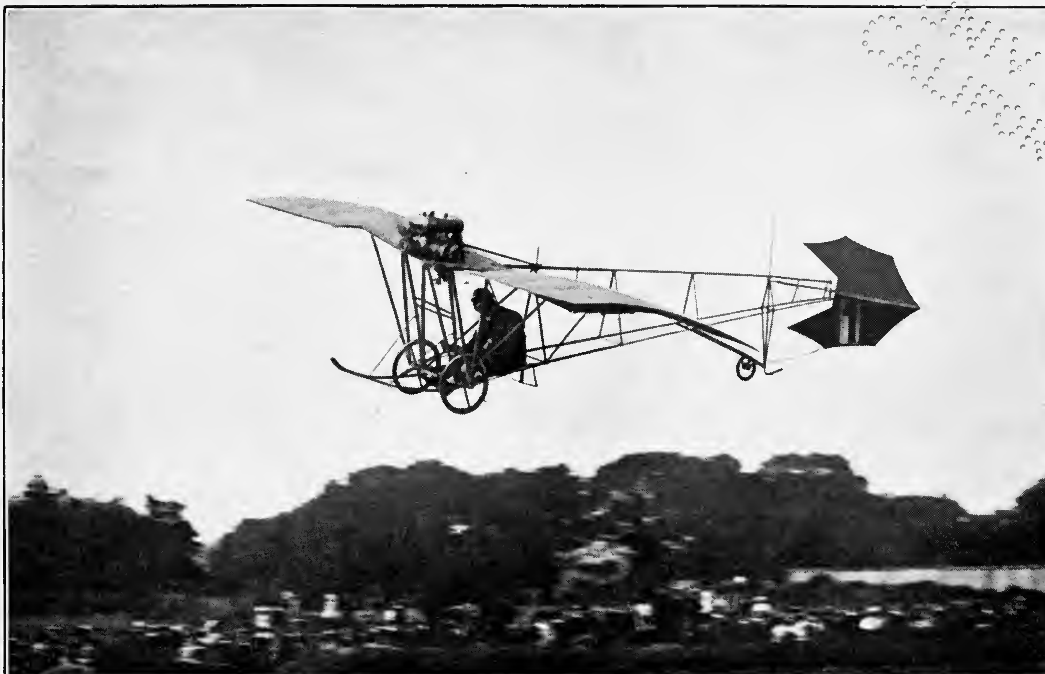

Photo: Topical Press

PLATE I.—THE SANTOS-DUMONT "DEMOISELLE" MONOPLANE

Frontispiece

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FOREWORD

So swiftly has dynamic flight become practicable and important that those who would make it their study are at a loss for instructors. A new branch of engineering science has appeared; a new and important industry is arising; and there is a steadily-increasing demand for a concise and accurate collation of the knowledge which has already been acquired.

The purpose of the present work is to provide a complete text-book of the elements of dynamic flight, and to set out in simple language the laws governing aviation. Moreover, bearing in mind the coming requirements of education, the authors have endeavoured to produce a book suitable for schools and colleges as well as for the student and the general reader.

Except for the opening chapter, the divisions are purely arbitrary. The factors involved in a consideration of the science and its practice are so interdependent and bound up one with another, that a certain amount of repetition is unavoidable and indeed, for the sake of clearness, essential. All controversial matter has been omitted, and only basic principles included. Aviation demands knowledge of a great many subjects, each of which is a separate study in itself, but the limits of the present volume have necessitated slight treatment in each division. It is hoped, however, that the book will find a sphere of usefulness as a comprehensive introduction to the latest and the most fascinating of the sciences.

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CHAPTER I

PROPERTIES OF THE AIR

Constituents—Weight—Effect of Pressure on the Density of the Air—Effect of Temperature on the Density of the Air—Effect of Humidity on the Density of the Air—The Atmosphere: its Extent—Decrease in Density of the Atmosphere—Variations in Temperature of the Atmosphere—General Atmospheric Variations—Compressibility and Elasticity of the Air—Air as a Fluid—Inertia of the Air—The Air in Motion—Wind Velocities—Increase of the Velocity of the Wind with Altitude—Direction of the Wind: Horizontal Currents—Vertical Currents—Irregularity in the Speed of the Wind—Irregularities in Direction—Wind Pressure—Summary.

1. **Constituents.**—Flight in all its aspects depends on a knowledge of the properties of the air and on their utilisation. Air is a mixture (not a chemical compound) of various gases. Its chief constituents are oxygen and nitrogen in the following proportions:—

	Parts (volume).	Units (weight).
Oxygen . . .	21	23·2
Nitrogen . . .	78·06	75·5
Other gases . .	0·94	1·3
	100	100

The constituents other than oxygen and nitrogen are: water-vapour, argon, carbon dioxide, hydrogen ammonia, ozone, and nitric acid, in addition to solid matter of various kinds, such as dust and smoke particles. But with the single exception of water-vapour these are of no importance for the laws of air-resistance and the science of flight.

2. Weight.—Normally, at sea-level, at a temperature of 0° C. (32° Fahr.), 1 cubic centimetre of air weighs 0·001293 grammes, or in English measure 1 cubic foot of air weighs 0·0805 lb. Consequently, air weighs about $\frac{1}{774}$th of water. The density of the air is, however, affected by three factors: (1) pressure, (2) temperature, and (3) humidity.

3. Effect of Pressure on the Density of the Air.—As in the case of all gases, the density of air is proportional to the pressure (Boyle's law). In the air of the atmosphere pressure varies from two causes. In the first place, atmospheric pressure constantly decreases with the altitude above sea-level; consequently the air diminishes in density with the altitude. At sea-level the normal pressure of the atmosphere, at a temperature of 0° C., is equal to that of a column of mercury 760 mm. (29·92 inches) high, which is equivalent to a weight of 1·033 kilogrammes per square centimetre (14·7 lbs. to the square inch); that is, the weight of the whole atmosphere pressing down on each square centimetre of the earth's surface amounts to 1·033 kg. As we ascend to a greater altitude, however, only a portion of the atmosphere remains above us, and its weight will therefore be smaller; consequently the density of the air decreases. The following rule holds good: *The density of the air decreases in proportion with the altitude to the extent of 0·12 per cent. for each* *mm. of mercury, or* 1 *per cent. for each* 7·6 *mm. of mercury.*

Secondly, owing to meteorological conditions, the atmospheric pressure at sea-level is subject to variations, which are measured by the barometer. These variations have a range (in our latitudes) of some 60 mm., and have the same effect on the density of the air as variations in altitude.

4. Effect of Temperature on the Density of the Air.—Variations in temperature constantly occur on the surface of the earth, and affect the density of the air to a notable extent. In common with all gases, air expands with a rise in temperature; that is, it becomes lighter for a given volume. Generally speaking, *a difference of temperature of* 1° *C. affects the density of the air to the extent of* 0·366 *per cent., or the density varies by* 1 *per cent. for each* 3° *C.*

5. Effect of Humidity on the Density of the Air.—Air is capable of absorbing a definite amount of water-vapour, until it becomes saturated; this point of saturation varies with the temperature, warm air being capable of absorbing more water-vapour than cold air. Thus saturated warm air, on suddenly being cooled, loses some of its power for carrying water-vapour; the latter is then deposited in the form of rain. Now the density of water-vapour is 0·623 of that of air, and since air can contain a proportion of water-vapour amounting to 3 per cent. of its volume, it is obvious that saturated air is lighter than dry air. On the whole, however, the effect of humidity on the air is insufficient to influence the science of flight to any appreciable extent, and may therefore be ignored.

6. The Atmosphere: its Extent.—We have already noted that the pressure of the atmosphere decreases with the height above sea-level, where it amounts to the weight of a column of mercury 760 mm. in height or to 1·033 kg. per sq. cm. Now, if air were incompressible like water it would be an easy matter to calculate the actual vertical height of the atmosphere: its limit would be reached 5 miles above sea-level. But air is actually compressible to a considerable extent; and we have already seen that its density decreases constantly as we ascend. Taking this fact into consideration, we may fix the limit of the atmosphere at a height of 75 km. (45 miles). At this point its density is $\frac{1}{10000}$ of that at sea-level. As a matter of fact it has been proved—by the observation of shooting stars, the refraction of light, &c.—that traces of air are actually present up to a height of 200 miles, but in so attenuated a form as to be negligible. Even so, in dealing with the science of flight, we need only consider the atmosphere from sea-level up to a height of 6 miles, or about 30,000 feet, since at greater altitudes the rarefied air is insufficient to support life. It may be noted that the eagle is said to ascend to 3½ miles and the condor to 4 miles, but it is improbable that these altitudes will be surpassed by a flying-machine.

7. Decrease in Density of the Atmosphere.—At sea-level the mean pressure of the atmosphere is 760 mm. of mercury; in order to lower this pressure by 1 mm., that is to obtain a pressure of 759 mm., we have to ascend about 10½ metres (34 feet). In other words, at sea-level the weight of 1 mm. of mercury is equal to the weight of a column of air 34 feet in height. But, as we ascend, every mm. of mercury represents a longer column of air than the previous one (owing to the smaller pressure of the atmosphere and density of the air); at a height of 1 km., consequently, 1 mm. is equivalent to a column of air of 12 metres (39 feet); at 2 km. to 13½ metres (44 feet); at 5½ km. (where the atmospheric pressure is 380 mm., or exactly half that at sea-level) it corresponds to 21½ metres of air (70 feet); finally, at a height of 10 km., or about 33,000 feet, each mm. of mercury represents 36 m. of air (or 120 feet). Since the density of air is directly proportional to the pressure, it is easy to calculate the density of the air at any height from the barometric pressure corresponding to that altitude. (See Table III.)

8. Variations in Temperature of the Atmosphere.—Regarding the variations in temperature of the atmosphere it is only possible to give one general law: temperature decreases about 1° C. for every 100 metres in altitude or 1° Fahr. for every 183 feet. Greater variations occur, especially in tropical lands, but the above is the mean for European countries.

9. General Atmospheric Variations.—The pressure of the atmosphere and the temperature always decrease with the altitude; further, both pressure and temperature may, independently, vary at any given height owing to meteorological conditions. Increase in temperature causes a *decrease* in the density of the air, in the proportion of 0·36 per cent. for each degree C. Increase in pressure brings about an *increase* in the density of the air to the extent of 0·13 per cent. for each mm. pressure. The converse, of course, is true in both cases. This law may also be stated as follows: the density varies inversely as the temperature by 0·36 per cent. for each degree C., and directly as the pressure by 1·3 per cent. for each mm.

10. Compressibility and Elasticity of the Air.—Air, like all other gases, is compressible; that is, its volume is proportional to the pressure to which it is subjected. In this it differs, as a fluid, from water, for instance, which is incompressible. Further, the air is perfectly elastic; that is, when it has been subjected to pressure—however great—it regains its former volume as soon as this pressure is removed.

11. Air as a Fluid.—Air is a fluid; that is, when its component particles are subjected to the slightest force they will move from their relative positions. In common with other fluids it possesses viscosity; in other words, its particles give rise to friction when they come into contact with other particles or bodies. In this respect air differs from the theoretical "perfect fluid," which is absolutely uniform and regular in its flow. It would, in fact, be difficult to conceive a more imperfect fluid than air: unstable to the last degree, flowing not uniformly but in a constant succession of invisible gusts, whorls, and eddies, it offers every conceivable difficulty to investigation. For this reason the laws of air-resistance have never yet been laid down with the accuracy that exists when we come to deal with water; and in part this reason, too, has so long delayed the practical advent of the aeroplane.

12. Inertia of the Air.—In common with every other body air possesses inertia, which may be explained as the property whereby a mass tends when at rest to remain at rest or when in motion to continue its motion indefinitely and in a uniform manner until acted upon by a force.

13. The Air in Motion.—The air that composes the atmosphere is seldom in a state of rest: a perfect calm is a very rare occurrence. The differences that constantly exist in the temperature and pressure at various points of the earth's surface cause the air to flow with greater or less speed from one region to another, and thus cause winds to arise. The study of winds and their causes constitutes the chief part of the science of meteorology, and need only be considered here in so far as it directly affects the science of flight.

14. Wind Velocities.—Wind, therefore, is simply air in motion. According to the average speed at which it blows it is termed a breeze, a gale, a storm, or a hurricane. The following is the scale of winds and their velocities that is now usually adopted:—

Beaufort's Scale of Wind Force

0	Calm	0– 5	miles per hour
1	Light air	6–10	„
2	Light breeze	11–15	„
3	Gentle breeze	16–20	„
4	Moderate breeze	21–25	„
5	Fresh breeze	26–30	„
6	Strong breeze	31–36	„
7	Moderate gale	37–44	„
8	Fresh gale	45–52	„
9	Strong gale	53–60	„
10	Whole gale	61–69	„
11	Storm	70–80	„
12	Hurricane	80 and over	„

15. Increase of the Velocity of the Wind with Altitude.—The surface wind in Great Britain has an average speed throughout the year of 12 miles an hour. But there is a phenomenon of the greatest importance for the aerial navigator: the velocity of the wind increases gradually with the height. This is almost invariably the case; so much so that when a practical calm reigns at ground-level, there may be a 20-mile wind some thousands of feet aloft. It is impossible to lay down accurate rules on this point. The following table, however, gives the approximate values of the wind velocity at various levels in summer and in winter (the speed of the wind at ground level is taken as 1; to find the speed at any other level, multiply the ground-speed by the figure corresponding to the level):—

Height in Feet		0 to 3,000.	3,000 to 6,000.	6,000 to 10,000.	10,000 to 13,000.	13,000 to 16,000.	16,000 to 20,000.
Speed	Summer	1·7	1·8	2·0	2·3	2·6	3
	Winter	1·9	3·2	3·8	4·7	6	8

16. Direction of the Wind: Horizontal Currents.—The general direction of the wind of course varies with the meteorological conditions, although the various regions of the earth usually have a well-defined prevailing wind. Further, such regular currents as the trades, the counter-trades, and the monsoon are of great importance for the aerial navigator. A noteworthy phenomenon, general throughout Europe, is the increasing twist of the wind towards the right as we ascend in the atmosphere, due to the earth's rotation. (See Chapter VIII. § 10.)

17. Vertical Currents.—At times the wind is horizontal; often it has an upward or downward direction. Such vertical currents are of great importance for aerial craft, and sometimes constitute a real danger. Generally they are due to one of two reasons: (1) the tendency of hot air to rise and of cool air to descend—this is especially noticeable in the vicinity of large expanses of water; or (2) they

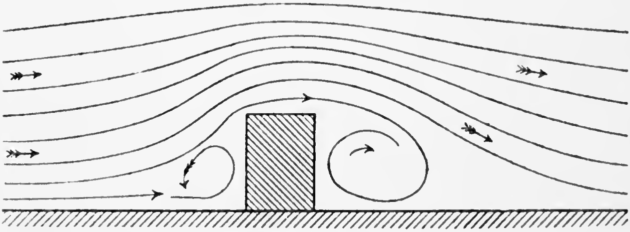


FIG. 1.

may be due to irregularity in the formation of the ground. If, in fact, an obstacle such as a mountain, a cliff, or even a house, rises in the path of a horizontal wind, it is obvious that the wind will have to rise above the obstacle in order to clear it, and will flow down again on the other side; these vertical currents, due to obstacles, are always accompanied by dangerous whirls and eddies, as will be seen from the sketch.

18. Irregularity in the Speed of the Wind.—So far we have considered the wind as blowing regularly at a uniform rate of speed. Actually this is far from being the case. Whatever the intensity of the wind, whether a light breeze or a strong gale, it blows in a series of constantly succeeding gusts of widely varying velocities. Thus, a wind averaging 20 miles an hour may vary within the space of a few seconds from dead calm to 40 miles an hour. The accompanying diagram, which represents the actual velocities recorded by Professor Langley with a sensitive anemometer, illustrates the various fluctuations of a wind whose mean is 24 miles an hour; it will be seen that in the third minute the wind fluctuated between 30 miles and zero. Since every wind is composed of a succession of similar gusts, it is obvious that the problems of flight are far more complicated than if the wind were a current of uniform motion. It has been attempted to deduce from this "internal work" of the wind an explanation of the obscure problem of the "soaring" flight practised by some birds. The cause of the gusty nature of the wind is the instability of the air and its friction against natural obstacles on the surface of the ground, or even the waves of the sea; at the same time, the higher we ascend in the atmosphere, the more regular becomes the flow of the wind.

19. Irregularities in Direction.—In addition to its variations in intensity the wind often exhibits considerable instantaneous variations in direction, both vertically and horizontally. These variations, again, have been invoked to explain away soaring flight, but data on these points are too scarce and unreliable to lay down any general rules. It is, however, certain that changes occur *instantaneously* in the direction of the wind, amounting to as much as 20° from its mean direction; similarly, even over per-

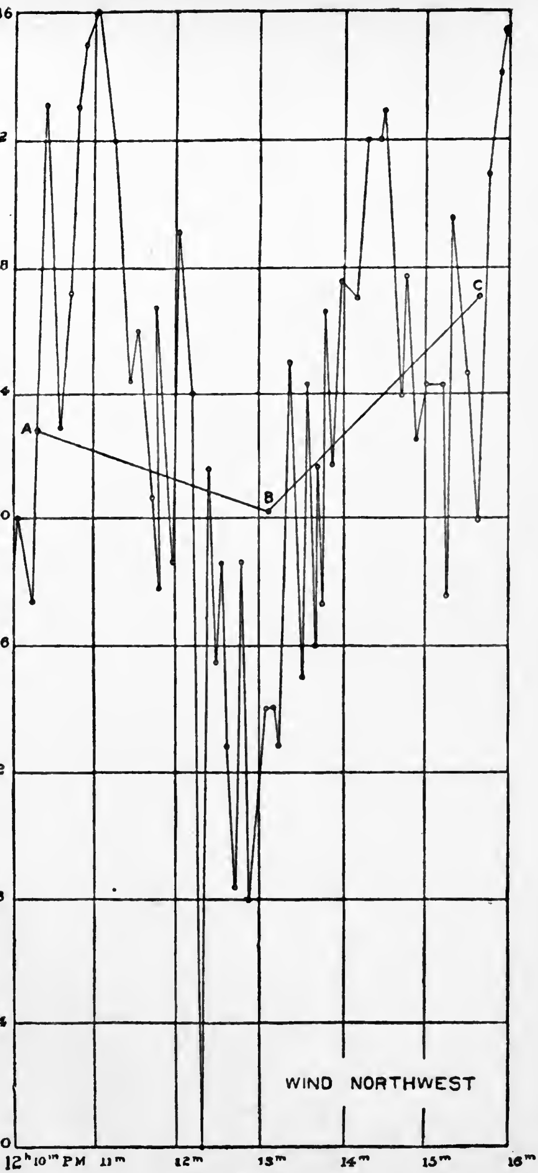


FIG. 2.

Ordinates.—Velocities in miles per hour.
Abscissæ.—Time in minutes.

fectly level country, the instantaneous variation of the wind reaches 5° to 10° from the horizontal.

20. Wind Pressure.—By reason of its tenuity and invisibility, the air is often considered as offering little or no resistance to bodies impelled through it. This is far from being the truth. In fact, the resistance of the air, which is most clearly seen in the pressure of the wind on exposed surfaces, such as buildings and bridges, is considerable, amounting in very high winds to as much as 30 lbs. per square foot of surface.

The actual pressures for various velocities on rigid flat surfaces are given in Table II. The pressure of the wind on such surfaces varies as the square of the velocity of the wind and in direct ratio with the area of the surface, the whole multiplied by a certain constant which will be considered in detail in the next chapter. If R is the pressure in kilogrammes per square metre, S the area of the surface in square metres, and ϕ the constant, the formula runs as follows:—

$$R = \phi S V^2.$$

21. Summary.—The density of the air varies from its normal (at 0° C. under 760 mm. pressure) owing to (1) variations in pressure and (2) variations in temperature. The former are due either to a meteorological change in atmospheric pressure or to elevation above the earth's surface; the latter are also due to meteorological conditions, and in addition the temperature decreases in proportion with the height above the earth's surface. The density of the air *increases* with increased pressure and *decreases* with increased temperature, and *vice versa*. The air is a compressible elastic fluid, most irregular in its flow. The wind increases in velocity the further we ascend above the earth's surface, while its direction gradually veers to the right. Upward and downward currents are frequently met with, and arise from meteorological conditions (such as variations in temperature or pressure) or from natural obstacles on the surface, such as mountains, houses, trees. The wind is not a current of uniform motion, but consists of a succession of gusts of varying intensity and direction, both horizontally and vertically. The pressure exerted by the wind on surfaces placed perpendicularly to it varies as the square of the velocity and directly as the area of the surface.

CHAPTER II

THE RESISTANCE OF THE AIR: THE INCLINED PLANE

The Force of Gravity—The Dynamic Flying-Machine—Motion through the Air—Air-Resistance—Factors of Air-Resistance—Density of the Air—Velocity—Size of the Surface—Shape of the Surface—Total Air-Resistance—Coefficient of Resistance—Coefficient K affected by the Density of the Air—Acceleration Neutralised by Air-Resistance—The Parachute—The Kite—Forms of Kites—The Inclined Plane—Aspect Ratio—Total Resistance of the Inclined Plane.

1. The Force of Gravity.—Every mass is acted upon by the force of gravity, which is the attraction towards the centre of the mass of the earth. In order to rise up into the air and to remain supported therein by means of a flying-machine it is necessary to produce a vertical force acting from below upwards which shall counterbalance the vertically downward force of gravity. In other words, we must have a vertical upward force equal to the weight of the machine. In order to obtain this force in the case of a dynamic flying-machine we utilise the resistance of the air.

2. The Dynamic Flying-Machine.—At this point it is essential that the precise meaning of the term "dynamic flying-machine" should be clearly understood. Two means are available for rising into the air: (1) the static or "lighter-than-air," and (2) the dynamic or "heavier-than-air." The former utilises a body which is itself lighter than a corresponding volume of air, and which therefore ascends into the air until its weight has become equal to the air, when it remains suspended without calling for the application of any further energy. The latter method consists in driving a heavy machine against the air in such a way as to utilise the resistance of the air itself as a means of support; it follows that in this case support in the air is derived from motion through it, and consequently that, as soon as this motion fails, the machine will be deprived of its support and return to the earth. To the former class belong balloons and dirigibles, to the latter flying-machines of every type, but principally aeroplanes.

3. Motion through the Air.—Generally speaking, the result remains the same whether a body moves through calm stationary air at any given speed, or whether the body is fixed and an air-current of the given speed blows against it: our only concern, in the science of dynamic flight, is with the *relative movement* between the body and the air. Once a flying-machine has risen into the air, the wind ceases to exist for it, save only so far as its position relatively to the earth is concerned. Its motion, *relatively to the air*, remains the same in a dead calm or in a 60-knot gale. It must here be explained, however, that in actual practice a difference does exist between the navigation of an aeroplane in still and in rapidly-moving air. This is due—apart, of course, from such difficulties as starting and alighting—to the fact that the wind is made up of a succession of gusts, and that its fluctuations in speed become the more marked the stronger the wind (Chapter I. § 18).

4. Air-Resistance.—The resistance of the air, as exemplified in the pressure of the wind, has been indicated in Chapter I. (§ 20). Since the dynamic flying-machine utilises the resistance of the air as its means of support, it now becomes necessary to examine the nature and the laws of air-resistance more closely. Wind-pressure, however, illustrates only one phase of air-resistance. Let us take another case. Take two sheets of paper of the same size and material and consequently of equal weight. Squeeze the first into a ball, and let both fall to the ground from the same height: the ball of paper will of course reach the ground much more quickly than the plane sheet of paper. This difference in the rate of fall is due solely to the resistance of the air, which acts with greater retarding effect on the large surface of the sheet than on the smaller surface of the ball. It is important to remember that the resistance of the air is equally exerted in every direction, vertical and horizontal.

5. Factors of Air-Resistance.—It has already been stated that air-resistance depends on two factors, the velocity and size of the surface. But, as a matter of fact, four separate factors must be considered. These are the following:—

(*a*) Density of the air.
(*b*) Velocity.
(*c*) Size of the surface.
(*d*) Shape of the surface.

6. Density of the Air.—Air-resistance varies in direct proportion to the density of the air. It has been shown (Chapter I. §§ 3 and 4) that the density of the air depends on the pressure and the temperature; therefore, since a difference in pressure of 1 mm. of mercury causes the density to vary by 0·13 per cent., and since a difference in temperature of 1° C. causes the density to vary inversely by 0·36 per cent., it follows that air-resistance is affected in precisely the same extent. In other words, the resistance of the air will be greatest during a period of great barometric pressure during the cold of mid-winter, and least during the smaller pressures in summer. In fact, the greatest possible variations that occur in the pressure and temperature on the face of the earth may cause the air-resistance to vary by as much as one-fourth of its normal value. The density of the air can be found from the following formula:—

$$\rho = 1{\cdot}293 \frac{H}{760} \times \frac{273}{273+t}$$

where ρ = density (in kg. per cubic metre), H = pressure in mm. mercury, and t = temperature in degrees C. Consequently, when the pressure in mm. mercury corresponding to the height is known (from Table III.) it is easy to calculate the density of the air at any given altitude.

7. Velocity.—Air-resistance varies as the square of the velocity (it should be remembered that the term velocity applies to the relative speed of the surface to the air; see Chapter II. § 3). This law may be said to be true for flying-machines of every type, although strictly speaking it only applies to velocities up to 200 miles an hour, in excess of which the resistance varies according to a higher power; but since the aeroplane is not likely to exceed 200 miles per hour, we may accept the law of the square of the velocity.

8. **Size of the Surface.**—In default of more accurate knowledge we must accept the rule that air-resistance is directly proportional to the area of the surface on which it acts. This is, however, known not to be perfectly true: in the case of very small surfaces, for instance, the resistance is, proportionately, slightly less than for very large surfaces. Again, it has been proved that resistance is influenced to some extent by the outline of the surface—the smaller the perimeter, the smaller the resistance; according to this observation, therefore, a surface of circular shape experiences less resistance than a square of the same area. But, for the present at all events, we must accept the rule as given above.

9. **Shape of the Surface.**—In this case we are on even more uncertain ground. The shape of the surface has undoubtedly a very great influence on air-resistance: this truth is a matter of everyday experience. In the case of an open umbrella, for instance, every one has observed that the outer or convex side offers far less resistance than the inner or concave side. A sphere offers less resistance than a disc of the same diameter, a cylinder with rounded ends less than a sphere. The shape offering least resistance of any is a fish-shaped, or fusiform, body with its blunt end forward. The cause of this variation in resistance with the shape lies in the fact that certain shapes allow the air to flow past them with less

disturbance than others, disturbance in the flow of the air always causing resistance. Since we are here only concerned with the *effect* of resistance, and not with its *cause*, we must content ourselves with the fact that every different shape of surface has a different value of resistance: this factor is termed the coefficient of resistance.

10. Total Air-Resistance.—Before dealing further with the coefficient of resistance we may here sum up the factors that influence resistance. For a moment we will omit the influence of the density of the air. The resistance R (in kg. per square metre) varies as the square of the velocity V, directly as the area S (the greatest area perpendicularly to the direction of motion, in square metres), and according to a coefficient ϕ (see Chapter I. § 20). This gives us the formula

$$R = \phi SV^2.$$

11. Coefficient of Resistance.—It is when dealing with the coefficient of resistance that we touch upon what has long proved the thorniest question in the whole science of aerodynamics. Fortunately, it is unnecessary to set down here the controversies that have raged round the point; we will be content with simply ascertaining its value. The fact that the coefficient of resistance varies according to the particular shape of surface adopted has already been made clear (Chapter II. § 9); it only remains now, for our purpose, to take a surface the shape of which shall be best applicable to the theory of the aeroplane. The surface that will best suit our purpose is a square plate, of the utmost possible thinness, placed perpendicularly to the direction of motion, or with its face so that it is struck full and square by the wind. Now, for a surface of this description the coefficient of resistance, denoted by the symbol K, is proved by experiment to lie between 0·07 and 0·08; the mean of these figures is usually adopted, so that we may definitely fix its value at 0·075. This value, however, only holds good for the metric system of measurement; in measuring the resistance in lbs. per square foot, the coefficient $K=0{\cdot}00143$; but in this and the following chapters only the metric value will be taken.[1] Let us take a surface of 1 square metre area, the velocity being 1 metre per second; if we apply the formula $R=KSV^2$, we obtain $R=0{\cdot}075$ (kilogrammes). A surface of 1 square metre moving at 1 metre per second therefore experiences a resistance from the air amounting to 75 grammes. Again, if we double the velocity, the same plate moving at 2 metres per second will receive a pressure of 300 grammes; that is, by doubling the velocity we quadruple the resistance.

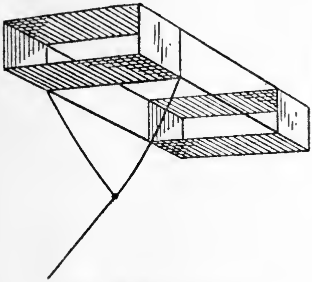
12. Coefficient K affected by the Density of the Air.—So far we have neglected the influence of the density of the air in the fundamental formula $R=KSV^2$; but it has been seen that the resistance is proportional to the density; therefore we need only modify the value of K according to the density. That is, for every decrease of 1 mm. mercury in the pressure we subtract 0·0013 of its normal value from the coefficient K, and for every increase in temperature of 1° C. we subtract 0·0036 of its normal value; since $K=0{\cdot}075$ for a pressure of 760 mm. and a temperature of 0° C.

[1] For values of K for other systems of measurement, see p. 121.

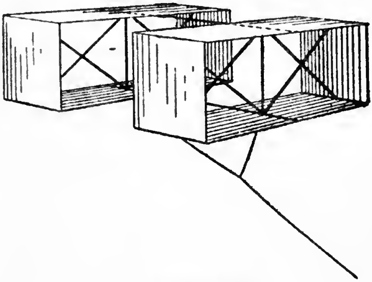
13. Acceleration Neutralised by Air-Resistance.—The above are the fundamental laws of air-resistance on which is based the whole science of flight. A certain amount of uncertainty still prevails in many cases, as has been indicated, but if absolute accuracy is still wanting in several respects, the laws laid down above in their main features are undeniably correct; moreover, they have the merit of being perfectly efficient in practice. An interesting consequence follows from these laws: a body falling through the force of gravity has a rate of fall that continually increases, a phenomenon which is known as acceleration. But we have seen that the resistance of the air grows as the square of the velocity; with a body falling through air there arrives, therefore, a moment when acceleration is balanced by the resistance; and from that moment onwards the body falls at a uniform rate of speed.

14. The Parachute.—One of the earliest and simplest types of air-machines depends on this principle. The parachute simply consists of an expanse of material below which is suspended the aeronaut. At the moment of release this material is folded up like a closed umbrella, and the fall is extremely rapid; but, as the rate of fall increases, the rapidly growing resistance forces open the umbrella, the resistance increases still further by the added expanse of the carrying-surface, until the rate of descent very soon becomes uniform, and the parachute with its load, upborne by the resistance of the air, gently descends at a slow, even rate of motion to the ground.

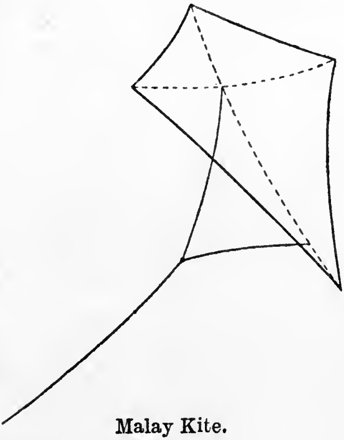
15. The Kite.—A still earlier form of flying-machine—but which has not been used for man-carrying until recent years—is the kite. This, in its simplest but quite effective form (the "Malay" kite), merely consists of a flat or plane surface main-



Hargrave Box Kite.



Hargrave Box Kite.



Malay Kite.

FIG. 3.

tained at an angle to the wind by a cord from the ground. Here again, therefore, we have the thin plane surface, whose laws of resistance have been discussed, but this time its face is no longer perpendicular to the wind, but inclined to it at an angle; that is, we have to deal with an *inclined plane.*

16. Forms of Kites.—It should be said at once that all types of kite, however much they may differ in appearance, are in their essence simply an inclined plane. This is true even in the case of the "box" kite, invented by Lawrence Hargrave, which consists of two or more superposed planes.

17. The Inclined Plane.—We now have to consider the effect on air-resistance of the inclination of the plane. This has long formed a subject of acrimonious discussion between mathematicians and scientists of various schools. Some, deriving their opinion from Newton, maintained that resistance varied as the *square of the sine* of the angle of inclination: had this been true the aeroplane would never have been realised, since it would have required engine-power in excess of anything that could be furnished. Fortunately they were mistaken. Others, on the other hand, claimed that resistance varied directly as *the sine* of the angle, and—although not quite accurate—this law has now been proved sufficiently correct to enable it to be applied to the aeroplane.[1]

[1] Accordingly, if α represents the angle of inclination of the plane with the horizontal, the fundamental formula becomes

$$R = KSV^2 \sin \alpha.$$

Another well-known investigator, Colonel Duchemin, proposed the formula

$$R = KSV^2 \frac{2 \times \sin \alpha}{1 + \sin^2 \alpha}$$

but the former is simpler and as effective in practice. It should be noted that, for very small angles, these formulæ approximately $= \alpha$. Therefore the resistance may be said to vary as α.

18. Aspect Ratio.—There only remains one factor to be taken into account before we can determine with absolute accuracy the resistance of a plane inclined surface. From the very earliest days it was generally accepted that an aeroplane should possess great span of wing as compared to its fore-and-aft dimension: this arrangement was apparent in every bird and flying creature in nature. But the reason was not clear; nor, in fact, has any one attempted, until quite recently, to calculate the effect on air-resistance of aspect ratio—that is, the ratio between the span and the fore-and-aft dimension of the wing of a bird or the surface of an aeroplane. This effect is, however, considerable, and its cause will be explained in due course in the next chapter.[1] As a matter of fact, the beneficial influence of a wide span as compared to a small fore-and-aft dimension only obtains in the case where the plane is inclined at only a slight angle; as soon as the angle exceeds a certain figure this influence is no longer observed. For instance, a plane whose span is 9 and whose fore-and-aft dimension is 1—that is with an aspect ratio of 9—has twice the lift of an inclined square plane (of the same area) when inclined at an angle of 2°, but only 1·25 times the lift when inclined at 12°.

[1] For the present it is sufficient to give the formula, first proposed by M. Soreau:

$$R = KSV^2 \lambda \sin \alpha$$

where λ is the coefficient giving the effect of aspect ratio.

$$\lambda = 1 + \frac{1 - m \tan \alpha}{\frac{1}{1+m^2} + \frac{2m}{1+m} \tan \alpha + 2 \tan^2 \alpha}$$

where $m = \frac{b-a}{b+a}$, a being the fore-and-aft dimension and b the span.

19. Total Resistance of the Inclined Plane.—We have now examined every factor entering into the resistance of an inclined plane of pronounced span. We have seen that it varies directly as the area of the surface, as the square of the speed, that it has a definite coefficient of resistance K (dependent on the density of the air); in addition, it varies directly as the sine of the angle of inclination and in a certain proportion with the aspect ratio. It will be seen, therefore, that the formula

$$R = KSV^2 \lambda \sin a$$

is in reality a very simple one, which enables us to calculate the resistance of an inclined plane without any difficulty. In the next chapter we can now examine the actual flow of air round a surface, from which we shall be able to deduce the manner and direction in which the resistance—that is, the support of the air—is exerted and to deal with the surface actually employed in the modern aeroplane —the curved plane.

CHAPTER III

FLOW OF THE AIR—THE CURVE—LIFT AND DRIFT

The Air as a Support—Resistance Normal to the Surface—Flow of the Air—Flow of Air round an Obstacle—Flow of Air round an Inclined Plane—Slip of Air over the Side Edges—Flow of Air round a Solid—Stream-line Body—Flow of Air round a Curve—Centre of Pressure—Distribution of Pressure—Lift and Drift of Flat Planes—Lift and Drift of a Curve—Coefficient K for a Complete Aeroplane—Effect of Disturbed Air on Planes—Superposed Planes—Different Types of Curves—Curvature : Shape of Curve—Skin-Friction—Resistance of Wires—Centre of Gravity : Centre of Pressure : Stability—Summary.

1. **The Air as a Support.**—So far the air has only been considered as offering resistance; it now remains to regard it as a supporting force. We are now in a position to calculate with a fair degree of accuracy the resistance offered by the air to the forward motion of an inclined plane, and it is this resistance which is partly converted into a supporting force.

2. **Resistance Normal to the Surface.**—Newton first enunciated the law that resistance is normal to the surface; that is, its direction is at right angles to the surface. In the case of a plane placed perpendicularly to the direction of motion, for in-

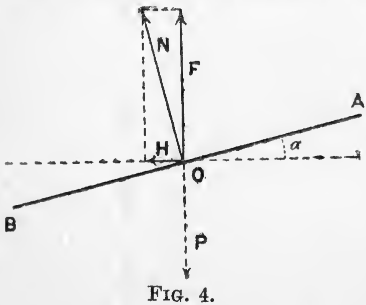


Fig. 4.

stance, the direction in which the pressure acts is parallel to the line of motion; in the case of an inclined plane, it lies at right angles to the plane.

In the accompanying diagram, which depicts the forces acting on an inclined plane, N = the total resistance of the plane, whose direction is normal to the plane. This force (like every other force) can be resolved into the two component forces, F and H.

F = vertical upward force or "LIFT,"
H = horizontal retarding force or "DRIFT."

Again

F = P, the weight of the aeroplane,
H = T, the force necessary to drive the aeroplane, also called the "tractive effort."

Of these various forces the only one already known to us is the total resistance

$$N = KSV^2 \lambda \sin a.$$

From this it is possible to deduce the values of the lift and drift of an aeroplane. But now arises the difficulty that the lift and drift of the surface universally employed in aeroplanes—the curved "plane"—vary enormously as compared to the flat plane. It therefore becomes necessary to examine the origin of these differences; and this is best done by first examining the actual flow of the air round plane and curved surfaces; from this we shall be able to ascertain not only the values of the two components of air-resistance, lift and drift, but the distribution of the pressure on a surface and its direction.

3. Flow of the Air.—Firstly, it must be remembered that the air is unstable in its flow, being composed of whirls and eddies, whereas fluids such as water, for instance, have a regular flow. If we imagine a regular stream of water to consist of an agglomeration of a vast number of minute threads of fluid, or "stream-lines," each of these different threads of water would flow onward regularly without disturbing its neighbours. In the case of air this is not so; the stream-lines, instead of flowing on separately, easily become mingled and disturbed. The instability of the air renders it impossible to compare its flow to that of water; nevertheless, for the sake of clearness, we shall here consider its

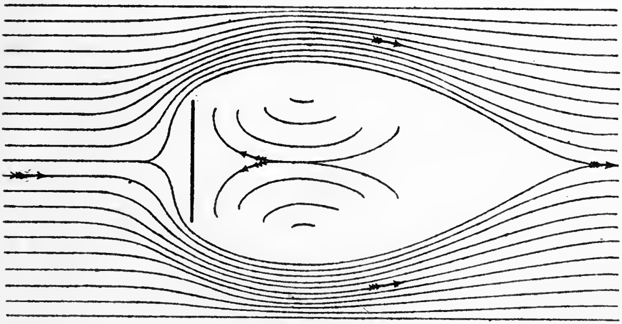


FIG. 5.

flow as being composed of a number of adjoining threads of air or "stream-lines."

4. Flow of Air round an Obstacle.—If the air in motion encounters an obstacle, such for instance, as a plane placed at right angles to its direction, the air will obviously have to flow round the edges in order to get past the obstacle. The stream-lines will separate about the centre of the surface and be forced outward in every direction to clear the edges; once these are passed the stream-lines will gradually return to their original direction. Two important phenomena should be observed in this case. Firstly, in seeking to flow away past the edges, the air is compressed to a considerable extent. Secondly, instead of returning immediately to its original line of flow, it only does so slowly, and eddies are formed behind the surface. Through these eddies the normal pressure on the rear of the plane is decreased, and negative pressure, or suction, is obtained. Actually, therefore, the total resistance of the surface is the sum of the "head-resistance" and suction; but for present purposes there is no need to consider these two factors separately. It will,

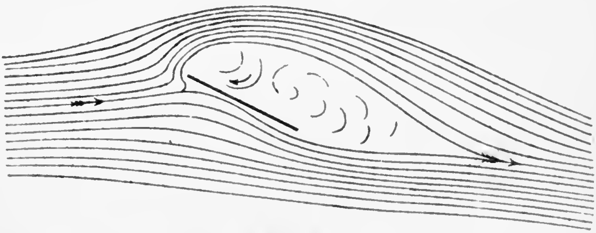


Fig. 6.

however, be obvious that the more this suction effect is reduced, the less will be the total resistance; consequently, a form of surface in which the stream-lines of the air meet again at the rear of the surface, without giving rise to eddies, will offer the least resistance to the air.

5. Flow of Air round an Inclined Plane.—If, instead of being at right angles to the stream, the plane is inclined as shown in Fig. 6, the same general phenomena are observed, but with one important difference: the stream-lines have but little difficulty in flowing away past the lower edge, but experience considerable difficulty in clearing the upper edge. As a consequence, greater compression will occur near the forward edge of the plane, which will experience greater pressure than the rear edge. In other words, in an inclined plane the "centre of pressure" is situated in front of the geometrical centre of the plane. The smaller the angle of inclination from the horizontal, the further forward is situated the area of greatest pressure.

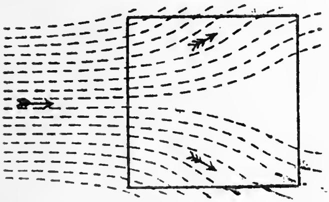


FIG. 7.

Slip of air over a square plane.

6. Slip of Air over the Side Edges.—Since the air naturally takes the path of least resistance, it will attempt to escape, not only over the forward and rear edges, but along the lateral sides of the plane as well. This renders it clear why a plane of wide span is so much more efficient than a square, and still more than one with its greatest dimension in the direction of flight. Figs. 7, 8, and 9 represent in plan form the flow of air round a square, a wide-span plane, and a short-span rectangular plane respectively.

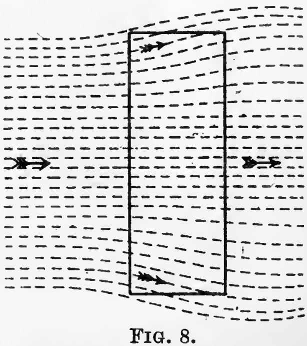


FIG. 8.

Slip of air over a wide-span plane.

It will be seen that, in its efforts to escape over the sides of the plane, the air acts upon these three forms in a very different manner: the wide-span plane alone receives practically the whole current of air; while in the other two cases only a small portion of the energy of the air is utilised, the remainder being wasted by slipping over the sides. In the case of an actual aeroplane, this tendency of the air to "side-slip" may be still further reduced by "leading" the current of air, by such means, for instance, as small ridges running along the surface of the plane from fore to aft. The "curtains" or "panels" of some biplanes, such as the early type Voisin, were also supposed to effect this purpose among other things.

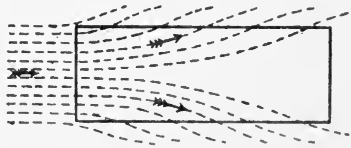


FIG. 9.

Slip of air over a short-span plane.

7. Flow of Air round a Solid.—If instead of a plane we take a solid, such as a sphere, certain

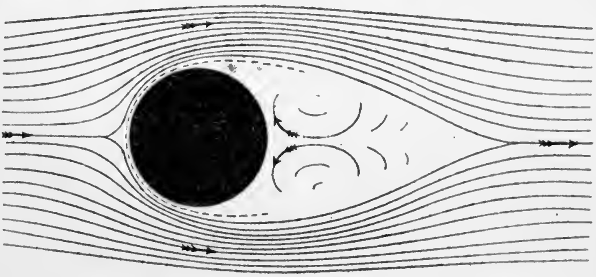


FIG. 10.

differences will be observed in the flow of air. It has already been stated that a sphere offers less resistance than a thin plane of equal area. Fig. 10 will make clear the reason. The stream-lines are not forced outwardly so violently, and the region of discontinuity behind the sphere is far smaller in extent.

8. Stream-line Body.—If in the above figure we fill in the outline enclosed by the regular stream-lines we obtain a body of the shape indicated in Fig. 11, in which the stream-lines are diverted along the path of least resistance and rejoin each other in the rear without leaving any region of discontinuity whatever. This is known as a

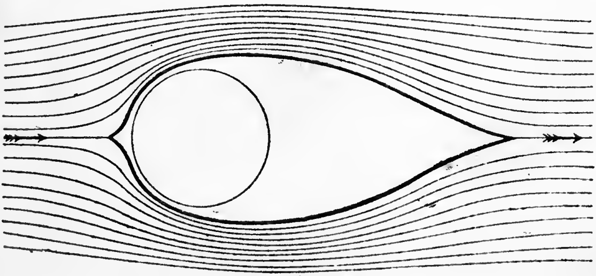


Fig. 11.

"stream-line" body, and offers the minimum of resistance. It is obvious, therefore, that every part of an aeroplane which produces "ineffective" resistance—that is, resistance which is not utilised for sustentation but simply opposes forward motion—such as framework, struts, the body, &c., should conform to stream-line section as much as possible in order to reduce the drift.

9. Flow of Air round a Curve.—Finally, it remains to consider the flow of air round a curve. On this point it is impossible to enter into detail, since the effect of curvature on the flow of the air is but imperfectly known. We will, therefore, only state the broad facts of the case, which have been over and over again demonstrated in practice, without analysing their origin too closely. Now, if we compare Fig. 6 and Fig. 12 the most essential difference is the more even flow of the air, especially over the upper surface of the curve, which is almost of stream-line form. Secondly, the region of discontinuity is very small—it is indeed questionable whether it need exist at all. The immediate

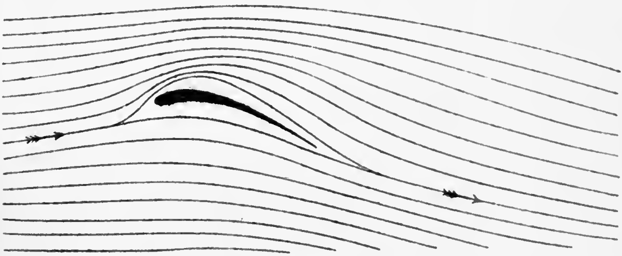


FIG. 12.

consequence of this is that the drift of a curve is far less than that of a plane of equal area. The third noteworthy point is the behaviour of the stream-lines under the forward part of the curve; Fig. 12 gives a slight indication of an eddy: that such an eddy exists is unquestionable, but its precise effect is unknown. Probably it plays an important part in the lift of a properly designed curved surface. Certain it is, at any rate, that such a curve, while having less drift, possesses far more lift than a plane surface; but, until the precise action of the air is more fully understood, it is impossible to hazard a complete explanation of this point, and we must perforce remain content with the results of practical experiment alone, which are ample to demonstrate the much greater efficiency of the curve as compared to the plane. Two important facts remain to be noted in regard to the curve: (1) a curved surface is subject to the same laws of air-resistance as the plane; (2) the pressure of the air on a curve is the same as that on a plane of considerably greater area, save only that in a curve there is *in addition* a certain amount of pressure along the path of forward motion; in other words, a curve is subjected, by the resistance of the air, to a certain amount of reverse pressure *in the direction of flight.* Certain specially shaped curves, at very small angles, may, according to the above rule, even be driven forwards by the wind; that is, *they may be made to advance into the teeth of the wind by the pressure of the wind itself.*

10. Centre of Pressure.—In dealing with the flow of air about an inclined plane, it has already been shown that the area of greatest pressure moves forward according as the angle of the plane diminishes. When the plane is perpendicular, as in Fig. 5, the centre of pressure is in the exact centre of the plane; as it is gradually inclined towards the horizontal the centre of pressure moves forward until, for very small angles indeed, it will be situated near the forward edge. The position of the centre of pressure is a point of capital importance in the science of flight; the following two formulæ locate its position in a plane, for different angles of inclination. In the accompanying diagram of a rectangular plane surface it is necessary to find the position of the centre of pressure P relatively to the centre of the rectangle G and the forward edge F. Let GF $=h$, GP $=x$, and PF $=y$. The first formula, proposed by Joessel, runs

$$\frac{x}{h}=0 \cdot 61\ (1-\sin a).$$

The second was proposed by Soreau:

$$\frac{x}{h}=\frac{1}{2\ (1+2 \tan a)}.$$

These formulæ give the exact position of the centre of pressure, the important point to remember being that it moves forward as the angle is reduced. In practice, the centre of pressure lies within the first third of the total fore-and-aft dimension of the surface from the forward edge. Strictly speaking, the above rule only applies to a plane surface, but in its general aspect the rule may also be applied to curves. A most important consequence is that in the case of surfaces of large span as compared to the fore-and-aft dimension—that is, whose aspect ratio is high—the relative movement of the centre of pressure is much less than in the reverse case, of a square for instance. And this fact, as will be seen hereafter, is of the greatest possible significance for the important question of stability. Finally, it may be well to make the term "centre of pressure" so clear as to avoid once and for all mistakes to which

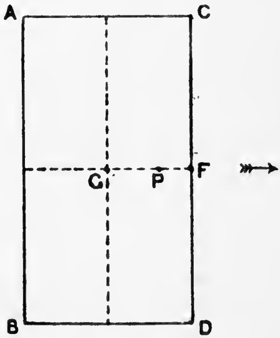


FIG. 13.

it sometimes gives rise. It should be understood that the term is a purely theoretical one, meaning "the point at which the resultant of all the forces of air-resistance on a surface acts." In other words, the pressure is not actually greater at this point than at all other points; the centre of pressure merely constitutes the centre of the area of greatest pressure.

11. Distribution of Pressure.—It has been shown that the greatest pressure on an inclined plane (whether flat or curved) is relatively close to the forward or leading edge. In the wide-span planes used in the modern aeroplane, it is situated, for small angles, about one-third of the total fore-and-aft dimension from the leading edge. The rear portion of the plane, therefore, does comparatively little work; from this it follows that there is every advantage in building wide-span, narrow planes; in other words, it is necessary to obtain as much "forward edge" as possible.

12. Lift and Drift of Flat Planes.—The distribution and the direction of the pressure acting on an inclined plane are matters of the greatest importance, constituting as they do the lifting-power and resistance to forward motion of an aeroplane. The total resistance of the air is normal to the surface; obviously we can break up this total normal force into two parts: the first acting vertically, the latter horizontal. The former produces "lift," the latter "drift" (see § 2). Now, a brief consideration will show that in designing an aeroplane surface, every effort should be made to increase the lift and reduce the drift; and precisely this, as has been seen, is accomplished by the curved surface. It is therefore important to know the precise relations between the lift and the drift of plane surfaces, from which it will be possible (see § 13) to learn the lift and drift of curved surfaces. A little consideration will show that, just as the total resistance varies with the angle of inclination, so must the lift and drift vary with the angle. In Fig. 14, which shows the direc-

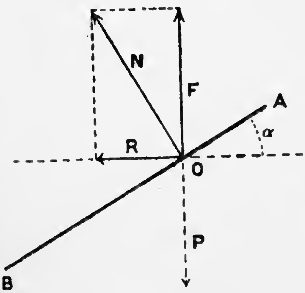


Fig. 14.

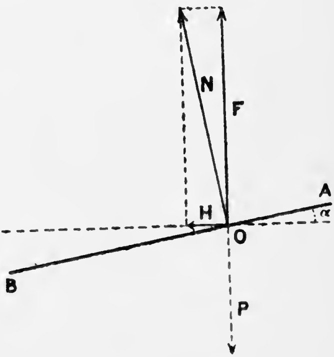


Fig. 15.

tion of forces on a plane surface, the total resistance N does not by any manner of means act vertically upwards; but, if the angle is decreased, as in Fig. 15, the immediate result is that the total resistance N comes to lie much closer to the lift F. In fact, in the case of the very small angles adopted in practice, the forces N and F almost coincide. Obviously, therefore, to obtain the best results, it is necessary to reduce the angle of inclination to the lowest possible degree which shall yet give sufficient lift. Now it is possible to represent the relation of the forces F and H—the lift and the drift—by formulæ, but, in view of the uncertainty that still prevails on the lift and drift of a curve, it has been deemed preferable to represent them by means of a table.[1]

13. Lift and Drift of a Curve.—The lift and drift of a curve, and their relation to each other, are, generally speaking, the same as for a plane surface *of considerably larger area.* But we have already noticed one important difference: the resistance of the air to forward motion, the horizontal component H, is appreciably lower. At this point is encountered the difficulty that insufficient data are available—due to the lack of experiments and an inadequate knowledge of the action of air on a curve—to enable us to determine the *exact* relation of lift and drift for curves of various depth and configuration. There is the additional difficulty, in applying the question to a complete aeroplane, that such parts of the structure as the body, struts, stays, and bracing-wires offer a considerable amount of additional resistance, which must be taken into account and reduces the efficiency of the aeroplane. Dispensing, therefore, with cumbersome, intricate, and certainly incomplete explanations, we will merely give the following table, compiled from M. Eiffel's work, which we believe to represent with fair approximate accuracy the actual lift and drift of an aeroplane surface. A coefficient x_a has been cal-

[1] The following formulæ represent the matter correctly: $F=N$ (for very small angles) $=KSV^2\alpha$; $H=KSV^2\alpha^2$. The relation of F and H of a curve is somewhat different. K in these formulæ has been modified according to the coefficient λ of aspect ratio. See the table on the next page.

culated for the horizontal component H, or the drift; and a coefficient y_a for the lift F. These coefficients are dependent on the angle of inclination a. All that is required is to multiply the usual value of resistance by x_a to obtain the drift, and by y_a to obtain the lift, as follows:—

Drift . . . . . $KSV^2 \times x_a$
Lift . . . . . $KSV^2 \times y_a$

a	x_a	y_a	a	x_a	y_a
−9°	−0·068	−0·011	3°	0·028	0·545
−8	−0·072	0·032	4	0·050	0·598
−7	−0·073	0·072	5	0·071	0·646
−6	−0·072	0·112	6	0·094	0·691
−5	−0·068	0·154	8	0·139	0·759
−4	−0·063	0·198	10	0·191	0·804
−3	−0·056	0·239	15	0·306	0·850
−2	−0·047	0·285	30	0·462	0·784
−1	−0·037	0·332	60	0·765	0·474
0	−0·024	0·381	90	1·000	0·000
1	−0·008	0·435			
2	0·009	0·488			

To take an example: the curved supporting surface of an aeroplane measures 35 square metres; the angle is 6 degrees; the speed is 20 metres per second; the lift and drift will be:

$$H = 0{\cdot}07 \times 35 \times (20)^2 \times 0{\cdot}094 = 92 \text{ kilogrammes.}$$
$$F = 0{\cdot}07 \times 35 \times (20)^2 \times 0{\cdot}691 = 677 \text{ kilogrammes.}$$

14. Coefficient K for Complete Aeroplane.— In the above example the value of the coefficient K has been taken as 0·07—the value for a square *plane* surface—and the value of the coefficient λ of aspect ratio has been ignored. In reality, for a well-designed aeroplane of average curvature, with an aspect ratio of 6 : 1 (which is about usual), the total value of K and λ together amounts to about 0·4. In future, therefore, λ may be added to K, and the value of the latter for an aeroplane taken as 0·4.[1]

15. Effect of Disturbed Air on Planes.—The pernicious effect of disturbed air is not only observable to the rear of a surface: it is of even greater importance that the air should not be disturbed before it meets the surface. To utilise to the full the energy of the air, it should strike the carrying planes without having previously been disturbed by large or small surfaces situated in front of the main planes. Examination of Figs. 6 and 12 will show graphically that when an inclined plane or a curve moves through the air, it deflects a portion of the air downwards ; if, therefore, a plane have another one situated immediately in front, it will be struck by this downwardly driven air with serious loss of efficiency.

16. Superposed Planes.—Modern practice has divided the aeroplane into two classes: the monoplane with a single surface, and the biplane with one surface placed above the other. An important question is to know whether the planes lose efficiency by being superposed. Practical experiment tends to prove that there is undoubtedly some loss—although very slight—of efficiency by super-

[1] For a complete aeroplane the following formula gives the lift and drift:—

Lift . . . . $F = KSV^2\alpha$

Drift . . . . $H = KSV^2(\alpha^2 + s)$.

Here $s = \frac{\phi\sigma}{KS}$, σ being the "equivalent surface"—that is, a square plane perpendicular to the wind whose resistance is equal to the resistance of all the useless parts of the aeroplane, such as the body, struts, &c.

posing the surface; this loss becoming more marked the smaller the distance between the surfaces. The usual practice is to make the distance between the planes equal to their fore-and-aft dimension. Although partly due to structural requirements, it seems that this method reduces the loss of efficiency to a very low figure. In fact, the compression of the air, and its disturbance beneath a plane, do not extend downwards sufficiently far

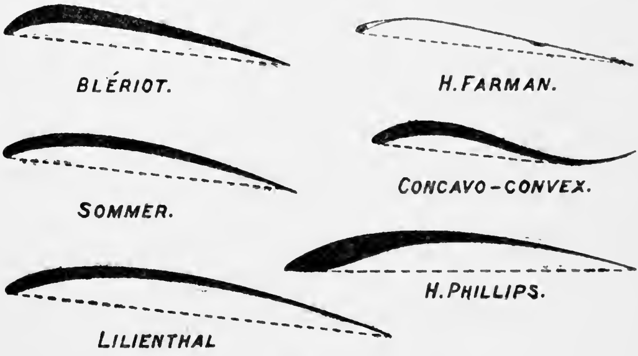


FIG. 16.

enough to affect the lower plane, if the above rule be followed.

17. Different Types of Curves.—It is scarcely an exaggeration to say that, practically, the planes of every aeroplane differ both in shape and in degree. The usual parabolic curve employed, for instance, by Farman, Sommer and Blériot, and other leading constructors, is here shown. Lilienthal, the famous German pioneer, built the surface of his gliders with a more uniform curve, practically the segment of a circle. Another form of curvature, with a reverse curve added, known as the "concavo-convex," has been used in America and in England. Finally, one of the most interesting curves of all is the one which owes its origin to H. Phillips, and has also formed the subject of independent experiments by Hargrave in Australia and Professor Montgomery in California. This curve, strictly speaking, is not actually inclined from the horizontal at all, since its front edge is bent downwards sharply, until in some cases the chord of the curve is actually inclined at a negative angle. This form of curve, nevertheless, exercises a certain amount of lift, an effect which is sometimes ascribed to the creation of a vortex or eddy under the deep part of the curve, the formation of the vortex being due to the "dipping edge."

18. Curvature: Shape of Curve.—One can lay down no definite rules either for the depth or the shape of the curve of an aeroplane surface. The most efficient form of sustainer has to be settled—for the present at all events—as the result of practical experiment. The curve usually adopted is parabolic, the deepest part of the curve being situated near the forward edge. This forward edge is usually thick in section, the surface tapering off to a fine point in the rear. The greatest depth of the curve—or as it is sometimes called, the "camber"—varies with the shape, the angle of inclination, and the weight and speed for which the aeroplane is designed. In practice the camber varies from 6 to 15 centimetres (2½ to 6 inches), for a plane with a chord—that is a fore-and-aft dimension—of 1·8 to 2 metres (6 to 7 feet).

19. Skin-Friction.—Air-resistance acts normally to the surface, as has been seen. There is, however, another part of air-resistance which is not exerted normally to the surface. If a body moved through a fluid that possessed no viscosity, the only resistance it would meet with would be that directly exerted on its face: its rear trailing portion would pass through the fluid without effort. But when a body, such as a plane or the hull of a dirigible, is moved through the air (which *is* viscous), the current on its way past the body rubs against its surface, and creates friction. This is known as "skin-friction," and its value is sometimes supposed to be sufficiently great to be taken into serious consideration. It may, however, be said with practical certainty that with the aeroplane skin-friction is negligible. In the case of the enormous bulk of a dirigible, skin-friction may, no doubt, amount to several hundreds of pounds, but in an aeroplane it could not possibly amount to more than a few pounds. When a plane moves through the air a curtain of "dead" air is formed in front (which is plainly shown in Fig. 10); similarly a film of air adheres to the surface along the sides; consequently the free air never comes into contact with the actual surface, but with the curtain of air wherewith the surface is surrounded. And although, as is known, air possesses viscosity greater than that of water, it is still insufficient to affect the result in the case of an aeroplane. At the same time, there is obviously every advantage in rendering all surfaces as smooth and unbroken as possible, so as not to impede the even flow of the air about them. This is done in the case, for instance, of the planes of an aeroplane by enclosing their framework within "pockets," or by constructing them with a double surface.

20. Resistance of Wires.—Few experiments have been made to determine the exact resistance of wires, and it is consequently impossible to give any definite information on the point. Undoubtedly the resistance of a vibrating wire is considerable: possibly it is equal to that of a solid body occupying the space covered by the vibrations. At all events, for this reason alone, it is most important that wires should be eliminated from an aeroplane to the last possible degree. (See p. 83.)

21. Centre of Gravity: Centre of Pressure: Stability.—Properly speaking, questions of stability belong to the study of aeroplane theory and design, and are accordingly dealt with in Chapter V.; but some of the elementary points, which arise directly from the consideration of the plane and curved surface, may be taken here. In an ordinary plane or curved surface the centre of gravity is situated in the geometrical centre of the surface; not so, when we come to deal with a weighted or load-carrying plane. For in the latter case—in practice—the weight carried is not situated at or near the centre of the surface, but well in front of it. The reason for this is simple. If we suppose the air to be a perfect fluid, flowing quite evenly at a uniform rate, and an aeroplane is propelled through it in a straight line, the aeroplane will be stable if the centre of gravity coincides with the centre of pressure. And, since we have seen that the centre of pressure lies somewhere near the forward edge, the centre of gravity will also be placed in approximately the same position, and the aeroplane will be stable—it will neither pitch nor roll, nor tend to upset—in the conditions we have supposed. But in reality, as has been seen, the air is a most turbulent medium, varying in velocity and direction, with the consequence that the surface is constantly struck by the air at different angles: the centre of pressure therefore constantly varies in position, whereas the centre of gravity of course remains fixed. It is this fluctuation in the centre of pressure relatively to the centre of gravity which produces instability, and must therefore be reduced to the lowest possible margin. Now we already know that a plane with wide span but very narrow in the fore-and-aft dimension, is more efficient as a lifter than a square plane of the same area. But it has this additional advantage: the narrower the surface, the smaller obviously is the extent to which the centre of pressure can fluctuate; the narrow plane, therefore, is more stable than the square one, as well as being a far better "lifter."

22. Summary.—The resistance of the air to the aeroplane is utilised to support it. The form of body offering least resistance to the air is a "streamline" body. A curve offers less resistance than a plane, but this resistance is more effectually utilised. The centre of pressure on a curve or a plane is situated near the forward edge, moving forward as the angle is decreased. The normal resistance (N) to a plane may be resolved into the two components Lift (F) and Drift (H), whose relative value alters with the angle of inclination. If the planes are superposed, the loss of efficiency is scarcely noticeable if the distance between the planes is equal to their fore-and-aft dimension. For a complete aeroplane the coefficient $K = 0{\cdot}4$. Skin-friction is negligible. The centre of gravity is fixed, the centre of pressure fluctuates according to the angle of inclination; the fluctuation in their relative positions gives rise to instability.

CHAPTER IV

GLIDING, AND THE THEORY OF THE AEROPLANE

Rate of Fall—Experiment 1—Experiment 2—Experiment 3—Experiment 4—Model Gliders—The Man-Carrying Glider—Forces Acting on a Glider—Construction of a Glider—Theory of the Aeroplane—Lift, Speed, and Angle—Angle of Incidence—Weight carried by an Aeroplane—The Speed of an Aeroplane—The Surface necessary to carry a given Weight.

1. **Rate of Fall.**—If a lump of copper is dropped from a height of 16 feet, it will reach the ground approximately in one second. If, however, this lump is beaten out into a thin sheet and dropped face downwards, the time taken to reach the ground will be very much greater. The quantity of air displaced by the fall of the lump is many times smaller than that displaced by the thin sheet, and therefore in the latter case more work has to be done before the copper can reach the ground, though the weight is exactly the same as in the first example. Langley, in 1891,[1] published an account of some experiments he had made with a plane-dropper, which was an apparatus of his own invention for measuring the time of fall in plane surfaces moving horizontally. He found that as the rate of horizontal speed was increased, the planes took longer to fall,

[1] "Experiments in Aerodynamics," by S. P. Langley. Smithsonian Institution, 1891.

and that a plane with its forward or leading edge greater than its length from front to rear took longer to fall at the same rate of speed than one whose forward edge was smaller than its length (see Chap. II. § 18). He came to the conclusion that if these planes could be driven forward at a sufficiently high rate of speed there would be no fall at all, but that the planes would be sustained by the resistance of the air.

2. **Experiment 1.**—If a flat sheet of paper is taken and allowed to fall face downwards in still air and afterwards rolled up into a ball and dropped again, the time of fall in both cases being noted, the resistance of the air to broad surfaces will be plainly demonstrated (see Chap. II. § 4).

3. **Experiment 2.**—The next step is to obtain forward motion. This is done by holding the paper horizontally between the finger and thumb, pushing it forward and releasing it. It will be found to turn over and over in the air with a distinct progressive motion. The best results will be obtained by a rectangular surface with an aspect ratio of about 4 (say 8 × 2 inches), launched with the longest dimension foremost. This experiment affords a very good illustration of the law of the forward edge. The pressure on the fore-edge being greater than on the back, the front of the plane is tipped up, the rear edge still pursuing its way comes to the front and in turn becomes the forward edge. The operation is repeated until the surface reaches the ground.

4. **Experiment 3.**—If the same plane is launched with its smallest dimension forward, the value of aspect ratio is clearly seen. The head of the surface

will be forced up, but the extent of the rear surface will prevent it turning over (unless a strong impulse is given to it), and the whole will slide backwards; the rear edge in this way becomes the front edge, and the operation will be repeated, the surface reaching the ground by a series of zigzags.[1]

5. Experiment 4.—It will be seen from Experiment 2 that if some means can be found to prevent the front edge from being turned over by the pressure of the air, the plane will move forward and remain level. Accordingly a split shot is clipped on to the

FIG. 17.

front edge, and the plane launched. The weight of the shot prevents the fore-edge from being tipped up; the apparatus therefore remains level, but pursues a regular downward path to the ground.[2] Some trials will be necessary before the exact weight which will give it its longest flight is discovered (Fig. 17).

6. Model Gliders.—Thus a model glider has been evolved; and the student and beginner is advised to experiment largely with all sorts and shapes of surfaces, to note the behaviour of each, and to assign definite reasons to their varied and various per-

[1] This experiment is best performed with a fairly large surface.

[2] If the two corners of the front edge are slightly bent up obliquely to the flight path, better stability will be maintained.

formances. The truth, or otherwise, of each reason given can always be proved by further experiments.

7. The Man-Carrying Glider.—A glider is a large aeroplane of the size sufficient to carry a man, but without a motor. As it has no high sustained speed capable of supporting it in horizontal flight by the opposing air-resistance, a glider has to be launched either from a height or shot off a rail by some exterior mechanical device in order that a glide of any extent may be accomplished. Pilcher used to raise himself into the air by attaching a line to his machine and getting it towed by men or horses, thus converting the glider into a kite, until the desired height was attained.

8. Forces Acting on a Glider.—It is evident that there are only two main forces acting upon a glider—gravity and the resistance of the air. The forward motion is entirely due to the effort of the mass to reach the ground along the path of the least resistance. The angle that this path makes with the ground is called the gliding angle, and generally ranges between 1 in 4 and 1 in 7—that is to say, the glider drops 1 foot for every 4 to 7 feet it moves forward.

9. Construction of a Glider.—In building a gliding machine the simplest form of construction is that of a biplane, which will be found the easiest to construct, and in the event of breakages the easiest to repair. The area of the main planes should be calculated on the basis of the weight to be carried, including the pilot and the weight of the machine, and should sustain from $\frac{5}{8}$th lb. to 1 lb.

per square foot, at a speed of 19 to 23 miles an hour. Apart from the question of power, a glider is subject to exactly the same laws as a motor-driven aeroplane.

10. Theory of the Aeroplane.—The aeroplane in motion is acted upon by three main forces: (1) gravity, (2) the resistance of the air, and (3) the thrust of the propeller. We have therefore to deal with the weight of the machine, the components of air-resistance—lift and drift (useful and useless resistance, respectively)—the speed, and the angle of incidence—all of which are interdependent.

11. Lift, Speed, and Angle.—It is not proposed in this chapter to mention the power except casually, as it is dealt with in the chapter on propulsion. In the following considerations the power is assumed to remain constant. An aeroplane with a fixed loading flies at a fixed speed at a fixed angle. The first and bed-rock fact to remember is that in horizontal flight the weight must equal the lift. As the weight equals the lift, and the lift depends on the speed and angle, it is plain that both speed and angle must remain fixed to maintain the aeroplane in flight. It is impossible therefore to vary the speed of any aeroplane unless the load (and the power) are varied. If the load only is increased the aeroplane will descend, for the speed which regulates the lift will remain the same. Again, if the load only is decreased—all other factors remaining the same—the aeroplane will rise. In this event level flight can only be accomplished by increasing the angle of incidence and thereby increasing the drift; at the same time the lift and the speed are decreased, the power remaining constant. As long as the load remains the same, it is impossible to vary the speed of any aeroplane unless the area of the surface (and the power) can be varied during flight. It should be clear that—all other factors remaining the same—a decrease in area of surface means a decrease in the lift, and therefore the speed, and consequently the power, must be increased to support it. If the area is increased the lift will increase, and the same conditions as a decrease in the load being reached, the speed is consequently decreased.

12. **Angle of Incidence.**—The best angle of incidence of an aeroplane in flight is equal to its gliding angle, and this is generally found by experiment. The gliding angle is increased and decreased according to the resistance, and varies between five and twelve degrees. The original Wright biplane has a gliding angle of 1 in 8.

13. **Weight carried by an Aeroplane.**—It has been shown that the lift F must equal the weight P, for if it does not the aeroplane will fall. Now the lift depends on the drift, the surface, the speed or velocity, and the angle of incidence, and has been found (see Chap. II.) to equal the product of the coefficient of resistance K, multiplied by the surface S in square metres, by the square of the velocity V in metres per second, and by the angle a.

This gives the simple equation :—

$$F = P = KSV^2a$$

Supposing, therefore, that an aeroplane has a surface of 20 square metres and a velocity of 10 metres a second at the angle 0·12 (about 7°), how much weight will it carry?

$$\overset{K}{P = 0{\cdot}4} \times \overset{S}{20} \times \overset{V^2}{100} \times \overset{a}{0{\cdot}12}$$

$$= 96 \text{ kilograms} = 211{\cdot}68 \text{ lbs.}$$

14. The Speed of an Aeroplane.—The speed of the aeroplane depends on the weight, the surface, the drift, and the angle, so that by transposing the square of the velocity and the weight in the foregoing equation, the correct answer may be obtained:—

$$V^2 = \frac{P}{KSa}$$

$$V = \sqrt{\frac{P}{KSa}}$$

Supposing, therefore, an aeroplane has a surface of 20 square metres, a weight of 96 kilograms, and travels at an angle 0·12, at what speed will it fly?

$$V = \sqrt{\frac{96}{{\cdot}4 \times 20 \times {\cdot}12}}$$

$$= 10 \text{ metres a second.}$$

15. The Surface necessary to carry a given Weight.—It now only remains to find the surface necessary to carry an aeroplane of a given weight, travelling at a given speed at a given angle. This can be done by substituting the surface for the velocity in the foregoing equation:—

$$S = \frac{96}{{\cdot}4 \times 100 \times {\cdot}12}$$

$$= 20 \text{ square metres.}$$

Note.—These simple formulæ only give approximate results, but will be found useful in rough generalisation.

CHAPTER V

STABILITY AND STEERING

Definition—Longitudinal and Lateral Instability—Equilibrium—Low Centre of Gravity—Methods of Preserving Stability—Automatic Longitudinal Stability—Advantage of Following Surfaces—Automatic Lateral Stability—The Dihedral Angle—Vertical Surfaces—Movable Surfaces—Front and Rear Controls—Warping—Ailerons—Variable Surfaces—Starting—Mechanical Launchers—Starting on Wheels—Alighting—Turning—The Glide or "Vol Plané."

1. Definition.—Stability is the most important problem of dynamic flight. When it is said that an aeroplane is stable, it means that it has the power of preserving the natural level in flight, *i.e.* its equilibrium, and, if from any cause this level is upset either by a sudden gust or in turning, of regaining the natural level with a minimum of oscillation. There are two ways in which an aeroplane may be unstable—in (1) the longitudinal, and in (2) the lateral dimension.

2. Longitudinal and Lateral Instability.—(1) Instability in the longitudinal or fore-and-aft dimension corresponds to the pitching and tossing of a ship, and occurs when an aeroplane in ordinary conditions of flight (in a steady wind or a calm) shows a tendency to rear up or to dive down.

(2) Instability in the lateral or from side-to-side dimension corresponds to the rolling of a ship, and

occurs when an aeroplane in ordinary conditions of flight shows a tendency to turn over sideways.

In high gusty winds the aeroplane will, of course, be seen to roll and pitch and dive under the varying pressure of the wind, but if it is stable it will not carry these movements to the extent of overturning, and by returning regularly to its normal level will fulfil the condition of stability.

3. Equilibrium.—The loss of equilibrium in flight is due to the constant changes in the centre of pressure. It has been explained that the centre of gravity is fixed, and that the centre of pressure is constantly changing (see Chap. III. § 21); it is therefore necessary that the centre of gravity should so be placed that it should always be as near the centre of pressure as possible. An ideal condition of stability exists when both these centres coincide; but as in actual practice such a condition is only possible momentarily, it is usual to place the centre of gravity at some point midway between the two points marking the extremes between which the centre of pressure oscillates in normal flight. If the centre of gravity is placed too far forward or too far back, or too high or too low, a loss of equilibrium immediately follows. In the one case the pressure exerts a lift behind the weight, and in the other in front of it, which has the effect of making the surface either fall over forwards or backwards. Where the centre of gravity is too high, any loss of

Fig. 18.

equilibrium immediately sets up a couple, which tends to upset the surface. A couple is the operation of two equal parallel and opposite forces (Fig. 18).

4. Low Centre of Gravity.—The final condition to be avoided is in having the centre of gravity too low, though, theoretically, the further it is placed beneath the surface the greater the stability. In actual practice this condition, however, is bad, chiefly because through the ceaseless fluctuations of the wind the speed of the aeroplane is constantly changing; and when, for example, the increased pressure checks the progress of the surface, it would have very little effect on the centre of gravity, the inertia of which would still carry it forward. Violent oscillations would be thus set up which could not be checked. In fact, with a low centre of gravity, any departure from equilibrium would result in oscillation which would tend to increase. But when the centre of gravity is placed as near as possible to the centre of pressure, all these adverse influences are lessened to the greatest degree possible.

5. Methods of Preserving Stability.—While the position of the centre of gravity is of primary importance in stability, an aeroplane cannot, on account of the ever-changing conditions of pressure and speed, be wholly dependent on it, and special aids to the preservation of the level in flight are accordingly used.

These are—

(1) The design and arrangement of the sustaining surfaces (automatic stability).

(2) Movable surfaces (controlled stability).

6. Automatic Longitudinal Stability.—Automatic longitudinal stability is obtained in a certain degree by having fixed auxiliary surfaces placed behind the main surface, and this arrangement is commonly in use at the present time; in fact all modern aeroplanes may be said to possess a degree of inherent longitudinal stability except the original Wright type, which depends entirely on the manipulation of movable auxiliary surfaces in front of the main surfaces for its return to equilibrium. An aeroplane, when its equilibrium is destroyed, swings about the axis of its centre of gravity. It follows, therefore,

FIG. 19.

that, by having surfaces at some distance from this centre, upward and downward motion is resisted by the pressure of the air upon them.

7. Advantage of Following Surfaces.—For example, take the case of a main surface A, with a following surface B, and a centre of gravity at C (Fig. 19). A gust of wind forces up A, and the apparatus assumes the position indicated in the dotted lines. The pressure thus exerted by B downwards lessens the tilt of A to a considerable extent; and as A and B both present a greater extent of surface to the wind, the speed of the whole is checked by the increased resistance; in consequence, A, which carries the greatest weight, falls to its original position. With the resultant lowering of resistance the speed increases, and normal flight is resumed. Automatic longitudinal stability can also be obtained by sloping the main surface back in a V-shape, in which case the rear portions perform the functions of an auxiliary surface. The drawback to this arrangement is that the value of the aspect-ratio is decreased owing to the smaller forward edge (projected), and consequently the machine will carry less weight in proportion to its total area.

8. Automatic Lateral Stability.—Automatic lateral stability is obtained by vertical surfaces or by the dihedral angle, or angle made by two surfaces forming a vertical V-shape; the idea underlying both methods being the same, which is that in any side-tilting an increased lifting surface is offered on the lowest side, which the pressure consequently forces back into its proper position. Neither of these devices has been found very successful.

9. The Dihedral Angle.—The dihedral angle, which necessitates a low centre of gravity, sets up an oscillation if carried to any pronounced degree, behaves badly in turning, and necessitates increased area of the wing surface. Consequently the very slight angle which is in modern use has little effect in the event of any extensive tilting.

10. Vertical Surfaces.—The disadvantages of vertical surfaces on main surfaces have been found to outweigh any advantage they may possess, and therefore they are only employed in front of or behind the main surface to provide a slight resistance in turning movements, thus making the machine more manageable, and to preserve "sense of direction"; that is to say, to prevent side-drifting, and to keep the course of the aeroplane straight. Their chief disadvantages when used on main surfaces are the greatly increased head-resistance and the resistance offered to turning.

11. Movable Surfaces.—It is thus seen that longitudinal and lateral automatic stability are not perfectly obtainable at the present time by any design or arrangement of fixed surfaces, and therefore movable surfaces are used on every machine to correct the shortcomings in their design, to assist a quick recovery to the natural flight level, to damp out oscillations, and to save the machine from overturning in case the limits beyond which inherent stability will not operate should be surpassed.

12. Front and Rear Controls.—Movable surfaces to assist longitudinal stability are called forward or rear "controls," according to their position with regard to the main surfaces, and besides being stabilisers are used in steering the machine up or down. These controls are also often used in conjunction, so that we can speak of a front- or rear-controlled machine, or of a combined-controlled machine. Machines are fitted sometimes with a front control only (original Wright, original Voisin, &c.), sometimes with a rear control (Blériot, Antoinette, &c.), and sometimes with both (Curtiss, Farman, Baddeck). The front control is, however, falling into disfavour, as it must be carried considerably in advance of the main surfaces on all tailed machines to get the sufficient leverage for quick up-and-down movements. Even then there is difficulty in getting the tail to move up or down quickly to change the angle of the aeroplane, because of the pressure of the air which resists the movement, so combined controls are sometimes used working together, *i.e.* if the front elevator is raised to a positive angle the rear elevator assumes a negative angle. In this way a couple is made—an upward pressure in front and a downward pressure behind, so that the whole machine swings easily about its centre of gravity.

The rear control has been found to act admirably by itself, and therefore in a great many modern aeroplanes this control alone is fitted. Movable surfaces to assist lateral stability are called lateral controls, and besides being stabilisers are used in turning. (See § 20.)

13. Warping.—Warping is a system of lateral control adopted by several constructors, notably the Wrights. It consists of twisting the flexible rear edge of the main surface, so as to increase the surface opposed to the air pressure on one side and to reduce it on the other. In some machines—Santos-Dumont's "Demoiselle," for example—the angle of incidence is increased on one wing while the other remains normal. The result in both cases is, of course, to raise the machine on the side on which the angle of incidence is increased.

14. Ailerons.—The most common method, which acts in precisely the same way as warping, is to fit ailerons, or movable flaps, to the rear of the main surfaces on each side or to place them between the main surfaces. Good examples can be seen on the Farman or Curtiss machines (Plates II. and III.).

15. Variable Surfaces.—Variable surfaces are the dream of most inventors, as, if it were possible to reduce the spread of the wings at will during flight, not only would a stabilising effect result from furling or hauling in on the higher side and letting out on the lower, but by furling or letting out both simultaneously, variable speeds could be achieved. The construction difficulties of this system are, however, so great that, until very much larger aeroplanes than any now made are employed, it is unlikely to come into general use.

16. Starting.—The force necessary to launch an aeroplane into the air is considerably greater than that necessary to sustain it when once it is under way. This is due to its inertia and to the friction of the wheels or skids with the ground. It has thus to be determined whether the additional power required shall be carried on the machine—*i.e.* by having a more powerful engine than is absolutely necessary for the designed speed of flight—or by a separate specially-contrived launcher.

17. Mechanical Launchers.—There have been many kinds of launching ways and mechanical launchers invented, but none have met with any success or wide use except the rail-and-falling-weight method originally used by the Wright biplanes. The machine, mounted on a wheeled support, is drawn along the rail, which is always arranged so as to face the wind, by the action of the weight falling from the top of a wooden tower. To this weight a cable is fastened which passes under the rail and returns above it, fastening by a hook to the front of the machine. As the weight falls the aeroplane rushes along the rail under the combined pull of the rope and the thrust of its propellers. Just before the end of the rail is reached the rope is detached, the elevating planes are raised, and the aeroplane rises off the wheeled support into the air. In this way a start can always be made, even in the calmest weather, after a run of about 60 feet.

18. Starting on Wheels.—The usual way of starting is by facing the wind and running over the ground on wheels until a sufficient speed is attained to raise the machine into the air. The length of this preliminary run will be seen to be entirely dependent on the speed of the wind. The machine is held back by assistants until the motor has got up speed and is heard to be running smoothly. As it is released it runs forward, and in all machines with following surfaces the tail rises first; the elevating control is then raised and the machine rises into the air. In high winds, starts have been made within a few feet; under average conditions the run is not generally more than from 80 to 120 feet. It may be interesting to describe the start of a Blériot monoplane of the cross-Channel type. After it is released the tail elevating planes are turned to a positive angle, and the tail lifts immediately; they are then quickly turned down to a negative angle, and the main surfaces lift; the elevators are next raised to a very slight positive angle to head the machine into a horizontal course, and finally are brought to rest in their normal attitude.

19. Alighting.—Landings should be made facing the wind in order to use its resistance as a brake, and also to prevent turning over, which may happen with a following wind. An aeroplane is not made to fly backwards, and if at any time, with the wind behind it, its speed is less than wind-speed—a condition which would occur when alighting with the wind—the pressure is likely to become so great on its rear or trailing surfaces that the machine will turn up and stand on its head. The usual method of alighting is to descend within a few feet of the ground, shut off the engine, and drop on the wheels —the impact with the majority of biplanes generally being so slight as to be almost imperceptible. With monoplanes, particularly those of the smaller and lighter type, there is almost always a rebound after the first touch, which is chiefly due to the dropping of the tail on alighting. It should be remembered that the attitude of all machines upon the ground is not their flying attitude, and that when at rest or running on all their wheels and skids they present a large angle of incidence.

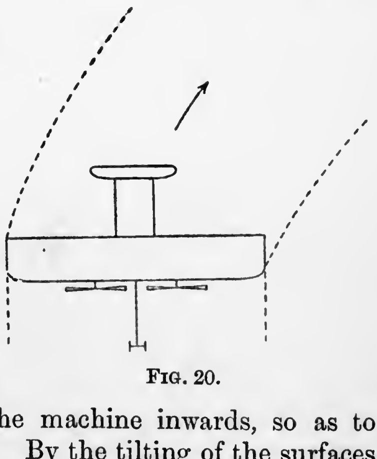


FIG. 20.

20. Turning.—When an aeroplane is making a turn, the centrifugal force tends to swing it outwards from its course. It therefore becomes necessary to "bank," or tilt, the machine inwards, so as to correct this tendency. By the tilting of the surfaces the lift is naturally decreased, especially with regard to the inside surface, which, since it is following a smaller curve than the outside surface, is not moving so fast (Fig. 20). The machine consequently drops to a certain extent in making a turn, and the inner surface has a tendency to drop lower than the inclination given to it by the banking on account of its lower speed. This must be corrected in biplanes by warping, or by lowering the aileron on that side. In monoplanes it has been found that warping, instead of giving a righting effect, often accentuates the tilt, therefore it is advisable to correct it by a judicious use of the vertical rudder.

21. The Glide or "Vol Plané."—This manœuvre is accomplished by shutting off the motor during flight, and thereby turning the aeroplane into a glider. In most machines it is safest to assume the gliding angle before shutting off the motor. This is especially true of biplanes and machines with a large head-resistance, otherwise the speed may decrease so rapidly that a steep dive to get up speed will be the result, and if the altitude is small disaster may follow. It is a common fallacy that steep and prolonged gliding puts a greater strain on the wings than when they are in normal flight. As a matter of fact this is not the case. In gliding an aeroplane moves at its highest speed—that is to say, the speed it attains when flying normally at its best angle of incidence. If the engine is restarted while a glide is in progress, the result is not to increase the speed, but to alter the angle of incidence—to tend to bring the aeroplane back to its normal flying attitude. An aeroplane cannot go faster than a certain speed; when that speed is reached any excess of power will serve only to lift it out of its path, and will not cause it to go any faster.

Supposing the aeroplane in the diagram is descending on the path B A, if the pilot wishes to descend at C he has two courses open to him: he

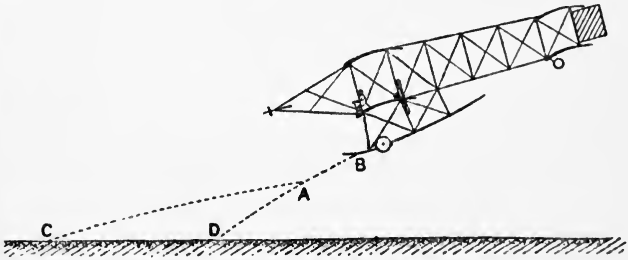


FIG. 21.

can either alter the angle of incidence with his elevator, or by starting up his engine (Fig. 21).

It should, however, be noted that by depressing the elevator and forcing the machine into a steeper path than its natural gliding path an abnormal speed can be produced, which is practically a fall.

Finally it may be mentioned that there is considerable danger in executing a glide with a following wind if it is gusty, as a sudden acceleration in its force may re-act on the rear plane, and turn the machine over.

CHAPTER VI

PROPULSION

Definition—Amount of Propulsion Required—Power for Horizontal Flight—Power to Ascend—Margin of Power Necessary—Waste of Power in Transmission—Flapping Wings—Nature's Examples—Valvular Wings—Paddle-Wheels—Feathering Oars—Steam Jets—Screw Propellers, Marine and Aerial—How the Screw-Propeller works—Angle of the Blades—Curvature of the Blades—Thrust and Air-Resistance—The "Pitch"—The "Slip"—Forward Edge, Centre of Pressure, and Aspect-Ratio—Diameter in Relation to Speed—Main Considerations in Design—Air-Resistance—Skin-Friction—Limit of Thrust in relation to Horse-Power—Windmill and Air-Fan different from the Screw-Propeller—The Speed necessary for Efficiency—Shape of the Blades: the Tips—The Main Consideration in Design—Diameter and Speed—Propeller Data Incomplete—To find the Speed of a given Propeller—Dihedrally-set Blades—Position on the Machine—The Number of Propellers Required—Varying "Pitch" Propellers—Helicoptères—Propellers on Movable Shafts.

1. **Definition.**—In aeronautical practice propulsion is the forcing of a machine through the air. The immediate means by which this is accomplished is called a propeller. With few exceptions propellers are of the type known as screw-propellers.

2. **Amount of Propulsion Required.**—We have seen that an aeroplane has a natural gliding angle, which is the resultant of the size, disposition, and resistance of its sustaining surfaces and of its total weight and the distribution thereof. By imparting

to an aeroplane a certain speed its gliding descent is overcome, and it maintains horizontal flight. Therefore, the machine with the small gliding angle—that is, the machine which descends most gradually—maintains horizontal flight at less speed than does the machine with a steep gliding path.

3. Power for Horizontal Flight.—In horizontal flight an aeroplane is constantly climbing a slope which has the same angle relatively to the air as that of its natural gliding angle. The power required to propel it horizontally, therefore, is that which would be required to raise its weight to a given height in a given time. As we have seen, the lifting efficiency of a plane increases with the speed, so that if horizontal flight be maintained at a speed say of 20 miles per hour an increase of that speed to 25 miles per hour causes the plane to ascend unless the angle of its incidence be modified. Head resistance, however, increases with increased speed.

4. Power to Ascend.—There is for every aeroplane a certain speed at which it maintains horizontal flight with the least expenditure of power. In order to make it rise from the horizontal path more power must be expended. Merely to alter the angle of the elevator will not have the desired effect unless additional propulsive power be given. Aeroplanes must be provided with sufficient power to enable them to attain the speed along the ground necessary to ascend: they must be able to attain sufficient speed for horizontal flight in spite of the friction of their wheels on the ground. It follows that, having left the ground, they have a considerable reserve of power for the attainment of speed above that which is strictly necessary, or for the attainment of higher altitude.

5. Margin of Power Necessary.—We will assume an aeroplane with a natural gliding angle of 1 in 9—that is, about 6 degrees—weighing 1000 lbs. including the driver and everything necessary, and that it must travel at the rate of 25 miles per hour in order to sustain flight. Its speed is, in other words, about 36 feet per second. In every second, therefore, a weight of 1000 lbs. must be raised a ninth part of 36 feet, since the gradient of the descent is 1 in 9—in every second 1000 lbs. must be raised about 4 feet. Now it takes one horse-power to raise 500 lbs. one foot in a second; therefore, to drive this aeroplane in horizontal flight we shall require 8 horse-power. But there must be a margin over and above that power to enable the machine to attain sufficient speed along the ground, and to ascend to a reasonable distance above the ground. It would not be advisable to make the machine fly with only just enough power for its sustentation, for it is not sufficient merely to maintain flight without having power to rise over obstacles near the earth's surface. The smallest reasonable addition to the 8 horse-power would be 2 horse-power, making 10 horse-power altogether.

6. Waste of Power in Transmission.—But, as we shall see, in transmitting the power from the motor through the connecting gear to the propellers there is waste, and propellers themselves do not give out anything like the power that is transmitted to them. Many of them only yield half of that power. The motor for our 1000 lbs. aeroplane should really develop at least 16 horse-power, or about 1 horse-power for every 62 lbs. The example we have chosen is purely speculative.

7. **Flapping Wings.**—So far, we have spoken of propellers in a general sense, and have not specified any particular type. One method of propulsion is by flapping and other reciprocating movements of wings or other members. Attempts have often been made to imitate flapping-wing flight mechanically both for marine and aerial vessels. Some success has been obtained in experiments in water, but the mechanical difficulties are very great; and they are greater still when working in the elastic fluid, air. Yet Hargrave made a machine giving 248 double beats to a minute with a 36-inch wing and used it in a model. These wings were, normally, flat and straight, but under the pressure caused by their motion their rear edges bent with a feathering action, giving propulsion to the machine. Reciprocating wings cannot work at anything like the speed of a screw-propeller, and Hargrave, who experimented also with screw propellers, which were, moreover, of an inferior type to those of later design, admitted that he could get no better result with the flapping wings.

8. **Nature's Examples.**—The idea that because the flapping wing is the method of flight used largely by birds and insects it should, therefore, be imitated by man need not be entertained. In the first place, it would be impossible for the revolving propeller, in any form, to be part of any living organism. Again, Nature's method of flight is, in innumerable

instances, that of the aeroplane, as exemplified in the outstretched wings of birds that glide and soar.

9. Valvular Wings.—The screw-propeller entails a great waste of power, but other types are even more wasteful. For instance, mechanical valvular wings, which present a large surface on the down-stroke but open on the up-stroke, have not proved successful.

10. Paddle-Wheels.—Another method is the paddle-wheel. The ordinary paddle-wheel of the marine type would be of no use in the air: in aerial navigation it would be totally immersed in the medium. Experimenters have encased a large part of the wheel in a sheath, so that only the blades revolving in the open portion have effect.

11. Feathering Oars.—Experiments are also made with oscillating surfaces with a feathering action like that of oars, but here again mechanical difficulties prevent the attainment of efficiency.

12. Steam Jets.—Steam jets have been suggested. High-pressure steam and compressed air have been discharged with great force through orifices of various sizes, the reaction to the force expended giving propulsive effect; but the results have not, so far, been encouraging, owing to the waste of power.

13. Screw-Propellers, Marine and Aerial.—As regards the screw-propeller, this, for aerial use, must differ from that used on marine craft on account of the very different nature of the media in which they work. The air is an elastic fluid: water is incompressible and inelastic. This difference has wide-spread effects in practice.

14. How the Screw-Propeller Works.—A screw-propeller blade for horizontal propulsion is a surface revolving in a plane normal to the direction of motion. It is an inclined plane, the speed of which takes it through the air in the same manner as the fixed inclined plane driven at great speed maintains horizontal flight and even ascends. The power of an inclined plane to rise is called its "lift," and the backward force exerted by the revolving screw-propeller is called "thrust."

15. Angle of the Blades.—The tip of the blade being farthest from the axis, or boss, it travels in a revolution farther in the same period of time than

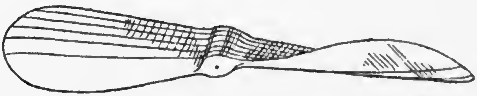


Fig. 22.

any other part of the blade. As in the fixed plane, the greater the speed the smaller the angle of inclination. In the propeller, if the angle of inclination were the same throughout the length of the blade, the thrust would be very much greater at the extremity, on account of its greater speed, than at the boss, where the motion is slow. It is, therefore, necessary to graduate the angle of inclination, making it comparatively small at the extremity; thus all parts of the blade push back the air with approximately equal velocity. Although in many propellers the blades start from the boss, it is certain that for a short distance from the boss they possess no efficiency.

16. Curvature of the Blades.—Just as it has been found that the curved plane is more efficient than the flat surface, so it is found that the propeller blade exercises more thrust if it be curved. The amount of the curvature and the angle of inclination are smaller in a screw-propeller designed for high speed than in one designed for small speed.

17. Thrust and Air-Resistance.—A blade that had no angular inclination and no curvature—a mere flat surface—would offer a minimum turning resistance, but it would exercise no thrust. On the other hand, a blade set at right angles like the blade of a paddle-wheel would present a maximum of resistance and it would give no forward motion. The problem is to obtain a maximum thrust for a minimum air-resistance.

18. The "Pitch."—The reader is advised now to

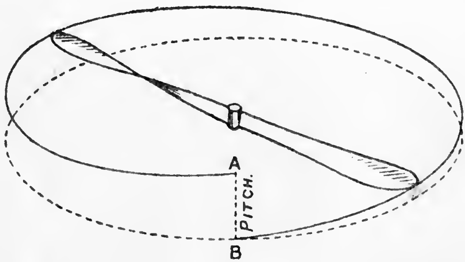


FIG. 23.

In one revolution the tip of the blade travels along an inclined circular path from B to A. The distance from B to A is the "pitch."

conceive the screw-propeller revolving in a thread cut in a solid, after the manner of a bolt in a nut.

The distance forward that it would travel then in one complete revolution is called its "pitch."

19. The "Slip."—In practice, it revolves in an elastic fluid, the air, and it does not move forward so far. It moves little more than half as far. The difference between its actual progress and its theoretical "pitch" is called "slip."

20. Forward Edge, Centre of Pressure, and Aspect-Ratio.—Practically, the principles that apply to each lifting surface of an aeroplane apply also to the screw-propeller. The greatest efficiency of thrust—the centre of pressure—is near its forward edge. At the trailing edge the efficiency is least. The law of the forward edge applies absolutely, so that it is better to have screw-propellers of large diameter (the diameter of the circle of their revolution) than small. Of two propeller blades having the same superficial area, the long, narrow blade is the more efficient. (See Aspect-ratio, page 30.)

21. Diameter in Relation to Speed.—A screw-propeller of large diameter turning at comparatively low speed gives more thrust than a small screw-propeller driven at high speed, other things being equal. In practice, it is common to "gear down" the speed of the engine in order to produce a slower rotation of the screw-propeller, and to use a screw-propeller of greater diameter than would be used for a high number of revolutions. Constructional exigencies, of course, have to be considered; so that on account of the lack of an absolutely ideal material, which would be one of tremendous strength although as thin as tissue paper, the ideal shape of the screw-propeller blade must be modified. The small propeller has the advantage of strength with comparative lightness: propellers of large diameter to be equally strong must be disproportionately heavy.

22. Main Considerations in Design.—In designing a propeller for any particular machine, its diameter and the width of the blades may be ascertained by various methods of mathematical calculation. The subject is, however, very complicated, and different authorities give different formulæ. The student who desires to pursue the subject further should consult the works of Drzewiecki, Ferber, and others.

23. Air-Resistance.—The increase of air-resistance with speed applies to the screw-propeller as it does to all other bodies. The resistance increases in the ratio of the square of the speed. Each speed-increase of a mile per hour requires the expenditure of greater power than the preceding increase of a mile per hour.

24. Skin-Friction.—Precisely what part is played by skin-friction in reducing efficiency is unknown. Certainly it is very small.

25. Limit of Thrust in relation to Horse-Power.—But as regards the limitation of efficiency in relation to speed, it is important to remember that a horse-power is equivalent to from 75 to 80 kilogram-metres per second. But the effective horse-power is very much diminished in the course of its transmission from engine to propeller. One can, indeed, only get a small proportion of that power; and beyond that small proportion all mere application of additional power is wasted. If in a laboratory a screw-propeller is driven on a stationary shaft with increasing power, a steady increase of thrust is obtained up to a certain point—up to some 30 or 40 lbs. per horse-power; but if that propeller is placed in a moving aeroplane the thrust will not exceed 16 lbs. per horse-power. And even this can scarcely be obtained in practice, for it depends on the complete avoidance of waste of energy through friction. Thrust is limited by the following rule. The thrust in kilogrammes per horse-power cannot exceed 80 divided by the axial speed of the screw-propeller in metres per second. In other words, the thrust in lbs. per horse-power cannot exceed 592 (80 kilogrammes equals 177 lbs.—this multiplied by the number of feet in a metre equals 592), divided by the speed in feet per second. Since aeroplane speeds are at least 32 feet per second, the maximum thrust is about 18½ lbs. per horse-power, assuming no loss whatever of energy. But as in practice there is considerable loss of energy, the thrust is very much less. Thus in the early Wright biplanes the thrust was only 6 or 7 lbs.

26. Windmill and Air-Fan different from the Screw-Propeller.—It must be clearly understood that the work of a screw-propeller is very different from that of a windmill or a revolving fan. The former is designed to rotate under the influence of a stream of air flowing past it. The fan is just the opposite, for it is designed to take from still air a column of air and set it in motion. A revolving fan and a stationary screw-propeller have a hundred per cent. of slip. But the screw-propeller for aerial navigation is intended neither to react from disturbed air flowing through it nor to create a current of air: its proper function is to bore a path through the air setting up the least possible disturbance, as nearly as possible as a bolt in a solid nut.

27. The Speed necessary for Efficiency.—In starting, in actual use, it operates very much after the manner of a fan sending back a column of air. It is then working at its least efficiency. The machine moves forward along the ground, gathering speed; but until it has attained a certain speed which the shape and size of the screw-propeller blades best fit them for, they are working with excessive "slip."

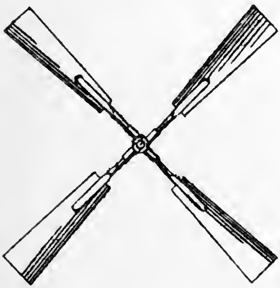


FIG. 24.

A four-bladed square-cut propeller.

28. Shape of the Blades: the Tips.—In some propeller blades the portion of the blade about a third of the total length from its tip is the widest. Towards the tip it is tapered off. The object of narrowing it at the extremity is to reduce skin-friction at that part of the blade which travels through the air at the greatest velocity. Some screw-propeller blades have square-cut extremities. Probably in these there is more loss of power owing to skin-friction.

29. The Main Consideration in Design.—The speed of the screw-propeller at the extremity of the blades is one of the principal factors considered by designers. In nearly all screw-propellers the speed is between 2000 and 6000 feet per second. The rotational speed is adjusted to the diameter so as to avoid any speed above that maximum. For at any greater speed the centrifugal pull exerted at the extremity of the blade would strain the strongest material.

30. Diameter and Speed (see also § 23).—It is better to obtain high speed at the blade extremities by the use of screw-propellers with large diameters revolving comparatively slowly than small screw-propellers at high rotational speed. Of two screw-propellers one having twice the diameter of the other but both having the same speed at the extremities, in the one with the large diameter the blades pass any given point half as often as the other, with the result that there is far less likelihood of the air acted upon by each blade being disturbed by the other blade or blades. And, for the same reason, under most circumstances the two-bladed screw-propeller has advantages over the screw-propeller with many blades.

31. Propeller Data Incomplete.—It should be clearly understood that the principles of propeller efficiency have by no means been finally determined; and we have therefore avoided entering into certain narrower considerations, and have only given the broad principles so far as they are understood.

32. To find the Speed of a given Propeller.—In order to find out the rate of progression in feet per second at which a machine would be driven by a given screw-propeller, it is usual to multiply the pitch of the propeller in feet by the number of revolutions per second and deduct the slip—that is, the velocity of the air thrust back by the propeller. A screw-propeller with a 5-foot pitch revolving ten times to the second will thus have a designed forward speed of 50 feet per second. If the air left it at 10 feet per second, the velocity of the machine would be 40 feet per second. The reader will understand that many considerations affect the precision of calculations of this kind.

33. Dihedrally-set Blades.—There are various types of screw-propeller. One has the blades sloped back from the boss at a dihedral angle. This probably has the disadvantage of waste of power through the flow of air over the sloping extremities.

34. Position on the Machine.—There are various positions for the propeller on the machine. The ideal position would be at the centre of pressure, and this design has been attempted in such examples as the Wright, Cody, and Curtiss biplanes. In monoplanes the propeller is usually placed in front, and it is then called a "tractor screw." This is supposed by many authorities to have the disadvantage that it does not derive any benefit from the air set in motion by the machine as a whole, which, according to this contention, neutralises some of the normal slip. On the other hand, some authorities hold that the flow of air at the back of a tractor-screw increases the air-pressure under the main planes. As success has been attained with both types of design, it is to be presumed that there is no very decided disadvantage of one as compared with the other. The position of the screw-propeller is largely determined by constructional exigencies. In monoplanes, for instance, it is much easier to design for a tractor-screw.

35. The Number of Propellers Required.—Some authorities advocate one screw-propeller, and some more than one. One advantage of the single screw-propeller placed centrally as regards the span of the machine is that it cannot deviate the machine from its course materially. Two propellers placed on either side, unless they are working with exactly equal efficiency, have a disturbing effect on the steering. It was formerly supposed that a single screw-propeller tended to turn the machine in one direction, and in some designs there were two screw-propellers revolving in opposite ways. What is known as "torque" is a bias set up by a screw-propeller revolving on a stationary or nearly stationary machine at the start. This, of course, is not a gyroscopic effect.

36. Varying "Pitch" Propellers.—We have seen that for higher speeds a different form of screw-propeller blade is necessary than that suited to low speed; for high speed the pitch should be comparatively small. Attempts have been made with some success to construct screw-propellers of variable pitch; some in which the variation is automatic, resulting from the pressure of air on the blades, others in which the engineer can effect the alteration at will. There are flaccid screw-propellers in which cleverly-placed weights and centrifugal force give to the blade different angles of incidence according to speed. There are propellers made to reverse and there are twin propellers mounted centrally on a compound shaft, one shaft revolving within the other in the opposite direction.

37. Helicoptères.—A machine driven by a screw-propeller revolving in a horizontal plane on a vertical shaft in order to obtain direct lift is called a helicoptère. Its simplest and most efficient expression is in the familiar toy. No particular success has been obtained with large models or man-lifting machines in which this principle is embodied. But the desire to construct a machine which will lift vertically induces many investigators to endeavour to combine the helicoptère and aeroplane types. It need only be said that a direct pull against gravity calls for a greater expenditure of power than an ascent at a low gradient and the utilisation of the sustaining quality of plane surfaces. The flight of an aeroplane can be sustained by overcoming its natural gliding descent of, say, 12 degrees: the flight of a helicoptère can only be sustained by overcoming its natural falling angle of 90 degrees. In dynamic flight, in which the mechanical power at our disposal is always small compared with the task of propelling heavy machines in the air, there are clearly difficulties in the way of the successful helicoptère, yet in combination with the aeroplane type it may possibly have a future.

38. Propellers on Movable Shafts.—The screw-propeller on a universally-jointed shaft, by means of which the driver of the machine can alter the direction of thrust from the vertical to the horizontal, and also by which he can change the direction of the machine to left and right, has been the subject of many patents.

CHAPTER VII

THE AEROPLANE

Monoplane and Biplane—Framework—Fabric—Points in Design—Resistance of Wires—Chassis—Types of Aeroplanes—The "Antoinette" Monoplane—The "Curtiss" Biplane—The "Farman" Biplane—The "Demoiselle" Monoplane—The "Blériot" Monoplane.

1. **Monoplane and Biplane.**—Modern aeroplanes fall into two classes: monoplanes and biplanes. A monoplane is a machine with a single spread of main supporting surface, of which the Blériot and Antoinette are well-known examples. Biplanes, as the name implies, have two main surfaces which are superposed or placed one above the other, as the Voisin, Farman, Curtiss and Wright machines. Both of these types have their advantages. Monoplanes will always be superior in speed, as their head-resistance must be less than that of biplanes, of which the necessary uprights, connections, and bracings between the upper and lower surfaces form an unavoidable drag. Biplanes, on the other hand, may be much more solidly constructed, and since it follows that they can be built with a considerably larger span, will be able to carry more weight than monoplanes. There are in existence multiplaned machines, having three, four, or more main surfaces, the most successful being the Roe triplane. But as none of them have yet been brought to the perfection

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of the above two classes, they will not be described here.

2. Framework.—The framework of the modern aeroplane is nearly always constructed of wood, of which the following varieties are in greatest favour: spruce, hickory, ash, birch, and poplar. Bamboo is also employed. Wood carefully selected and well seasoned possesses the toughness and strength of the best metals and alloys without their rigidity or weight. There is perhaps no other construction that, like the aeroplane, demands at the same time so high a degree of strength and of flexibility.

3. Fabric.—The fabric used to cover the surface is made of canvas, silk, linen, and many other materials specially designed for this purpose. The ideal fabric must not stretch, and must be light, smooth, air-tight, water-proof, unshrinkable, reasonably strong, rot-proof and non-inflammable—thus calling for a concentration of excellences that is somewhat difficult to obtain.

4. Points in Design.—In designing an aeroplane, it is well to take note of the following points. The load should be distributed between the extreme points of the oscillation of the centre of pressure, and not concentrated in one place. This will decrease the moment of inertia, and enable the machine to be handled more easily in flight. The points will be found to be slightly in advance of the geometrical centre of the main surfaces, and the centre of gravity must of course fall between them. The thrust of the propellers, the centre of pressure, and the centre of gravity should lie as nearly as possible on the same plane. A low centre of gravity should in all cases be avoided, for it necessitates its separation from the centre of pressure and the thrust being nearer to the centre of pressure than to the centre of gravity. Therefore, if the engine should suddenly stop, the stability is upset by the elimination of this factor (the thrust), and the machine will not glide unless it is forced into position by the exercise of great skill; and, if the machine is near the ground with small clearance for recovery, an accident is almost unavoidable. Passive, or head, resistance should be minimised as much as possible by the employment of the steam-line form in the body or fuselage and in the struts and uprights of the framework, the use of the circular shape in all vertical surfaces, and by eliminating as much of the cross-bracing with wires as possible.

5. Resistance of Wires.—Wires always vibrate while in flight, and are said to offer 1·25 times their stationary resistance. Reduction of head-resistance means greater speed for the same power.

6. Chassis.—The chassis, or the undercarriage of the aeroplane which carries the wheels and skids on which the machine runs and alights, is almost always made of steel tubing, though wood is sometimes employed. Rubber or helical steel springs are employed as shock-absorbers. It is of the utmost importance that this part of an aeroplane should be strong, as the safety of the pilot and of the machine entirely depends on its ability to stand severe shocks caused by bad landings and by running over rough ground. A great many serious accidents have been caused by bad workmanship and design relative to this part of the machine. Its main members should be made as far as possible an integral part of the whole machine, and not an adjunct, as frequently occurs. Short skids should be avoided, as they are liable to catch in the ground; they should be made long, and carried well up in front of the machine. It is an essential condition of safety that the wheels or skids on which the landing is made should project considerably in front of the centre of gravity.

7. Types of Aeroplanes.—The following list of some of the principal types of aeroplanes gives the salient points of each, and should be studied in connection with the illustrations.

8. The "Antoinette" Monoplane.—The Antoinette monoplane (No. VII.) has a main surface with wings set at a slight dihedral angle tapering towards their extremities. From tip to tip its span is 46 feet. The chord of the wings from front to rear in the middle is 10 feet, which narrows to 6 feet 8 inches at the extremities. The total length of the machine is 40 feet. The flying weight with the pilot is about 1200 lbs. It is driven by a two-bladed tractor screw off a 50 horse-power motor.

A rear elevator and wing-warping arrangements are fitted. The rudder which forms the vertical member of the tail is operated by the movement of a pivoted foot-rest. A wheel rotating vertically on the pilot's right controls the elevator, and a similar wheel on his left controls the warping.

The machine is mounted on two wheels placed beneath the main surfaces, and the tail is supported

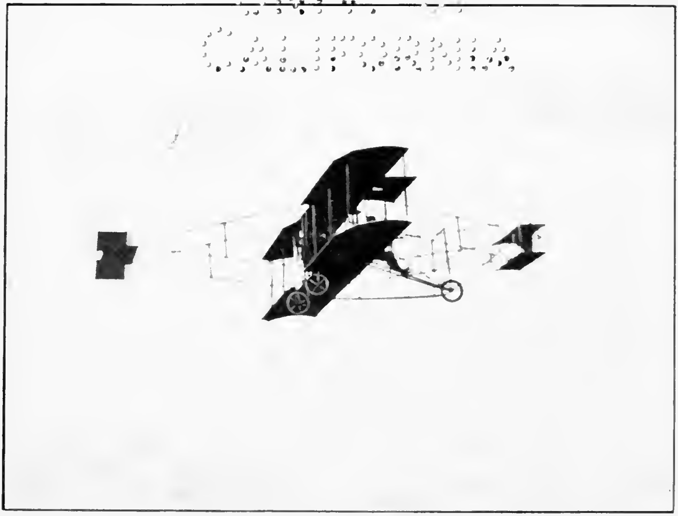

Photo: Topical Press

THE "CURTISS" BIPLANE

Photo: Topical Press

THE "ANTOINETTE" MONOPLANE

PLATE II.

by a skid. A long ash skid projects in front of the machine to prevent the machine tipping forward on landing.

Earlier types of Antoinette had ailerons fitted at the ends of the rear edge of the main surface, but these have since been discarded in favour of warping.

9. The "Curtiss" Biplane.—The Curtiss biplane has two main surfaces 32 feet by 5 feet, and 5 feet apart. The total length is 36 feet. The flying weight with the pilot is about 800 lbs. It is driven by a two-bladed screw-propeller, 7 feet in diameter, off a 50 horse-power motor.

It has a front elevator and ailerons situated midway between the main surfaces. These ailerons, measuring 9 feet 11 inches by 2 feet 9 inches, project 4 feet beyond the ends of the main surfaces. A cross-tail, of which the rudder forms the vertical member, is carried in rear. A triangular fin in the biplane elevator gives directional stability. The front elevator and the rudder are connected with a wheel in front of the pilot. Pushing the wheel forward lowers the elevator, and pulling back raises it. Twisting the wheel to the right or left moves the rudder in the same directions.

The ailerons are connected with a lever forming the back of the pilot's seat, so that the natural motion of swaying the body to keep it upright preserves lateral stability. Thus if the machine heels over on the right side, the pilot naturally swings his body to the left; this movement raises the right-hand aileron and depresses the left, so that, the pressure becoming greater on the right side, the machine is raised to the horizontal. The machine, which is constructed of ash and spruce, is mounted on three wheels, two beneath the main planes and one between them and the front elevator. Small skids are carried beneath the extremities of the lower main surface.

10. The "Farman" Biplane.—The Farman biplane has two main surfaces, 38 feet 6 inches by 6 feet 4 inches, and 6 feet apart. The total length from front to rear is 43 feet. The weight of the machine without the engine is 616 lbs., and its flying weight, including pilot, is about 1100 lbs. It is driven by a two-bladed screw-propeller 8 feet 6 inches in diameter off a 50 horse-power motor.

It is fitted with front and rear controls, and ailerons hinged at the rear of the main surfaces on each side.

The front and rear elevators are connected so that the leading edge of the front elevator and the rear or trailing edge of the rear elevator are raised or lowered together. This dual operation enables the machine to alter its angle very quickly.

The wires working the elevators and the ailerons are connected to one lever, which is moved backwards and forwards to operate the elevators and from side to side to operate the ailerons.

The rudder in the biplane tail is moved by the action of the feet on a foot-rest pivoted in its centre and connected by wires to the rudder.

The machine is mounted on a combination of wheels and skids, so arranged that on alighting the wheels give to the impact and the shock is borne by the skids.

11. The "Demoiselle" Monoplane.—The Santos-Dumont "Demoiselle" monoplane has a main surface with wings set at a dihedral angle. The span is 18 feet, and the length of the wings from front to rear

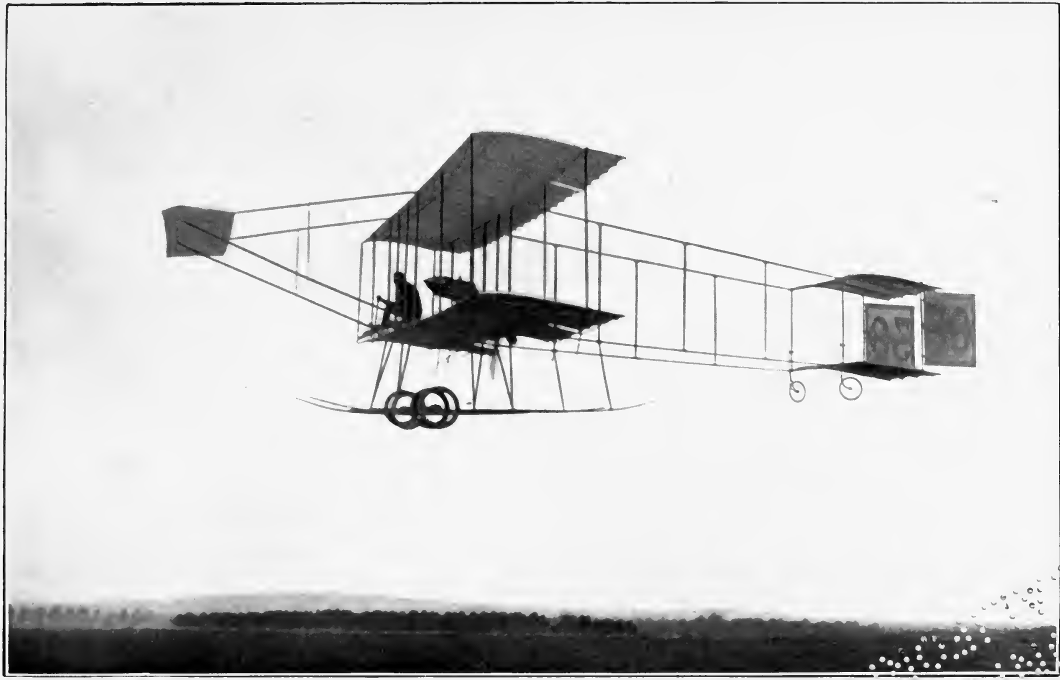

Photo: Topical Press

PLATE III.—THE "FARMAN" BIPLANE

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is 6 feet 5 inches. The total length of the machine is 20 feet. The flying weight with the pilot is about 500 lbs. It is driven by a two-bladed tractor screw off a 35 horse-power motor. (See Frontispiece.)

A rear elevator and arrangements for wing-warping are fitted. The cross-tail moves as a whole on a universal joint, the vertical surface acting as the elevator and the horizontal as the rudder.

The elevator is operated by a lever and the rudder by a wheel situated on the right and left respectively of the pilot. The warping is accomplished by the swaying of the pilot's body moving a lever fastened to his back. The pilot is strapped into his seat. The machine is mounted on two wheels placed beneath the main surface, and the tail is supported by a skid. The framework of the original chassis was bamboo, but steel tubing is now used.

This aeroplane, it should be observed, is one of the most dangerous to fly, and requires the highest skill from its pilot. The sustaining surface is so small that, should the engine stop, it glides at a steep angle, and therefore must always be kept close to the ground. The position of the motor above the pilot, and the propeller revolving in front of him, together with the fact that should the chassis crumple on landing, the pilot, being so low, is almost certain to be injured, make this aeroplane one only to be flown by the professional expert.

12. The "Blériot" Monoplane.—The Blériot monoplane (No. XI.) has a main surface with wings set at a slight dihedral angle and tapering slightly at the tips. The span is 28 feet and the length of the wings from front to rear 6 feet. The total length is 25 feet, and the flying weight with the pilot about 700 lbs. It is driven by a two-bladed tractor screw off a 50 horse-power motor.

A rear elevator and arrangements for wing-warping are fitted. The wires controlling the elevators and the warping lead to an inverted cup on a universal joint in front of the pilot's seat, which the pilot operates by means of a lever arm carrying a horizontal wheel. By moving this wheel to and fro the elevators are worked up or down, and by moving it from side to side the wings are warped; that is to say, a small portion of the rear edge of a wing on one side or the other is pulled slightly down.

The machine is mounted on two wheels placed beneath the main surfaces and one wheel just in front of the tail.

The first of this type, which crossed the Channel, had a span of only 23 feet 6 inches.

Photo: *Topical Press*

PLATE IV.—THE "BLÉRIOT" MONOPLANE

Single-seater; 1910 type; fitted with 50 H.P. Gnome motor.
(An auxiliary petrol-tank is placed beneath the body.)

Facing p. 88

CHAPTER VIII

NAVIGATION

Aerial Navigation different from all other Kinds—Speed is in relation to the Air (moving or still Air) not to the Ground—Deviation by Wind—Allowing for Effect of Wind—The Need to know the Direction and Strength of the Wind—The Sailing Ship no Parallel to any Aerial Craft—Amount of Deviation is precisely that of the Wind—Gusts and the Inertia of the Machine—Tacking Impossible with Aerial Craft—Increase of Wind at High Altitude—Advantage of High-Flying: Radius of Descent—Decreased Weight of the Air at High Altitudes—The Back-wash from Machines Overhead—Causes of Vertical Currents and Eddies—Finding the Way—The Compass only of use when Earth is Visible—Taking the Meridian—Atmospheric Roads.

1. Aerial Navigation different from all other Kinds.—Aerial navigation is fundamentally different from all other kinds except submarine. The aerial vessel is completely immersed in the medium in which it moves. The only parallel is the submarine boat; but in the case of the submarine the currents met with are never more than a few miles an hour, whereas the currents of the atmosphere are quite commonly 25 and 30 miles per hour, and are often as fast as 60 and 70 miles per hour.

2. Speed is in relation to the Air (moving or still Air) not to the Ground.—The aerial vessel being totally immersed in the air, its speed is in relation to the air and not in relation to the earth beneath. Many of the speeds spoken of in relation to aerial navigation have no regard to this point, and many of the early "records" were quite valueless since they attributed to the machine speeds which were in great measure those of the air in which the machine was flying. It is exceedingly important to remember this, because the failure clearly to realise it is responsible for many popular errors. The reader is advised to conceive it in this way, namely, that to the aviator wind does not exist; he is in calm; the only wind-pressure experienced by him, personally, is that set up by the independent motion of his vessel, and he feels this in unvarying degree whether he be flying with or against the air-current. In the condition known as "windy," to him it is the earth that moves, not the air. The aeroplane may be in a current of air moving say from west to east at 30 miles per hour. With whatever speed it may

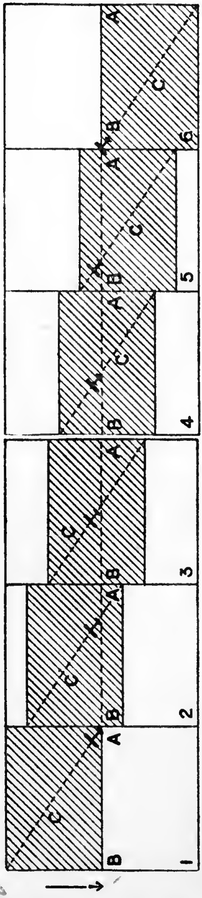

FIG. 25.

A starting point, B destination. The shaded portion is a body of air, *i.e.* the wind, moving in the direction of the arrow. The diagonal line C is the path of the aeroplane with regard to the air. The dotted horizontal line is its path with respect to the earth.

be capable of the aeroplane can move freely about in all directions in that air-current. Obviously, if its speed be only 30 miles per hour and its head be pointed to the west it will seem to the observer below to be standing still in the air, although it will in fact be moving through the air at its own independent speed. If the aeronaut desire to make a point due north his aeroplane will drift to the east to the distance covered by the wind in the time taken by the journey. It will have travelled with its head pointing to the north, and the wind felt by the aeronaut will be from stem to stern; to the observer below the aeroplane will appear to have a crabwise motion. The aeronaut will not have felt the west wind that has carried him out of his course, although it has had so great an effect upon the direction of his aeroplane.

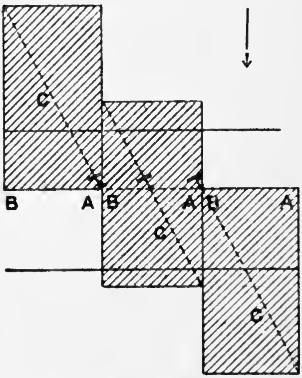

FIG. 26.

Same as Fig. 25 except that in this case the wind is stronger, *i.e.* a longer body of air passes in a given time. The aeroplane therefore has further to travel with regard to its passage through the air and takes longer to arrive at B. Apparently, while the aeroplane is at a much greater angle to the line of flight, it moves along the line A, B as before.

3. Deviation by Wind.—In these circumstances, if out of sight of earth, in cloud or at night, should no fixed lights be visible, if ignorant of the fact that there is a west wind the aeronaut would be absolutely unaware of his deviation from the desired route. For there is nothing to convey to his senses or to indicate to him in any way the cause.

4. Allowing for Effect of Wind.—In daylight, or when able to see his course, the aeronaut would shape his way as a ferryman does when crossing a stream. He would head about towards the north-west to be sure of reaching his goal. But, of course, unless his speed were superior to that of the wind, he could not attain it.

5. The Need to know the Direction and Strength of the Wind.—Imagine an aeroplane travelling

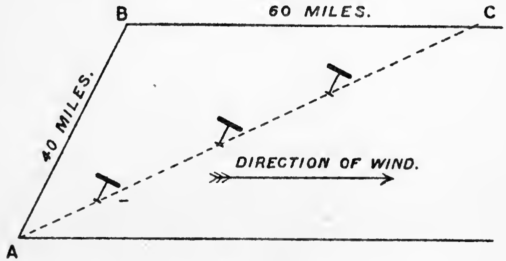

FIG. 27.

Aeroplane (speed 20 miles per hour) sets course for B without allowing for the wind of 30 miles per hour from the left. In two hours, therefore, instead of arriving at B it reaches a point C, 60 miles to the right.

with its own speed in addition to that of a favouring wind. It is moving through the air at its own independent speed, and the aeronaut may be totally unaware of the fact that his speed in relation to the earth is 20 or 30 miles in excess of the independent speed of the machine. Only on alighting on the ground does he discover the existence of this following wind; but it is most important to him to know the direction of the wind, for it is often dangerous to alight without first bringing the head of the machine round to face the wind.

6. The Sailing Ship no Parallel of any Aerial Craft.—In a marine ship there is a keel giving leverage in the far denser medium, water, bearing against the effect of the wind on the sails. In aerial navigation the conditions are entirely different.

7. Amount of Deviation is Precisely that of the Wind.—In order to travel in an aeroplane capable, let us say, of a speed of 30 miles an hour from London to Rugby against a wind of 15 miles an hour the aeronaut must take on sufficient fuel to suffice for a journey in calm air to Liverpool, for he will have to travel through just as much atmosphere as on a calm day extends from London to Liverpool. If he have an aeroplane capable of a speed of 100 miles per hour, and on a day when there is a scarcely perceptible breeze of 6 miles per hour from the north he travels from London to Bristol, he will go out of his course 6 miles in every hour that the journey occupies.

8. Gusts and the Inertia of the Machine.—In practice, as a matter of fact, these conditions are sometimes very slightly modified—modified, indeed, to so small an extent as to be scarcely appreciable—owing to the intermittent character of all air currents. Wind never blows with uniform velocity (see Chapter I., page 9), and an aeroplane having a certain degree of inertia does not instantly respond to the change of speed. The amount of inertia varies with different types of air craft.

9. Tacking Impossible with Aerial Craft.—It is sometimes stated that an aeroplane or dirigible balloon can "tack" after the manner of a sailing ship. It is, of course, impossible for any aerial vessel to tack. If its independent speed be less than the speed of the adverse wind it has nothing to gain by attempting an oblique course for tacking. That would not prevent its being driven away. The longer it remains in the air the farther will it be driven from its goal. It loses the least possible ground by flying at its best speed with its head (in a wind that is blowing absolutely straight from the goal) pointed directly towards the goal. If its speed exceed that of the adverse wind, even slightly, it has nothing to gain by a zigzag course. It is true that an aeronaut, even with his goal in full sight, often fails to steer a direct course, but that is because he is not aware that a side or a half-side wind may be blowing. The wind then takes him out of his course, and afterwards he has to recover. But if he is aware of the direction of the wind and its strength he will set the head of his machine toward a point either to the right or left of his goal and steer steadily towards that. Yet the line he will pursue with respect to the earth below will be approximately straight.

10. Increase of Wind at High Altitude.—The reader should now bear in mind the conditions of the atmosphere as they affect aerial navigation (see Chapter I.). He will remember that it is usual to find an increase in wind speeds at increased altitudes. Also a difference in their direction is common.

At increased altitudes it is generally found that the velocity of the wind increases. At high altitudes the small specific gravity of the air reduces its resistance. The average increase of speed is shown in the following tables.

At Boston, U.S.A., observations of clouds during one year yielded the following averages:—

Height.		Velocity.	
Feet.	Metres.	Miles per Hour.	Km. per Hour.
1,676	510	19	30
5,326	1,625	24	38
12,724	3,880	34	55
21,888	6,675	71	114
29,317	8,940	78	125

Kite observations at Manchester on one day gave the following result:—

Height.		Velocity.	
Feet.	Metres.	Miles per Hour.	Km. per Hour.
1,100	335	21	34
2,000	610	24	38
3,000	915	46	74
4,000	1,220	54	89

This specimen shows the existence of great variations. Further details will be found in the Reports of the Meteorological Department of the Manchester University.

With increased altitudes the speed of the wind usually increases by about two miles per hour for every thousand feet.

From the following table the reader will be able to estimate the number of days in a year on which an aerial vessel of any given speed would be navigable. The table applies to Paris, where the atmosphere is somewhat calmer than that of London.

Speed of the Wind in Metres per Second.	Speed of the Wind in Kilometres per Hour.	Possibilities (in parts of a thousand) that the Wind Velocity will be less than that of the first two columns.	Number of Days in one Year when there would be a possibility of Wind Velocity being less than that of the first two columns.
2·50	9	109	39
5·00	18	323	117
7·50	27	543	197
10·00	36	708	258
12·50	45	815	297
15·00	54	886	323
17·50	63	937	342
20·00	72	963	350
22·50	81	978	354
25·00	90	986	358
27·50	99	991	361
30·00	108	995	363
32·50	117	996	364
35·00	126	998	364
37·50	135	999	364
40·00	144	1,000	365
42·50	153	1,000	365
45·00	162	1,000	365

Taking an average of the surface winds throughout the year, Professor Loomis found the following average velocities for the wind in various parts of the earth.

	Mean Velocity of Wind (miles per hour).	Mean Velocity of Wind (km. per hour).
Europe	10·3	16·6
United States . . .	9·5	15·3
Southern Asia . . .	6·5	10·5
West Indies . . .	6·2	9·9

In the northern hemisphere in high altitudes there is a greater prevalence of westerly winds than at lower altitudes and near the ground. The deviations increase as we ascend, and it is generally to the right or clockwise. According to Berson the wind in 75 cases per 100 deviates to the following extent:—

0 and	3000 feet the deviation to the right is	15	degrees
3000 ,,	6000 ,, ,, ,,	13	,,
5000 ,,	10,000 ,, ,, ,,	11	,,
10,000 ,,	13,000 ,, ,, ,,	1	,,
13,000 ,,	16,000 ,, ,, ,,	3	,,
16,000 ,,	19,000 ,, ,, ,,	6	,,
19,000 ,,	22,000 ,, ,, ,,	6	,,

a total twist of 55 degrees in about 4 miles; so that, for example, a south wind on the ground becomes a south-west wind at a height of 4 miles. Under certain conditions of the weather, deviations from these figures naturally occur, and sometimes there is a twist in the opposite direction—*i.e.*, to the left as we ascend.

In the southern hemisphere the deviation is still clockwise, but the prevailing winds are from a different direction.

The general distribution of the wind is shown by the table constructed by Hann:—

Geographical Latitude.	Wind on Surface of Earth.	In the Middle Strata, 10,000 to 32,000 Feet	In the Upper Strata, above 32,000 Feet.
60° N.	W.-S.-W.	W.-N.-W.	W.-S.-W.
30° N.	N.-E.	S.-W.	W.-S.-W.
10° N.	E.-N.-E.	E.	E.-S.-E.
Equator:			
10° S.	E.-S.-E.	E.	E.-N.-E.
30° S.	S.-E.	N.-W.	W.-N.-W.
60° S.	W.-N.-W.	W.-S.-W.	W.-N.-W.

11. Advantages of High Flying: Radius of Descent. —Although the wind is usually stronger at high altitudes and, on occasion, it may be contrary to the direction in which the aviator desires to travel, it is always safer to fly at comparatively high altitudes rather than near the ground. For this there are two main reasons. In the first place, the wind is steadier at high altitudes, and there is less danger from perplexing currents and eddies

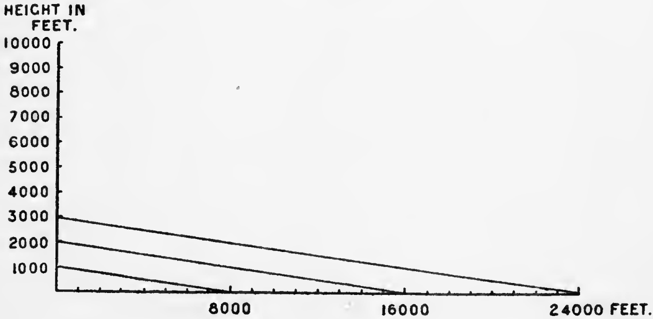

FIG. 28.

set up by the contour of the ground. Again, by flying high the aviator has a greater radius for descent, and especially is this valuable in the case of involuntary descents through any failure of the machine. Further, a machine with a small gliding angle has a larger radius for descent, height for height, than a machine with a steep gliding path. Assuming that you have an aeroplane with a gliding path of 1 in 10, and you are flying at a height of 1000 feet, it is clear that for every foot downward you have a horizontal path of 10 feet.

In other words your gliding radius is 10,000 feet. In cross-country flying, in mountain flying, and in flying over towns it is of vital importance always to have a large gliding radius in order that a safe landing-place may be secured.

12. Decreased Weight of the Air at High Altitudes.—The attainment of high altitudes entails extra labour on the motor, and in regions where the specific gravity of the air is appreciably less than it is at sea-level an aeroplane, to maintain horizontal flight, must fly at increased speed in order to obtain sufficient air-pressure to support it. Flying at the increased speed necesssary for support adds to the head-resistance which otherwise in this attenuated air would be diminished.

13. The Backwash from Machines Overhead.—Clearly there is less risk of collision in aerial navigation than in terrestrial or marine, for there is the vertical dimension as well as the lateral in which to travel. But the aeronaut who passes below another flying-machine runs the risk of being forced downward by the "backwash" from it. A flying-machine continually thrusts downwards a column of air. The force and extent of these columns have not been accurately determined.

14. Causes of Vertical Currents and Eddies.—As already stated, currents and eddies are set up by various causes. Vertical currents are caused by changes of temperature. The aeronaut must study the conditions which set up local currents. In flying near the ground it will often be found that a clump of trees, or a cliff, or a hillside will produce rising currents for which the aviator must be prepared (see Chap. I.).

15. Finding the Way.—Finding the way in the air offers certain difficulties. It is often difficult to recognise familiar country seen from above, and special maps showing features of the country that are easily recognisable from above are desirable. Maps which indicate safe landing-places and the nature of local meteorological conditions are also needed.

16. The Compass only of use when Earth is Visible.—The magnetic compass is, of course, a necessity. It must be mounted in a manner that prevents vibration, secure from the disturbing influence of the magneto of the motor. All the while land is in sight it is possible to keep a straight course, but over the sea or at night, or when over clouds, it is impossible for the aeronaut to ascertain to what extent he is being driven out of his course. In such cases a "dead reckoning," making allowance for the supposed direction and velocity of the wind, must be made. But, obviously, on again coming into view of the ground it will often be found either that sufficient allowance for deviation was not made, or that the deviation was over-estimated.

17. Taking the Meridian.—Taking the meridian is the same as that on board ship, except that in the case of airships an artificial horizon must be used, since the natural horizon from any considerable height usually appears indistinct.

18. Atmospheric Roads.—With experience of aerial navigation the winds are being more accurately measured and better understood. It is certain that there are various more or less constant currents of the atmosphere as there are of the sea. It is believed that migrating birds take advantage of definite "atmospheric roads," and even of storm currents. Attempts have been made to chart the more or less constant winds in a manner suitable for the purposes of the aerial navigator. Communications from stations on the ground to aerial navigators, and from aeroplane to aeroplane by means of signals and wireless telegraphy, giving information as to the wind, will be of great assistance.

CHAPTER IX

MOTORS

Power for Model Aeroplanes—Clockwork and Compressed-Air Motors—Simple Elastic Motors—Early Steam-Engines for Flying Machines—Principles of the Steam-Engine—Transmission of Power for Mechanical Purposes—The Fly-Wheel—The Expansive Power of Steam—Internal Combustion Engines—The Carburetter—The Explosion Cycle—Speed of the Petrol Motor—Various Types of Petrol Motors—The Gnome Rotary Motor—The Rotation of Explosions—Lubrication—Starting the Motor—Fuel Consumption—Amount of Horse-Power per Work Required—Advantage of the Many-Cylindered Motor—Difficulties of the Aero-Motor—Air-Cooling and Water-Cooling—Reliability the most desirable Quality—Motors for High Altitude Flying—Effect of Diminished Efficiency—Electric Motors.

1. Power for Model Aeroplanes.—The subject of mechanical power to drive the propulsive members of an aeroplane is extensive and complicated. Only the principal considerations can be discussed in this book; and, first, since we have already employed the model aeroplane for the purpose of illustrating principles of dynamic flight, and much may be learned from power-driven models, we will illustrate methods of obtaining power for models.

2. Clockwork and Compressed-Air Motors.—Owing to the difficulty of contriving a steam-engine or a petrol motor small enough and at the same time light enough for models, the model-maker is obliged to utilise energy supplied from without and stored up, such as compressed-air, clockwork, and twisted rubber. Of these the two former do not give good results. Clockwork does not yield sufficient power to drive a screw-propeller of reasonable dimensions; but it is believed that there may be a future for the small compressed-air motor. Twisted rubber gives by far the best result. By its means it is possible to store up sufficient power to drive a model a third of a mile.

3. Simple Elastic Motors.—A simple form of elastic motor is shown in the diagram. The elastic, in flat strips, is stretched over two hooks, one fixed,

Fig. 29.

the other free to revolve. This is wound up by turning the screw-propeller with the fingers until the elastic is sufficiently twisted. The model is then held in position ready for flight, and released. The untwisting of the elastic revolves the screw-propeller with great rapidity, sufficient for flight. Complicated forms of elastic motor can be made. There are, indeed, numerous varieties; and the reader who desires to experiment is advised to refer to a book dealing with the subject, one of which is mentioned in the bibliography on page 116.

4. Early Steam-Engines for Flying Machines.—Until the invention of the petrol motor, which is the most practicable form of internal-combustion engine, experimenters in dynamic flight were compelled to utilise steam-engines. The great weight of steam-engines relatively to horse-power yielded prevented success, although two experimenters, Ader in France, and Maxim in England, obtained partial success. Ader made an ascent as long ago as October 14, 1897, on his historic "Avion," which was driven by two steam-engines each of 20 horse-power, and each weighing 44 lbs., excluding the boiler. Maxim, in 1894, built a machine which demonstrated its lifting power with two steam-engines developing 360 horse-power, and weighing, together with the boiler, nearly 7000 lbs.

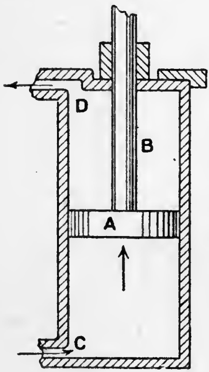

FIG. 30.

A, piston; B, piston rod; C, inlet for steam; D, outlet valve.

5. Principles of the Steam-Engine.—The reader should have some knowledge of the method by which steam-power is utilised in mechanics in order to understand the problems in connection with the light internal-combustion engine which is used in most motor cars and aeroplanes. A steam-engine consists mainly of a cylinder closed at each end, and containing a piston, which is a thick disc whose circumference fits closely the interior wall of the cylinder, leaving a chamber at each end inside the cylinder. The piston fits so closely as to prevent the passage of steam between it and the cylinder sides, yet has sufficient freedom of motion to enable it to move up and down in the cylinder. Small apertures are provided at the cylinder ends, and are furnished with valves by which steam is admitted or allowed to escape. The valves are operated mechanically, opening and shutting at the precise moment necessary for the efficient working of the engine. Steam is admitted at one end of the cylinder under pressure, and its expansive quality under the influence of heat is utilised to force the piston to one end of the cylinder. That end of the cylinder is then in its turn filled with steam, and, by a repetition of the same operation, the piston is driven back to the other end of the cylinder. The movement is facilitated by the condensation of the steam after its expansion, by means of a water jet, into water producing a vacuum in each end of the cylinder in turn.

6. Transmission of Power for Mechanical Purposes.—The piston is connected with the exterior of the cylinder by means of a rod, called the piston-rod. The movement of this piston, or connecting-rod, is usually converted into a rotary motion by a crank at its end. The crank is attached to the end of the piston-rod by a crank-pin and bearing (see Fig. 31).

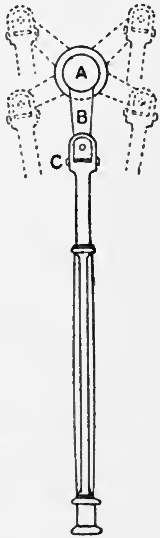

Fig. 31.

Connecting - rod and crank shaft B, which moves on crank-pin A, taking up in its revolution positions shown in dotted lines.

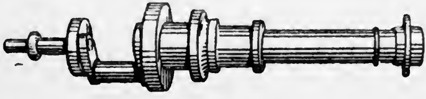

Fig. 32.

7. The Fly-Wheel.—In the course of its conversion to rotary motion there are two points when the crank-pin assumes its highest and lowest positions, which are called the "dead points," at which there is a tendency for the rotary motion to cease. It is prevented from stopping partly by its own momentum, and partly by a heavy fly-wheel, the revolution of which carries the movement on. The complete steam-engine consists of this simple contrivance, or of some elaboration of it in which two or more cylinders are used, and of a boiler, or steam-generator, which may be simple or highly complicated.

8. The Expansive Power of Steam.—A quart of water evaporated under ordinary circumstances will produce about 1700 quarts of steam, but this proportion varies with circumstances, such as atmospheric pressure. If water be boiled under an atmospheric pressure of 30 lbs. per square inch, a cubic inch of water will produce half a cubic foot of steam; if it be boiled under a pressure of 15 lbs. it will produce a cubic foot of steam.

9. Internal Combustion Engines.—The internal combustion motor differs from the steam-engine fundamentally in that the expansive substance which drives the piston up and down in the cylinder is admitted into a combustion-chamber, and there exploded by an electric spark. This expansive substance is an explosive compounded of gas or petrol vapour, and a due proportion of air.

Petrol is distilled from crude petroleum, which is a mineral oil. It is a volatile liquid, and is rendered available for use in an internal-combustion engine by means of a spray, by which a given portion of the petrol is readily converted into a vaporous form, in which condition it is admitted into the cylinder with air in the proportion which renders the mixture highly explosive. The valve by which this mixture is admitted automatically closes, an electric spark is produced either by a magneto or by a coil and accumulator, and the mixture explodes, its expansion driving the piston along the cylinder. The piston returns and drives out the spent or "exhaust" gases, and is then ready for another explosion. As in the steam-engine, it is necessary to have a fly-wheel to carry the motion of the crank over dead-centres.

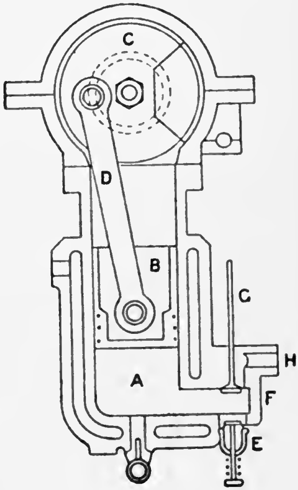

FIG. 33.

A, cylinder; B, piston; C, internal fly-wheel; D, connecting-rod; E, inlet valve for petrol vapour; F, exhaust valve; G, exhaust valve stem; H, exhaust opening.

10. The Carburetter.—The petrol vapour (the hydro-carbon constituent) and air are mixed in a chamber, known as the carburetter, outside the combustion chamber of the cylinder. Thence they are drawn into the cylinder by the outward movement of the piston.

11. The Explosion Cycle.—The complete cycle is as follows, and it is known as the Otto cycle, from Dr.

Otto, who first contrived it for a practical gas-engine. First, the outstroke of the piston sucking explosive mixture from the carburetter into the combustion chamber; second, an instroke of the piston which compresses this mixture in order to make the explosion of greater power; third, the firing of the mixture, which forces the piston back, doing work through the piston-rod and crank, as in a steam-engine; fourth, instroke of the piston driving out the exhaust of the explosion. The arrangements of the valves cause the inlet to close immediately the mixture is drawn into the combustion-chamber, so that the mixture is not forced out again when the piston returns compressing it. When the piston has travelled as far as it can under the influence of the explosion, the valve reopens.

12. Speed of the Petrol Motor.—The stroke of the piston is the distance it travels in the cylinder. It is usually longer than the diameter, or bore of the cylinder. As there is a limit to the speed at which a piston can travel in a cylinder, it is usual to obtain a great number of revolutions with a short stroke, rather than few revolutions and a long stroke. A motor gives 1000 or 1200, and even more revolutions to the minute.

13. Various Types of Petrol Motors.—The ordinary motor of two, four, six, and more cylinders works with various elaborations due to design and size, but on this general principle; but the needs of mechanical flight have provoked the evolution of new types in which automaticity is very highly developed, since it is impossible to give the personal attention to a motor on an aeroplane that it is to a motor on the road.

The desire to save weight, also, has induced inventors to make all sorts of modifications and changes. For instance, instead of the usual vertical or horizontal engines, we have motors in which the cylinders are set on the crank-case in V fashion, and others in which they revolve round a fixed crank-shaft, so that instead of the crank-shaft revolving and producing work, they force themselves to revolve round it, and themselves do the work by their own revolution, their own weight obviating the necessity for a fly-wheel, since the motion is readily carried beyond the dead centre. The first successful motor of the rotary type was the Gnome, and since this motor was largely responsible for great advances made in aviation in the years 1909 and 1910, we will take it as a type and describe the manner in which it works.

14. The Gnome Rotary Motor.—The working of a rotary motor is so different from those of stationary cylinders, that even at the cost of recapitulating some portion of what has already been said, we will watch the progress of the petrol from the tank throughout its task. In the Gnome engine the main shaft, which in other engines revolves, is stationary. It is hollow, and through it the petrol from the tank above, after passing through the carburetter, where it is vapourised and mixed with air, passes into the central part of the motor called the crank-case. The quantity increases automatically with any increase in the speed of the engine. The portion of the shaft which carries the crank is in the crank-case.

The arms which project from the crank-shaft are called cranks. The member which joins these two projections from the shaft is called the crank-pin. Now the important business of the shaft lies at the crank, the length of which is an important factor in this, as in other engines, since it is a form of lever. On the crank-pin is mounted a disc, from the side of which projects one of the seven pistons, or connecting-rods. This connecting-rod is fixed, and is called the

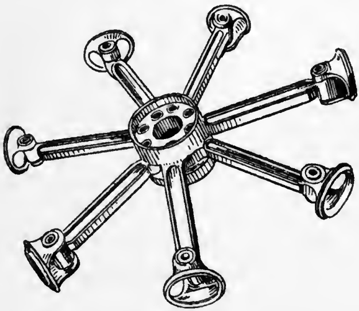

Fig. 34.

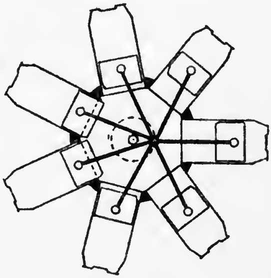

Fig. 35.

main connecting-rod. Whilst the main shaft remains stationary, the crank and crank-pin revolve, carrying the disc in a circle, the centre of which is co-incident with the axis of the shaft. As it revolves the rod with the piston at its other end moves in and out of one of the cylinders, of which there are seven radiating from the crank-case. When the piston is pulled down the cylinder some of the explosive mixture in the crank-case is drawn into the combustion chamber, which is on the other side of the piston at the extremity of the cylinder; and as the valve is closed to its escape the mixture is compressed when the piston is driven back. At the moment of compression an electric spark ignites it, with the result that the piston is forced down again towards the crank-case. But that is only one of the seven pistons, and only one of the seven connecting-rods. To the disc to which the main connecting-rod is fixed are attached the ends of the six secondary connecting-rods, each of which has its own piston working in its own cylinder. The forcing up and down of one of the connecting-rods moves the crank round part of a circle, and while the crank is turning continually with the disc, each of these connecting-rods with its piston is pulled up and down its cylinder, performing the same operation. Thus each of the seven cylinders provides an explosion which assists in turning the crank and itself round the fixed crank-shaft. The seven cylinders revolve, carrying with them the screw propeller which is fixed outside.

15. The Rotation of Explosions.—In this motor there is one complete revolution to every seven explosions, that is, 4200 explosions to the minute. The explosions do not take place in consecutive order, but as follows, 1, 3, 5, 7, 2, 4, 6, This is in order to get exactly equal intervals between the explosions. If they were taken in rotation the intervals would be irregular.

16. Lubrication.—The 50 horse-power Gnome motor revolves at about 1200 to the minute, and the problem of keeping the bearings oiled so that they run without friction is, as it is in all high speed motors, serious. Pure castor-oil is used, and this is supplied through a copper pipe carried within the hollow crank-shaft. The shaft is pierced with fine holes to allow the oil to pass through to the pistons and bearings.

17. Starting the Motor.—It is impossible to describe the mechanism in all its details here. It need only be said than when the mechanic gives a turn to the propeller and cylinder, and the pistons begin to move up and down, explosions in some of the cylinders are automatically produced, and directly they begin the rotating cylinders carry on the movement. The passage of the cylinders through the air keeps them cool, and their exteriors are finned so as to increase the cooling effect; thus water-cooling by means of a radiator is not necessary. Nor is a fly-wheel necessary, for the momentum of the cylinders carries the movement over dead centres.

18. Fuel Consumption.—Fuel consumption is a most important consideration. It may be taken to be roughly one pound of petrol per horse-power per hour. This, however, varies slightly in different machines and under different circumstances. The amount of lubricating oil also varies with different types of motor.

19. Amount of Horse-Power per Work Required.—It is possible to work out the proportion of horse-power to plane-area and weight carried. In a number of machines the proportion is roughly 1 horse-power to 9 square feet of area, and 1 horse-power to 25 lbs. lifted. But the Santos-Dumont monoplane has only 5 square feet of plane area, and 16 lbs. weight to each horse-power. The Blériot-Gnome combination, of 50 horse-power, has about 1 horse-power to 3 square feet and $11\frac{1}{2}$ lbs. A simple method of ascertaining the approximate horse-power required to do a certain amount of work is as follows—multiply the thrust of the propeller by the number of revolutions per minute, and by the pitch (in feet), and divide by 33,000, and the result is the required horse-power.

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

As we have seen, in a moving aeroplane there is a strict limit to the amount of thrust per horse-power. In estimating the power necessary an important factor is that, whereas the thrust varies as the fourth power of the diameter, the power consumed varies as the fifth power.

20. Advantage of the Many-Cylindered Motor.—As to the type of motor which gives the best results, the advantage appears to lie with the motor of many cylinders on the score of trustworthiness, but the failure of even one cylinder in eight means a great reduction of propeller power.

21. Difficulties of the Aero-Motor.—The engines used in flying machines are, as a rule, less efficient than motor-car engines, because they have comparatively small cylinders, very great speed, and the cooling contrivances are imperfect.

22. Air-Cooling and Water-Cooling.—Air-cooling and water-cooling has each its advocates. When air is used for cooling it must be forced over the cylinder heads with a certain velocity before it is of any use. Under a certain speed, therefore, the cooling is inefficient. Water-cooling on the other hand, adds to the weight of the engines, the combustion chamber must have a double wall with piping for the flow and return, while a radiator and reservoir are also required.

23. **Reliability the most desirable Quality.**—There is no doubt that many motors designed for aeronautical work fail through the weight being cut down at the cost of reliability. This sacrifice is needless, such extreme lightness as is aimed at not being necessary. An aero-motor, above all things, must be able to take care of itself. Progress, however, has been extraordinarily rapid, so much so that aviation, which could only be undertaken under great difficulties and at great risk up to the end of 1909, is now easily practicable.

24. **Motors for High-Altitude Flying.**—For flying at high altitude a contrivance capable of supplying the cylinders with the proper mixture under reduced atmospheric pressure seems to be necessary; but altitudes to 10,000 feet are within the compass of the ordinary motor.

25. **Effect of Diminished Efficiency.**—The necessity for getting the best work out of the motor is seen when it is realised that a small percentage drop in propeller speed means more than a proportionate decline of thrust. Thus if the engine, through the failure of one cylinder or other cause, should lose only 5 per cent. of its speed, it would mean 10 per cent reduction in pull.

26. **Electric Motors.**—The electric motor would be ideal for aeronautical application, because it permits great speed and develops its power through directly rotating elements, but the weight, so far, has proved too great. Electric motors have been used in dirigible balloons, but not since the petrol

motor became practicable. The discovery of a light magnetic metal would make the electric motor available for aviation. In that case the aeroplane of the future will be propelled simply by an armature between two electro-magnets. It may be too, that the experiments being made in wireless transmission of energy will sooner or later prove successful.

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GLOSSARY

Aeroplane.—A flying-machine provided with fixed planes supported dynamically by its movement through the air.

Ailerons.—Movable auxiliary horizontal surfaces, used for maintaining equilibrium, and sometimes for steering.

Angle, Dihedral.—Term denoting that the planes are so arranged as to form an obtuse angle thus : \/ the angle made being the dihedral angle.

Angle, Gliding.—The angle made to the horizontal by the flight-path of a glider or aeroplane with the motor shut off.

Angle of Incidence.—The angle at which a plane is inclined to the horizontal.

Angle, Negative.—The angle to the horizontal made by a surface with its leading or forward edge lower than its rear or trailing edge.

Angle, Positive.—The angle to the horizontal made by a surface with its forward edge higher than its rear edge.

Aspect Ratio.—The ratio between the span and the fore-and-aft dimension (chord) of a plane.

Camber.—The depth of the curve given to a sustaining surface.

Centre of Gravity.—The point through which the mass of an aeroplane acts.

Centre of Pressure.—The point through which the resultant of all the forces of air-resistance on an aeroplane acts.

Chord.—The fore-and-aft dimension of a cambered plane.

Coëfficient K.—The resistance of the air to a thin square plane, of one square metre area, moving normally to the air at one metre per second.

Drift.—The horizontal component of air-resistance: the retarding force experienced by an aeroplane moving through the air.

Flying-machine (dynamic).—A generic term denoting machines used in aviation as distinct from those employed in aerostation.

Fuselage.—The body of an aeroplane in which the pilot sits, and to which the chassis, motor, controls, and sustaining surfaces are fixed. In many biplanes a shortened fuselage is used, which contains only the motor and control levers.

Helicoptère.—A dynamic flying-machine whose sustentation is provided either wholly or partially by propellers rotating on vertical or nearly vertical axes.

Lift.—The vertical component of air-resistance: that portion of resistance which is utilised to support an aeroplane.

Normal.—At right-angles to, perpendicularly to.

Ornithoptère.—A dynamic flying-machine maintained in flight by reciprocating wing surfaces.

Pitch.—The distance forward that a screw-propeller would travel in one complete revolution if there were no slip —*i.e.* if it were moving in a thread cut in a solid.

Pressure, Atmospheric.—The weight of the atmosphere. At 0° Cent., at sea-level, normally = 760 mm. (29·92 inches) mercury.

Pressure.—*See* Resistance.

Skin-friction.—The tangential resistance caused by the flow of air around a body or sustaining surface.

Slip.—The difference between the actual progress of a screw propeller and its "pitch."

Span.—The dimension of the surface transverse to the direction of flight.

Stability.—The property, in an aeroplane, of returning regularly to its equi-poise or equilibrium, with a minimum of oscillation.

Stream-line Body.—The conformation of a body, which permits a regular flow of air around and along it. In general terms, a fish-shaped body tapering from head to stern.

Suction (or Negative Pressure).—The part of air resistance set up in rear of a moving body by eddies and discontinuity of the air-flow.

METRIC AND ENGLISH EQUIVALENTS

Linear

1 mm.	=	0·03937	inches	1 inch	=	25·4	mm.
1 cm.	=	0·3937	„	„	=	2·54	cm.
1 m.	=	39·37	„	„	=	0·0254	m.
„	=	3·2809	feet	1 foot	=	0·3048	m.
1 km.	=	1093·63	yards	1 mile	=	1609·3	m.
„	=	3280·9	feet		=	1·609	km.
„	=	0·6214	mile				

Square

1 sq. cm.	=	0·155	sq. inch	1 sq. inch	=	6·452	sq. cm.
„	=	0·001076	sq. feet	„	=	0·000645	sq. m.
1 sq. m.	=	10·764	sq. feet	1 sq. foot	=	0·0929	„

Cubic

1 cu. m. = 35·32 cu. ft. | 1 cu. foot = 0·0283 cu. m.

Weight

1 gramme	=	0·0353	oz.	1 oz.	=	28·35	gram.
„	=	0·0022	lb.	„	=	0·02835	kg.
1 kg.	=	2·205	„	1 lb.	=	0·454	kg.

Coefficients of Air-Resistance

(*On a thin plane, normal to the wind, at* 0°*C. and* 760 *mm. pressure*).

K_m (kg.) = 0·075 × S (sq. m.) × V^2 (met. per sec.)

K_x (lb.) = 0·00143 × S (sq. ft.) × V^2 (feet per sec.)

K_y (lb.) = 0·003 × S (sq. ft.) × V^2 (miles per hr.)

$K_m = K_x \times 52{\cdot}49$

$K_m = K_y \times 24{\cdot}45$

$K_x = K_m \times 0{\cdot}01902$

$K_y = K_m \times 0{\cdot}0408$

TABLE I.

Metres per Second and Miles per Hour.

Metres per Second.		Miles per Hour.
0·447	1	2·24
0·894	2	4·47
1·341	3	6·71
1·788	4	8·95
2·235	5	11·80
2·682	6	13·42
3·129	7	15·66
3·576	8	17·90
4·023	9	20·14
4·47	10	22·37
4·92	11	24·61
5·36	12	26·84
5·81	13	29·08
6·26	14	31·32
6·71	15	33·55
7·15	16	35·97
7·60	17	38·03
8·05	18	40·27
8·49	19	42·51
8·94	20	44·74
9·39	21	46·98
9·83	22	49·21
10·28	23	51·45
10·73	24	53·69
11·17	25	55·92
11·62	26	58·16
12·07	27	60·34
12·52	28	62·64
12·96	29	64·87
13·41	30	67·11
17·88	40	89·48
22·35	50	111·85
26·82	60	134·22
31·29	70	156·59
35·76	80	198·96
40·23	90	201·33
44·70	100	223·70

TABLE II.

Velocity and Pressure of the Wind.

Kg. per Square Metre. ($R = \cdot 075\ V^2$).		Lbs. per Square Foot. ($R = \cdot 003\ V^2$).	
Metres per Second.	Kg.	Miles per Hour.	Lbs.
1	·075	1	·003
2	·300	2	·012
3	·675	3	·027
4	1·200	4	·048
5	1·875	5	·075
6	2·700	6	·108
7	3·675	7	·147
8	4·800	8	·192
9	6·075	9	·243
10	7·500	10	·300
11	9·075	15	·675
12	10·800	20	1·200
13	12·685	25	1·875
14	14·700	30	2·700
15	16·875	35	3·675
16	19·200	40	4·800
17	21·675	45	6·075
18	24·300	50	7·500
19	27·075	60	10·800
20	30·000	70	14·700
25	46·875	80	19·200
30	67·500	90	24·300
35	91·875	100	30·000
40	120·000	150	67·500
50	187·500	200	120·000

TABLE III.

Barometric Height Table.

Pressure mm. Mercury.	Altitude at 0° C.		Altitude at 10° C.	
	Metres.	Feet.	Metres.	Feet.
760	20	66	22	72
750	127	417	132	433
740	235	771	243	797
730	344	1129	356	1168
720	455	1493	471	1545
710	567	1860	587	1926
700	680	2230	705	2312
690	796	2610	825	2707
680	913	2995	946	3103
670	1032	3386	1070	3510
660	1152	3780	1195	3921
650	1275	4183	1322	4337
640	1399	4590	1450	4757
630	1525	5003	1581	5187
620	1654	5426	1714	5633
610	1784	5853	1850	6070
600	1917	6288	1987	6519
590	2052	6732	2127	6979
580	2189	7182	2269	7445
570	2328	7639	2414	7920
560	2470	8104	2561	8402
550	2615	8579	2711	8894
540	2762	9061	2863	9593
530	2912	9553	3019	9905
520	3065	10,056	3177	10,324
510	3221	10,568	3339	10,955
500	3380	11,090	3504	11,496

TABLE IV.

MILES AND KILOMETRES CONVERSION TABLE.

Miles.		Kilometres.
·621	1	1·609
1·242	2	3·219
1·863	3	4·824
2·486	4	6·437
3·105	5	8·047
3·726	6	9·656
4·347	7	11·265
4·968	8	12·879
5·589	9	14·484
6·213	10	16·093
6·831	11	17·702
7·453	12	19·312
8·074	13	20·921
8·695	14	22·530
9·316	15	24·139
9·937	16	25·748
10·558	17	27·357
11·179	18	28·966
11·800	19	30·575
12·426	20	32·185
18·641	30	48·279
24·854	40	64·373
31·069	50	80·466
37·283	60	96·559
43·497	70	112·652
49·710	80	128·746
55·924	90	144·839
62·13	100	160·934

TABLE V.

Feet and Metre Conversion Table.

Feet.		Metres.
3·281	1	·305
6·562	2	·609
9·843	3	·914
13·123	4	1·219
16·404	5	1·524
19·68	6	1·829
22·96	7	2·134
26·25	8	2·438
29·52	9	2·743
32·81	10	3·047
36·09	11	3·353
39·37	12	3·657
42·65	13	3·962
45·93	14	4·267
49·21	15	4·572
52·49	16	4·877
55·77	17	5·181
59·06	18	5·486
62·34	19	5·795
65·62	20	6·095
98·43	30	9·144
131·23	40	12·192
164·04	50	15·240
196·85	60	18·287
229·66	70	21·336
262·47	80	24·384
295·28	90	27·431
328·09	100	30·479
3280·90	1000	304·787

TABLE VI.

Degrees, Gradients, and Sines.

Degrees.	Gradients.	Sines.
1	1 in 57	·0175
1·91	„ 30	·0333
2	„ 28·5	·0349
2·29	„ 25	·0400
2·87	„ 20	·0500
3	„ 19	·0523
4	„ 14·3	·0698
4·78	„ 12	·0833
5	„ 11·4	·0872
5·73	„ 10	·1000
6	„ 9·8	·1045
6·38	„ 9	·1111
7	„ 8·1	·1219
7·18	„ 8	·1250
8	„ 7·2	·1392
8·22	„ 7	·1430
9	„ 6·4	·1564
9·6	„ 6	·1667
10	„ 5·7	·1736
11	„ 5·2	·1908
11·53	„ 5	·2000
12	„ 4·8	·2079
13	„ 4·5	·2250
14	„ 4·1	·2419
14·48	„ 4	·2500
15	„ 3·9	·2588
16	„ 3·6	·2756
17	„ 3·4	·2924
18	„ 3·2	·3090
19	„ 3·1	·3256
19·45	„ 3	·3333
20	„ 2·9	·3420

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