THE COMPLETE AIRMAN

G. C. BAILEY


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THE COMPLETE AIRMAN

VICKERS VIMY COMMERCIAL AEROPLANE—ROLLS ROYCE ENGINES

THE
COMPLETE AIRMAN

BY

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WITH NUMEROUS ILLUSTRATIONS

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INTRODUCTION

THIS book aims at providing the airman with a reasonably complete outline of such knowledge as he ought to possess. The title, " Airman," designates primarily the pilot, together with all who actually fly, but it is also intended in its wider application to include the director, the manager, etc., of commercial enterprises connected with aviation, as well as that very important person, the mechanic, the value of whose interest and intelligent co-operation is, unfortunately, often under-estimated. It is hoped that the book may also prove of interest to persons less directly concerned with its subject.

The ideal airman must necessarily be somewhat versatile. He must have in him something of the sailor, the engineer, and the scientist, added to which he must possess more than an average share of common sense.

The title, " Complete Airman," is inevitably somewhat misleading, since it is obviously impossible to compress within the limited space available in a book of this type more than a very small proportion of the matter which covers so wide a field. The fact that it is written with a view to being of use and of interest to such widely differing classes of airmen further adds to the difficulty of choosing what to include and what to omit.

Theory as such has as far as possible been everywhere avoided. The aim throughout has been to enunciate fundamental principles and to point the way to their development rather than to describe the actual practices ultimately resulting from them. No catalogue of isolated facts, however complete, is to be compared, from the point of view of general utility, with a sound knowledge of principles, backed by common sense in their practical application. The illustrations are mainly diagrammatic, and are in all cases designed to make principles clearer and more obvious.

The subject-matter of the book has been split up into sections. Each chapter aims at dealing with one of these. The chapters, while thus available separately as a brief study of the particular subject with which they severally deal, nevertheless follow one another in such a way as to form a continuously developing course, which gives to the whole a certain element of completeness.

The first four chapters are devoted entirely to theory. The first consists of a brief survey of certain principles of elementary mechanics, together with a few remarks on the flow of air. It is designed to refresh the reader's memory as to matters probably less familiar now than in former days. It is further intended to emphasise the fact that there is no mystery in the phenomenon of flight, and that a comparatively elementary knowledge of ordinary mechanics suffices to explain the problems of flight in general.

Chapters II, III, and IV deal with the theory of flight. They lay no claim to completeness, but should, it is thought, be sufficient to put the reader in the way of understanding the theoretical aspect of most practical problems, chiefly by referring him to first principles. He is therefore urged thoroughly to master these chapters if not already familiar with their subject-matter.

The care and construction of machines have been dealt with in subsequent chapters, and this from an essentially practical point of view.

The principles of actual flying and of instruction in this are elsewhere discussed. A certain amount of space has been devoted to rules and advice which, while by no means new to the average pilot, are unfortunately less often acted upon than should be the case.

Chapters dealing with such matters as may be described as auxiliary equipment, namely, sheds, aerodromes, etc., have been included. Airships, seaplanes, etc., have also received brief mention.

The financial value of a sound knowledge of aeronautics will be apparent to all airmen engaged in commercial enterprise.

The general cost of wear and tear in any flying concern must inevitably form a very high percentage of the working expenses. Nothing can so effectually reduce the amount of this outlay as a good practical grasp of the principles of aeronautics generally on the part of all concerned. For example, "wear and tear" includes "crashes," which are nearly always the result of either ignorance or carelessness.

Owing to the wide field which has to be covered, even in an elementary work such as the present one, it is impossible to more than touch on the various subjects involved. It is no easy matter to allot the available space amongst these, or to decide as to their relative importance. In this the personal equation which can never wholly be eliminated adds a further complication. Points which present considerable difficulty to one airman, and are therefore of the greatest importance to him, are relatively unimportant to another whose difficulties perhaps lie in quite a different direction. Herein lies the main problem from the writer's point of view, namely, what to include, what to exclude, what to emphasise, and what to pass over with as brief a mention as possible. Suggestions as to modifications in these respects will be welcomed.

A further difficulty lies in the fact that the aeroplane must necessarily undergo a certain process of evolution as the result of the change from war to peace conditions. Whereas in war-time the chief necessities were speed climb and "manœuvreability," the main needs of peace-time aviation are reasonable speed combined with capacity for weight-carrying, and economy of running and upkeep. In any case, however, it is tolerably certain that many years must elapse before this evolutionary process results in the production of the "fool-proof" aeroplane, the flying and care of which necessitates no technical knowledge whatsoever.

In conclusion the author wishes to thank all the various makers who have so kindly supplied photos of machines, engines, etc., as illustrations for this book. He wishes also to express his gratitude to Mr. G. Watts for his valuable help in reading through some of the chapters, and for making many valuable suggestions with regard to them.

THE COMPLETE AIRMAN

CHAPTER I

MECHANICS

THIS chapter is intended to put before the reader the minimum amount of theoretical mechanics required to enable him to understand the terms and explanations which occur in other parts of the book.

The vector method of indicating forces and velocities graphically is very commonly used in mechanics. A force or velocity may be fully represented by a straight line. The angle at which it is drawn shows its angle relative to other forces or velocities. The sense in which it acts is indicated by an arrowhead. The line is termed a "Vector." Diagrams of forces only will be here discussed. Consider the simple case of a system of weights supported by strings over pulleys, as shown in Fig. 1. The forces acting at the centre are the pulls of the two strings and the force of gravity (i.e. its own weight) acting vertically downwards. Supposing that the weight of the body be 3 lbs., the vector diagram representing the forces acting on it is as shown. Obviously the system will move into such a position that it is in equilibrium. That is to say, it will

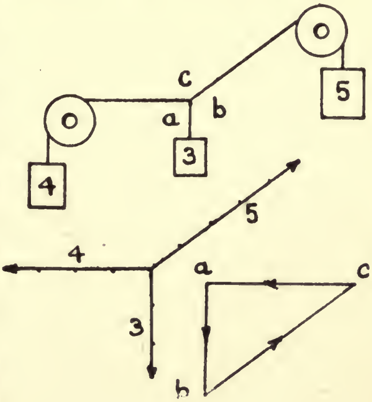


FIG. 1.

move so as to adjust the angles at which the various forces act until they balance one another. If the vectors representing the three forces acting are drawn in order, the second commencing from the end of the first, and the third from the end of the second, it will be found that they will form a closed figure. This is found to be true for all systems in equilibrium, and leads to the law of the Polygon of Forces. This states that if a body be in equilibrium under the action of a number of forces, the lines of action of which pass through one point, then the vectors representing these forces when taken in order form a closed polygon.

Consider once more the system shown in Fig. 1 (which also shows the Polygon of Forces for this case). As only three forces are involved, the resulting figure is a triangle—that is to say, the simplest form of polygon. It is drawn as follows: Adopting any convenient scale, draw a line *ab*, in length and direction equal and parallel to the force *ab*, i.e. the weight. From *b* draw *bc* equal and parallel to the force *bc*. From *c* draw *ca* equal and parallel to the force *ca*. As the system is in equilibrium, the triangle will close. The system of notation adopted above—i.e. placing the letters serially between the lines of action of the various forces and adopting them for the angular points of the vector diagram—is known as Bowe's notation. Its advantages are obvious, and it should always be used in problems of this nature.

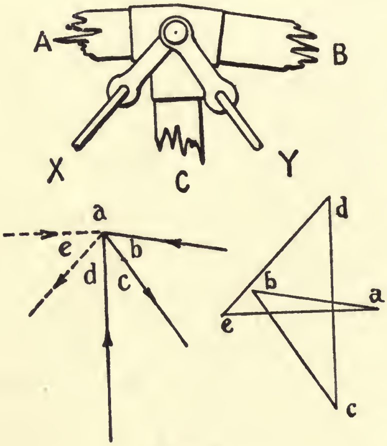


Fig. 2.

The resultant of two or more forces is the force equal and opposite to that force which is required to keep them in equilibrium. In the system just discussed the resultant of *bc* and *ca* is equal and opposite to *ab*.

To consider a more complicated case: Take the fuselage joint shown in Fig. 2. Suppose that the forces in the struts B and C and in the wire Y are known. The problem is to find the forces in the strut A and the wire X. It is possible to draw three sides of the polygon, namely, *ab*, *bc*, and *cd*. Drawing *de* and *ea* parallel to the respective forces gives us the intersecting point *e*, and fixes the magnitude of the unknown forces.

Up to the present, only the equilibrium of forces, the lines of action of which pass through a common point, has been considered. Suppose a body be acted on by three equal forces at 120°, the lines of action of which do not all pass through one point (see Fig. 3). Were the force C to act at a point on the line XY the law of the Polygon of Forces would be satisfied. What, then, is the effect of the forces not passing through a common point? It is evident that the body tends to turn — in this case in a clockwise direction. The body will continue to rotate until it assumes a position of equilibrium. This, of course, demands that the lines of action of the forces shall pass through one point, and that the Polygon of Forces is satisfied. This leads to the other great law of equilibrium, the Law of Moments, which states that if a body is in equilibrium under the action of a number of forces, the sum of the moments of these forces about any point must be zero. The moment of a force about a point is the amount of the force multiplied by the distance of its line of action from the point. It is considered + when acting in an anti-clockwise, and − when acting in a clock-wise direction. It may be expressed in foot-lbs. or inch-tons, or in any other convenient unit.

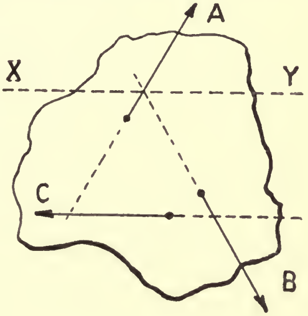


FIG. 3.

FIG. 4.

Take the simplest application—the lever illustrated in Fig. 4. The force P required to lift the weight W may first be found. The forces acting on the lever are P, W, and F (F being the force at the pivot). F is neither known nor required to be known; moments are therefore taken about B, which is on the line of action of F, thereby excluding it from the calculation. From the law of moments;

$$P \times AB = W \times BC$$
$$P = \frac{BC}{AB} W$$

Were it necessary to find the value of F, moments would be taken about A. The forces need not, of course, be parallel. In Fig. 5 the law of moments would be satisfied, provided that either

$$F \times AB = W \times AZ$$

or

$$P \times BX = W \times BY$$

moments being taken about A or B respectively.

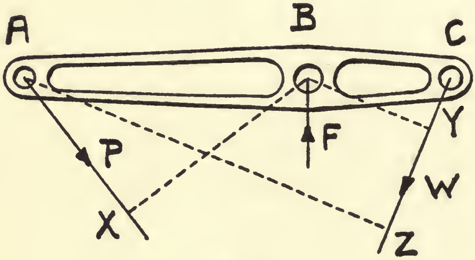


FIG. 5.

The method of calculating the centre of gravity of a body is arrived at by applying the law of moments. The centre of gravity of a body is that point at which the resultant of the forces due to gravity on the body may be considered to act. For example, it is evident that the centre of gravity of a uniform rod is its centre point, likewise the centre of gravity of a square plate of uniform thickness is at the intersection of its diagonals. As a more complicated illustration the centre of gravity of a very light rod, AC with weights P, Q, and R on it, shown in Fig. 6, may be found. The resultant force will act at some intermediate point B. Its magnitude is necessarily

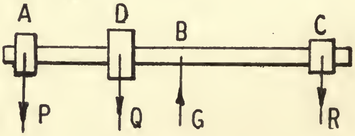


FIG. 6.

$$P + Q + R = G.$$

By taking moments about A :

$$Q \times AD + R \times AC = G \times AB$$

or by taking moments about C :

$$P \times CA + Q \times CD = G \times CB$$

from either of which equations the position of B may be found.

There is a very simple experimental method of finding the centre of gravity of complicated bodies. Since the centre of gravity of a body is that point through which the resultant force due to gravity acts, then the body will necessarily balance about that point. Suppose it is required to find experimentally the centre of gravity of an irregularly shaped body, as shown in Fig. 7. If suspended by a string from the point H the resultant force of gravity is evidently on the vertical line of suspension HX. It is then hung from another point B, the line BY being found. The centre of gravity is necessarily at the intersection of these two lines, namely, the point G.

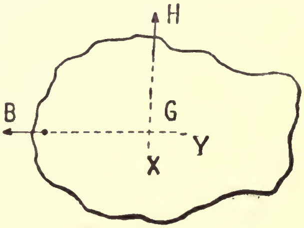


FIG. 7.

Centrifugal forces are frequently met in considering problems of practical aviation. When a weight is rotated about an axis which does not pass through its centre of gravity it has a tendency to fly outwards; the amount of this force is expressed thus:

$$P = \frac{WV^2}{gR} \text{lbs.}$$

W = Weight of the body.
V = Its velocity in feet per second.
R = Radius in feet at which its centre of gravity rotates.
g = The acceleration due to gravity (32·2 feet per sec. per sec.).

This force acts radially at the centre of gravity of the body. It is thus that the forces which are brought into play when an aeroplane turns, or the out-of-balance forces due to an ill-balanced propeller, are calculated. An important point to notice is that the force varies as the square of the speed. The importance of small out-of-balance masses when moved at a high speed, as, for example, in the case of a propeller, is thus evident.

The horse-power is the unit of work, and is defined as 33,000 foot-lbs. per minute. That is to say, it is equal to the lifting of a weight of 33,000 lbs. through a distance of one foot in one minute, or the equivalent of this, e.g. 1000 lbs. through 66 feet in two minutes. As an example, suppose that the head resistance of a machine going at a speed of 60 miles an hour is 400 lbs.

It travels 5280 feet per minute; therefore, 2,112,000 foot-lbs. of work are done per minute, and the horse-power necessary is approximately 64.

Another mechanical term which is frequently met with, and has considerable application in aeroplane design, is Torque. The torque of a force is the twisting moment which it exerts, and is measured, as are all moments, by a force multiplied by a distance, usually in foot-lbs. Engine Torque may be considered. The turning moment required to force the propeller through the air absorbs the whole of the available power of the engine. Suppose that this turning moment is equivalent to a weight of M lbs. at L feet, the moment or torque is then ML foot-lbs. In relating torque to horse-power it must be remembered that the weight travels the complete circumference of the circle, therefore—time being calculated in minutes, weights in lbs., and distances in feet:

$$\text{H-P} = \frac{2\pi L \times \text{revolutions per min.} \times M}{33{,}000}$$

$$\text{or Torque} = ML = \frac{33{,}000 \times \text{H-P}}{2\pi \times \text{revs. per min.}}$$

Action and reaction are equal and opposite. Thus, if the engine is exerting a torque of 200 foot-lbs. on the propeller, the machine must exert an equal and opposite torque on the engine to prevent it from turning. For this reason machines are commonly arranged with slightly more lift on one side than the other. A machine having a propeller which rotates clockwise when looked at in front must therefore have slightly more lift on the right hand or starboard planes, i.e. those on the right-hand side of the pilot when he is sitting in the machine.

Since air is the medium in which an aeroplane moves the reader should have some knowledge of the laws concerning the flow of gases. There are two quite distinct forms of flow —streamline flow and eddying flow. Air is said to flow in stream lines when each particle may be considered as following a perfectly definite steady path in the direction of the general motion. The course of any of the particles would in no way be affected if a number of very thin tubes were to be inserted in the lines of the flow. When air flows in a streamline manner comparatively little energy is required to move it. Eddying flow occurs when the particles of air are so disturbed that they eddy round and round in addition to moving in the general direction of the motion. This eddying is a source of loss partly on account of the fact that the particles travel much farther and faster than is necessary, and partly because of the friction between the particles. The designer of an aeroplane aims at avoiding this eddying flow as far as possible. It arises from three main causes. The first is friction and excessive velocity. If air is forced through a passage at an excessive speed eddying flow is always induced. The second cause is too sudden changes in the direction of flow of the air due to sharp corners, etc. The third cause may be expressed as "expanding flow." The first two causes are perhaps sufficiently obvious to make further explanation unnecessary. The third requires some comment, especially as its practical application is of the utmost importance. Consider air passing in a streamline manner through a constricted passage, as in Fig. 8 (I). As the air passes to the narrow portion B the streamlines contract in cross section, the velocity of the particles being increased correspondingly. As the streamlines pass from B to C their cross section increases and the velocity of the particles becomes reduced. It is in the expanding streamlines, as at BC, that eddying most readily occurs. That is to say, supposing that in a short length of tube it were necessary to make a constriction of such form as would be least liable to interfere with the streamline flow, a section, as indicated in Fig. 8 (II), would be adopted, the air flowing in the direction of the arrow. The application of this to aeroplane design may now be considered. Suppose air is flowing past a strut or other section in a streamline manner, as indicated in Fig. 9. When the speed is increased it is at B

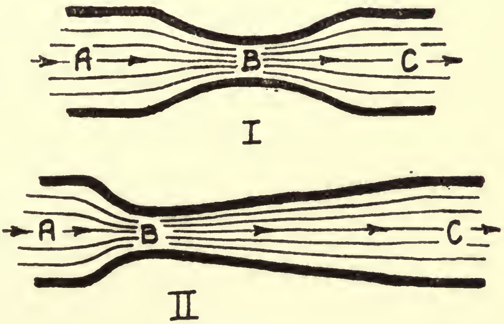


Fig. 8.

that unsteady flow may be expected; thus it is at the part aft of the widest section that most attention must be paid to streamlining. The resulting section adopted is therefore usually as indicated in the figure.

The following law, which is approximately correct for conditions met with in practice, is exceedingly important:

$$P = KA\rho V^2$$

or, in words, the force P required to propel a body through the air is proportional to the area of the body A, the density of the air ρ, and the square of the velocity V at which it is travelling, K being a constant. This law is of extreme importance when regarding problems of flight from a theoretical standpoint. Its general application is worthy of analysis. First, the force is proportional to the area. This fact is sufficiently obvious and requires no comment. Secondly, the force is proportional to the density of the air; this means that the higher a machine is flying, and consequently the less the density of the air, the smaller the force required to propel it at the same speed. Thirdly, the question of the effect of velocity may be considered. The force varies as the square of the velocity; thus, if the speed of a machine is doubled, the engine pull must be multiplied by four, or the actual horse-power by eight. This explains the exceptionally high powers necessary when extreme speed is required. Further, consider the effect of loading on the landing speeds of a machine. The velocity of the machine through the air induces the forces which support it. To double the weight of the machine will increase its minimum landing speed by about 40 per cent. (i.e. $\sqrt{2}-1$).

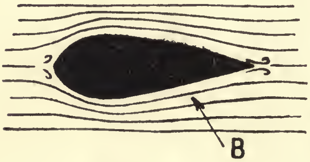


FIG. 9.

The law $P = KA\rho V^2$ is mathematically correct for the streamline and frictionless flow of non-viscous air past bodies of similar shape. No bodies met with in practice can exactly satisfy these conditions, nor can the viscosity of air be entirely neglected. By suitably increasing the value of K, the equation may, however, be applied with tolerable accuracy to the practical cases met with in design. The values of K have been obtained experimentally for most of the sections in common use

The Centre of Pressure of a surface or body situated in a current of air is that point at which the resultant of all forces due to the pressure of the air on the body may be considered to act. It should be noted that this definition is analogous to the definition of centre of gravity.

Skin friction between the air and the various surfaces of the machine is another unavoidable source of loss of power. This again varies approximately as the square of the speed. For this reason it will be noted that an increase in the value of K in the equation already referred to will for similar bodies also take care of the effects of friction.

CHAPTER II

THEORY OF FLIGHT

SUPPOSE a long flat section plate be situated in a current of air, its long dimension being at right angles to the direction of the air flow. Let it make a small angle with the direction of the flow. The nature of the air currents round it will be somewhat as indicated in Fig. 10. At the lower surface the flow is practically streamline, a positive pressure being produced on the plate by the deflection of the air flow. The state of affairs at the top surface is more complicated. Were the flow slow, streamline flow would also be attained here, the then downward deflection of the streamlines producing a suction or negative pressure on the surface. As a matter of fact, at the air speeds met with in practice, eddies as indicated are induced on the top surface. This eddy area produces a much lower pressure than would be produced by streamline flow.

Fig. 10.

The force exerted on a surface by a gas, assuming no friction, is always at right angles to the surface. Let the force P be the resultant of the pressure of the air on the plate, it acts at some point C (see Fig. 11), which is the centre of pressure. Owing to the surface friction (to which, in the case of practical wing sections, may be added other effects) the direction of P is not quite at right angles to the plate. The force P may be resolved into two equivalent forces—one D parallel to the

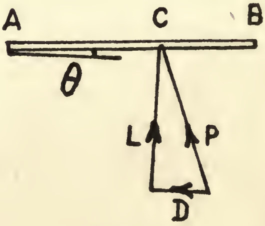


Fig. 11.

direction of the air current, the other L at right angles to it. The angle θ being small, and the resultant force P being approximately normal to the plate, it follows that L is large compared with the D. Therefore, by means of a comparatively small tractive or propelling force a large weight can be supported. This is the fundamental principle from which the aeroplane has been developed.

If the condition of horizontal flight be assumed, L becomes the vertical component of P, and D the horizontal. For practical purposes it is usually convenient to consider the forces on an aeroplane in the components indicated. The vertical component L, known as the "Lift," supports the machine and its load in the air, being at right angles to the direction of flight, it exerts no drag or fore and aft effect, thus having no effect on its speed. On the other hand, the force D, known as the "Drag," is that component of the air pressure in the direction of flight. It does not in any way support the weight, but is the total force to be overcome in dragging or propelling the aeroplane through the air.

The following nomenclature is universally adopted. Referring to Fig. 11, the plate may be called an "Aerofoil," this being a general term applied to all plane sections. The line AB is called the Chord. B is called the Leading Edge, and A the Trailing Edge. The angle θ is known as The Angle of Incidence. The length of the aerofoil (at right angles to the section shown in the figure) is termed the Span.

Consider the aerofoil shown in Fig. 11 as a weight-carrying aeroplane. If the aerofoil itself be assumed to have no weight, a weight equal to L being concentrated at C, then, by applying (say, by means of a cord) a steady force of D at the point C, the plate would be propelled forward horizontally with velocity V relative to the air.

The relation between the angle of incidence and the airspeed for horizontal flight should be noted. Consider the case illustrated. With the angle θ and the speed V, a load L is supported. If V is increased, the angle of incidence must be reduced or the lift becomes greater than the load, thus upsetting the equilibrium. The speed of an aeroplane in horizontal flight, therefore, is fixed entirely by the angle of incidence. The effect on the relative values of L and D of varying the angle of incidence may now be considered. In order to carry as much weight as possible with the minimum power, it is evident that the ratio $\frac{L}{D}$ must be as great as possible. This ratio is called the " lift-drag ratio " of an aerofoil or of an aeroplane, and is a measure of its efficiency.

Let the effect of the angle of incidence on the efficiency be considered. It is not difficult to do this quantitatively; for the present purposes, however, a simple qualitative consideration will suffice. The plane is most efficient as a weight carrier at that value of θ, which makes the ratio $\frac{L}{D}$ a maximum This angle is termed the Optimum Angle. D is in part due to air friction and in part due to the inclination of the plate to the direction of the air motion. The frictional component at any given velocity will alter little as θ is varied, being dependent chiefly on the surface exposed. Suppose that θ is zero, L disappears. The frictional component of D, however, remains. The efficiency of the plane is then zero. As θ increases above some small angle also, the ratio $\frac{L}{D}$ will decrease. It is then evident that there is some small value of θ, which gives the greatest efficiency. For actual plane sections this is usually in the neighbourhood of 4°.

A further point of considerable influence is the position of the centre of pressure. In order that the aerofoil shall be in equilibrium the three forces acting on it must pass through a point. As the resultant force due to the air acts at the centre of pressure the centre of gravity of the load and also the point of application of the propelling force must be situated at this point. The nature of the movement of the centre of pressure must also be considered. For example, it is evident in the case of a flat plate that as the angle of incidence increases, the centre of pressure will move from the leading edge towards the trailing edge. It is interesting in this connection to examine the inherent stability of the aerofoil. This may be defined as its automatic tendency to correct itself in the event of its condition of steady flight being disturbed. Suppose that the aerofoil be travelling as indicated in Fig. 12, and that, owing to some disturbing element, θ becomes slightly increased, C will then move to C′. The point of application of the load W and the propelling force D do not move. The movement of C therefore introduces a couple which tends to restore the equilibrium. In this respect the flat section aerofoil satisfies a primary condition of inherent stability.

The Aspect Ratio of an aerofoil is the ratio $\frac{\text{span}}{\text{chord}}$. This ratio, owing to what is known as "end effect," has considerable influence on the lifting efficiency. The flow of the air near the centre of the span is practically two-dimensioned, i.e. it is confined to a plane at right angles to the span. This is the most desirable condition for the production of lift. At the ends the air, so to speak, escapes, and a certain amount of flow occurs in the direction of the span. This affects the lifting efficiency very adversely. The extreme ends of the planes exert practically no lift at all, the lifting efficiency of sections increasing rapidly as the centre of the span is approached. For this reason the aspect ratio for an actual aeroplane is seldom made less than about six.

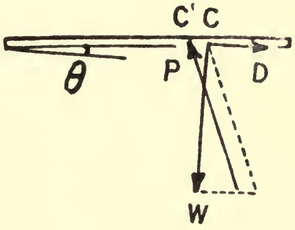


FIG. 12.

The aeroplane so far discussed consists of a single plane (Fig. 11), the load being arranged so that its centre of gravity is at C and the power unit exerting a tractive effort at the same point. Although in the case of a flat section plane, this has a certain degree of inherent stability, it is, however, entirely insufficient; moreover, no convenient system of control can be fitted. The stability can be greatly increased, and a ready means of control may be provided, by the addition of a tail.

Considering the fore and aft conditions, i.e. climbing and diving, air disturbances cause angular movements owing to the resulting movement of the centre of pressure relative to the centre of gravity. What is sought then is some means of influencing this movement either automatically for inherent stability or mechanically for control. The equilibrium is disturbed by the moment of the force P about the balancing point, which is the centre of gravity. The movement of the centre of pressure in the case of actual wing sections is not normally very great. To maintain equilibrium it is necessary then to provide a balancing moment. This is produced by the tail. On account of air resistance and weight of this element, which usually adds nothing to the carrying capacity of the machine, it is desirable that it should be made as small as possible. In order, therefore, that it shall have a considerable moment about the centre of gravity, it must be situated as far from that point as possible.

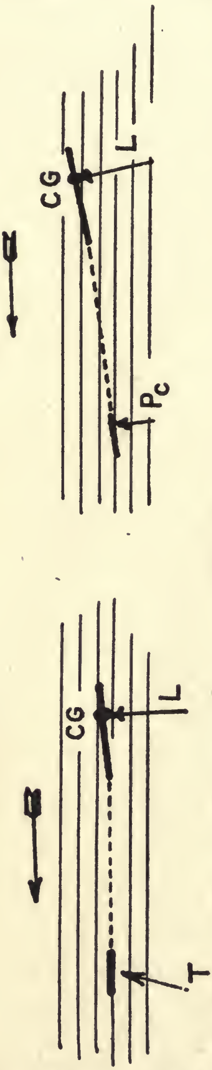


Fig. 13.

Fig. 13 shows the aeroplane previously considered, but fitted with a tail. The tail plane T is usually arranged to have no lift when the main aerofoil is in the position of normal flight. Consider now the effect of any alteration in the position of the machine. Suppose, as indicated in Fig. 13, the nose of the machine is thrown upwards. The tail plane is thus turned into such a position that it presents an angle of incidence to the air, a force P_c being introduced, which tends to restore equilibrium. It is easily seen that the converse action takes place if the machine drops its nose. It is evident then that the tail is a source of inherent stability. In the case of variable speed machines there is an upward or downward air reaction on the tail plane in normal flight. The reaction will be upward in fast and downward in slow flight. It will be noted, however, that this fact does not affect the aforegoing argument. Any movement of the tail alters the air reaction in such a manner as to restore equilibrium. Some form of fore and aft control must be given to the pilot. This is done by adding controllable flaps or "elevators," as they are called, at the trailing edge of the tail plane, as indicated at E in Fig. 14.

Let the lateral conditions now be examined. Suppose that for some reason one wing tends to drop. What is to prevent this? In the aeroplane so far developed there is obviously nothing. In order that movements of this nature may be controlled, flaps are provided at the wing tips. It being advisable that these flaps or Ailerons, as they are called, should be small, and yet exert the greatest righting moment possible, they are placed in the position most remote from the longitudinal axis of rotation. They are usually so connected that as one turns upwards the other is turned downwards. This has the effect of increasing the incidence at one wing tip and decreasing it at the other, thus making it possible to introduce the desired righting moment.

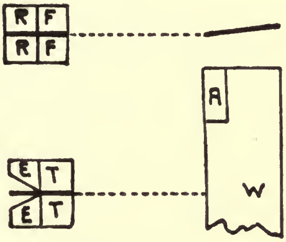


FIG. 14.

A degree of inherent lateral stability may also be provided by arranging the planes with a Dihedral Angle. Fig. 15 illustrates the end view of an aeroplane with dihedral. The total lift of the plane L may be divided between the two planes. Let the lift effect of the planes be l_s and l_p respectively. As the planes are arranged at an angle, these forces will not be quite vertical. It is evident that, if the aeroplane be turned slightly about its axis of lateral rotation, the vertical component of the lift force on the lower side is increased, whereas that on the raised side is decreased, a righting moment being thus produced. The most important result of dihedral, however, comes into play when "side-slip" occurs. The aeroplane necessarily slips sideways when one wing is lower than the other. It will be seen that in the direction of the side-slip the effect of the dihedral angle is to increase the incidence of the lower wing and to decrease that of the

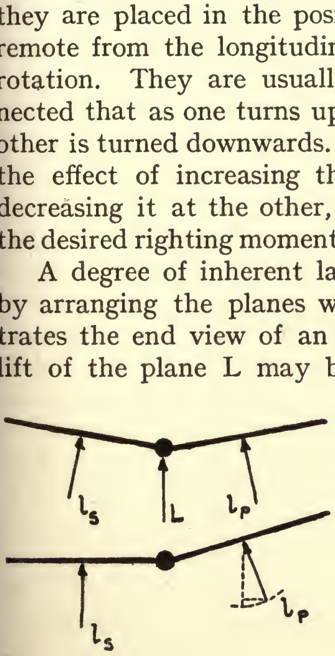


FIG. 15.

higher. The sideways motion thus brings into play a considerable righting moment.

A method of controlling the direction of flight or turning the aeroplane must now be provided. This is done by means of the fin and rudder. In order that the maximum turning movements may be produced, these are fitted on the tail at F and R, as indicated in Fig. 14. The action of the fin in a directional manner is exactly the same as that of the tail plane in the fore and aft.

The action of the rudder in turning the machine is more complicated, and involves the consideration of the effects of the side surfaces of the machine. The side surface, or keel surface, as it is commonly called, includes the side area of the fuselage, struts, wires, wheels, etc., and also the effect of the dihedral angle. Fig. 16 (I) shows the machine when the rudder has just been applied. The fin and rudder may be considered together as constituting a rudely cambered plane. An air reaction P_R is introduced, and the machine commences to adopt a crabwise motion, as indicated in Fig. 16 (II). Owing to this motion, an air reaction P_S, due to the incidence of the side surfaces, is introduced. The machine commences to turn bodily under the action of the forces P_R and P_S. It is noted, however, that there is no equilibrium; if the couple indicated alone were to act, its effect would be simply continuously to accelerate the speed of turning. However, as soon as the turn commences, centrifugal force begins to act upon the machine at its centre of gravity W as indicated by C. Equilibrium can exist between P_R, P_S, and C, the machine continuing in a steady turn.

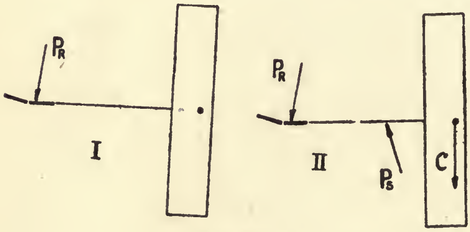
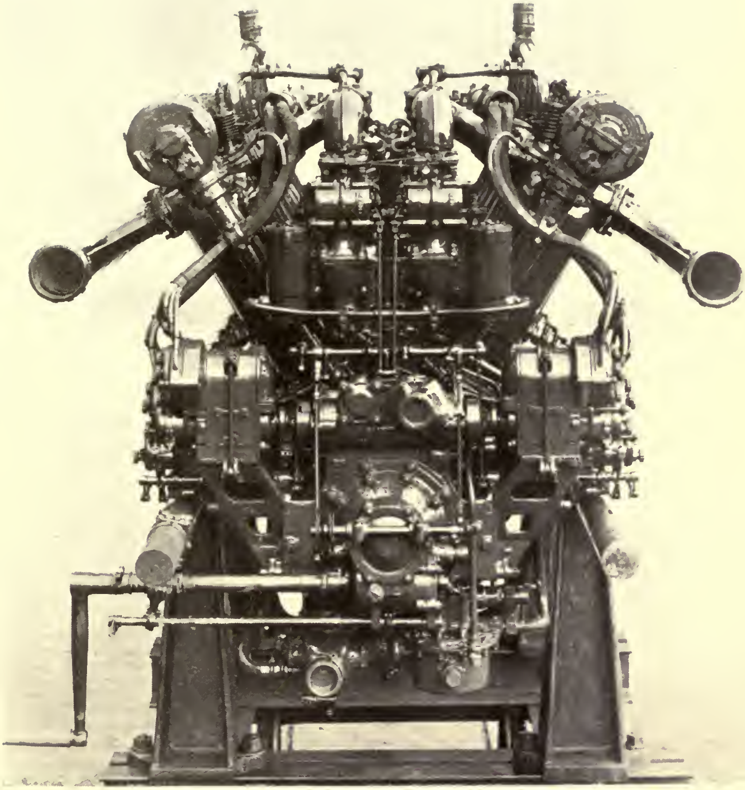


Fig. 16.

Let the state of affairs be further examined. Suppose that the machine is turning fairly rapidly, the centrifugal force C will then be considerable. It is evident that, if the equilibrium of the turn is to be maintained, the force C, and also the force on the rudder and fin, must be balanced by P_S, which must therefore

PLATE II



ROLLS ROYCE ENGINE—EAGLE SERIES VIII—350 HORSE-POWER

also become very great. P_S is, however, induced solely by the crab-wise movement of the machine. The result of turning a machine rapidly in this manner would be then that, in addition to turning it would side-slip outwards to a degree that would be dangerous. This motion also causes a grave loss of efficiency. It is necessary in some other manner to balance the centrifugal force. This is done by "banking." The machine is banked so that its inner wing is lower (see Fig. 17). The lift force L may then be resolved into W acting upwards and C acting inwards. C is then utilised to balance the centrifugal force. As the machine goes into the turn it is banked until the centrifugal force is just balanced.

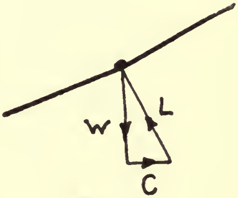


FIG. 17.

It will be noted that the bank necessitated by turning reduces the vertical component of the lift forces in Fig. 17. The result of this is that if the speed and the angle of incidence be unaltered during the turn, the machine will lose height. If height is not to be lost during the turn, then the angle of incidence must be increased so as to increase the value of L. The maintenance of the speed when the angle of incidence is increased calls for an increase in the tractive force.

CHAPTER III

FURTHER THEORY OF FLIGHT

UP to the present horizontal flight only has been considered. In the triangle of forces (ABC in Fig. 18) the propelling force (D) being just sufficient to maintain the weight of the machine in flight. Suppose now that the power of the machine be altered, the elevators of the machine not being adjusted, what happens? As the point at which D and W act is unchanged, P must continue to act at the same point. The machine does not therefore alter its incidence. The only way in which the machine can move to adjust the equilibrium is by altering its flight path. Suppose the power be increased to AC_1 the new triangle of forces is shown in Fig. 18.

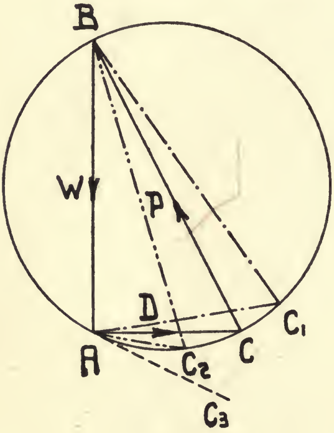


Fig. 18.

It may be drawn as follows: W, being the weight, remains unchanged either in direction or magnitude, and is represented by AB. As the angle of incidence is unchanged, the angle between the propelling force (which is assumed parallel to the axis of the machine) and the line of action of the resultant air pressure must remain unaltered—i.e. the angle ACB must remain the same. If a circle be drawn through A, B, and C, then (the angles in a segment being equal) the new position of C must be on this circle. If the power is increased, the new triangle of forces is therefore ABC_1. It will be noted that, the line of action of the propelling force being coincident with the axis of the machine, the machine climbs at an angle CAC_1. Furthermore the new value of P is slightly less, therefore the speed of the machine is evidently slightly reduced. If the propelling force be reduced to AC_2 the machine dives at an angle CAC_2, its speed being slightly increased.

The extreme cases are of interest. If the propelling force is equal to the weight, C becomes coincident with B, the force P disappears, and the machine hangs motionless on its propeller. Of more practical importance is the case when the engine is stopped and D becomes zero. The downward angle of flight becomes CAC_3, which is the tangent to the circle at the point A. The force P becomes equal to W, the speed thus being slightly reduced. Geometrically the angle CAC_3 is equal to the angle ABC. The angle which a machine adopts when the engine is stopped is termed its gliding angle. The rate of glide of a machine, i.e. the amount it falls in a certain distance, is therefore the ratio $\frac{AB}{AC}$ or the ratio $\frac{\text{Drag}}{\text{Lift}}$. The angle of glide of a machine is then a measure of its efficiency. A machine which has a steep gliding angle requires more power for a certain load than would another machine having a finer angle.

The importance of correct streamlining is readily demonstrated by reference to the triangle of forces. A well-designed aeroplane has a gliding angle of about 1 in 6. The triangle ABC is therefore normally shaped, as shown in Fig. 19, BC being about one-sixth AB.

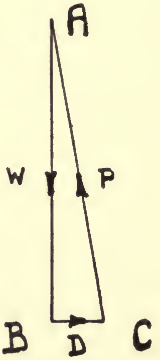


Fig. 19.

Consider the power increase necessitated by the addition of, say, a strut to the machine. The strut section most economical of material is the round one ; its head resistance is, however, high. A streamline section strut of the same strength is about twice the weight, but offers approximately only one-tenth the head resistance. The power required to propel the strut has (1) to carry its weight, and (2) to overcome its head resistance. From the triangle of forces (Fig. 19) it is evident that an addition of, say, 6 per cent head resistance calls for an increase of power of 6 per cent, whereas an addition of 6 per cent weight will only call for an increase of power of 1 per cent. Let the two equally strong struts be compared. In the case of the round one, if its diameter is 1 inch and its weight 5 lbs., its head resistance at 60 m.p.h. will be about 20 lbs. The increase in engine pull required will then be $\frac{5}{6}+20=$ about 21 lbs. In the case of the streamline strut the weight would be 10 lbs., but the head resistance only 2 lbs. The increase in engine pull would be $\frac{10}{6}+2=$about 3 lbs. The necessity for correct streamlining of all parts, even at the expense of considerable additional weight, is thus abundantly evident.

The general problem of stability may now be discussed. It is one which, although commonly treated in terms of somewhat abstruse mathematics, is quite easily understood in a general manner without reference to them.

An aeroplane changes its position relative to its flight path only when the point of application of the resultant air pressure on it moves relative to the centre of gravity. In the case of controlled movement, say, a dive, the elevators are operated inducing an upward air reaction on the tail; the resultant of the air forces on the machine is thus moved aft of the centre of gravity and the dive results. The problem of control is a simple one, and it is not proposed to discuss it here. When the stability of a machine is referred to, inherent stability is implied. If a machine is inherently stable it will of itself return to a normal position of flight from any position in which it may temporarily find itself. This inherent stability is entirely dependent upon the disposition of its various surfaces. This disposition must be such that when the position of the machine becomes abnormal, air reactions are induced which tend to turn the machine to a normal position. The machine may assume abnormal positions as a result of gusts or currents of air, or because it is controlled into those positions by the pilot. A machine in automatically regaining a normal attitude on its flight path usually loses height. It is desirable for reasons of safety that this loss of height should be a minimum. There is, however, still another point to be considered. If a machine has great inherent stability it may become excessively heavy on control as it strongly resists being forced from its normal attitude.

The problem is usually examined in three sections: first, as regards fore and aft movements, i.e. the stability about an axis OY (Fig. 20); secondly, the lateral stability about an axis OX; thirdly, the directional stability about an axis OZ.

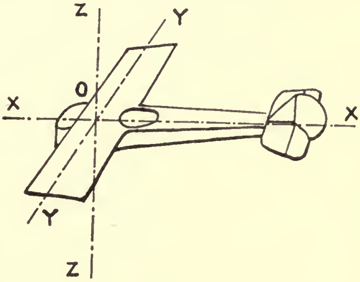


FIG. 20.

The most important factor in providing for fore and aft stability is the tail plane, the action of which has already been discussed (p. 14). Other points having an important bearing are, however, the vertical position of the centre of pressure of the machine and the position of the line of action of the propelling force.

Referring to Fig. 21, the forces acting on the machine are the air reaction P, the engine pull F, and the weight W. As the machine is in equilibrium under the combined action of these, they must pass through a point shown by O. The centre of pressure CP must be on the line of action of P, and the centre of gravity CG on the line of action of W. If the machine is subject to a fore and aft gust, as the gust rises P will increase, and as it falls P will decrease. Suppose, as shown in Fig. 21, that the moment of P is clockwise about the centre of gravity, then the tendency of the machine will be to climb in an increasing gust and to dive in a decreasing one. This is a desirable condition, as the machine tends to gain height with an increase of air speed, and, when the air speed decreases, to dive and so maintain its speed relative to the air. Another factor to be considered is the position of the

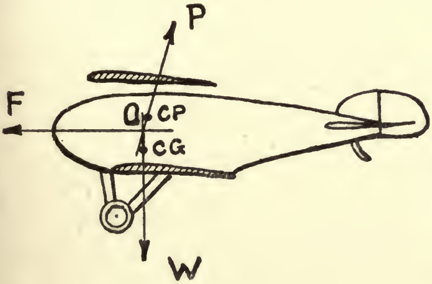


FIG. 21.

line of action of the propeller pull. If this be above the centre of gravity, then as the throttle is opened the nose of the machine will be dragged downwards and the speed increased ; conversely any decrease in the pull will be accompanied by a decrease in speed. This effect is desirable within limits, but should not be excessive. With varying speed the angle of P varies considerably. In order, then, that the effect on stability shall not be excessive it is desirable that the centre of pressure be near the centre of gravity.

Both lateral and directional stability depend upon the dihedral angle of the planes and the position of the centre of pressure of the side surfaces. For the purpose of qualitative explanation as opposed to quantitative analysis, it is most simple to discuss them together. As the space available is limited, the explanation will be simplified if, to commence with, the conditions of surface distribution, etc., conducive to stability be assumed, the effects of the assumptions in the course of lateral and directional movement being examined. The assumptions made are : (1) that the planes are set at a slight dihedral angle (usually about 3°), and (2) that the centre of pressure of the side surfaces is a short distance aft and above the centre of gravity.

Suppose that, owing to a gust, the machine rolls to the left, i.e. drops its left wing. As a result it will commence to sideslip to the left. The air reactions introduced will have effects as follows :

(1) As the centre of pressure of the side surface is aft of the centre of gravity the machine will commence to turn to the left.

(2) Owing to the dihedral angle the lateral movement of the machine will introduce an increased lift on one side, and the machine will as a result tend to roll to the right.

(3) The effect of turning to the left will be to make the right wing travel faster than the left. This will introduce an increased lift on the right, and the result will be that the machine tends to roll to the left.

(4) The same cause as in (3) causes an increased drag on the right wing. This force tends to turn the machine to the right.

(5) As the centre of pressure of the side surface is above

the centre of gravity the air reaction on the side of the machine will tend to make it roll to the right.

It will be noted that, so far as rolling motion is concerned, (3) opposes (2) + (5), which tends to restore the machine to a normal position of flight. Lateral instability might result therefore if (3) were excessive. The effect of (3) could only become large if the turning effect of (1) were very great, i.e. the centre of pressure of the side surface very far aft. For this reason an excessively large fin may cause instability.

The reader must carefully bear in mind the assumptions made. Any alteration of these would entirely alter the effects described. For example, suppose that say, owing to the excessive area of the wheels, etc., the centre of side pressure is below the centre of gravity. The force (5) would become reversed. In these circumstances (2) would have to be greater than (3) + (5) to ensure stability.

Let it now be assumed that the machine turns directionally or "yaws" to the left. The air reactions brought into play will be as follows:

(1) Owing to the fore and aft position of the centre of pressure of the side surfaces a force tending to turn the machine to the right will be introduced.

(2) The motion of the machine when yawing is not entirely in the direction of its axis. It has a certain velocity, depending on the amount of the yaw, to the right. Owing to this lateral movement the dihedral introduces an air reaction tending to roll the machine to the left.

(3) The machine will tend to roll to the right (see (3) in the previous case).

(4) The machine will tend to turn to the left (see (4) in the previous case).

(5) Owing to the vertical position of the centre of side pressure the air reaction on the side surfaces will have the effect of causing a roll to the left.

Considering directional conditions it is seen that (4) opposes (1), which tends to restore equilibrium. (4) is usually small compared with (1). Laterally it is desirable that the machine should bank in the direction of the yaw. It is seen that (2) + (5) favour this, whereas (3) opposes it. It will be noted that the consideration of the problem commencing from the assumption of an initial yaw is practically a reiteration of the previous discussion. It serves, however, further to illustrate and emphasise the principles involved.

The aforegoing discussion pretends to no completeness. It should, however, indicate to the reader the various factors affecting lateral and directional stability and their relative importance. The reader is advised to study the subject himself further, assuming other arrangements of the controlling factors, and anticipating the nature of the resulting instability.

As concerning stability in any direction the disposition of the weight of an aeroplane is of great importance. If a machine is to be quick on control and is to answer quickly to its automatically induced stabilising forces, all the weights must be concentrated as near to the centre of gravity as possible. This is simply a question of inertia. It is analogous to the case of spinning a metal ball weighing two pounds or a stick having a one pound weight at each end.

The aforegoing discussion should enable the reader to anticipate for himself what would happen to an inherently stable machine placed in any position and left to itself to recover a normal flying attitude. To take particular examples and work them out is in this connection both interesting and instructive.

CHAPTER IV

THE AEROPLANE

THE most essential portions of an aeroplane are necessarily the planes. The other portions merely control and assist the main planes in their function.

Up to the present it has been assumed that flat planes were being dealt with, the general principles of flight having been studied, without the question of efficiency being more than generally considered.

Let the forces on a plane, flat or cambered, be considered quantitatively. If they be considered in their components, then

$$L = K_l A \rho V^2$$
$$D = K_d A \rho V^2$$

The magnitude of K_l and K_d will vary with the value of the angle of incidence θ and the section of the aerofoil. Suppose, then, it is necessary to compare a number of wing sections. K_l gives a measure of their lift, K_d a measure of the necessary power for a given speed. The ratio $\frac{K_l}{K_d}$, as already stated, is a measure of their efficiency.

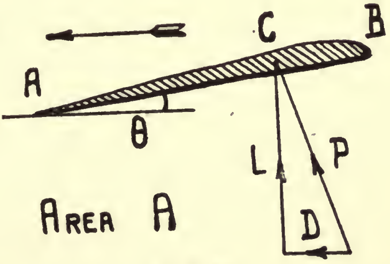


FIG. 22.

Another factor concerning which information is required is the position of the centre of pressure. The centre of gravity must be situated in the same vertical line as this point if the tail is not to support any load. Likewise it is necessary to know the movements to which the centre of pressure is subject as the angle of incidence is varied. The smaller these movements are, the less will be the size of the tail required to control them.

The information which we possess on these matters is practically all the result of experiments with models. Scale models are made of the section to be tested. These are supported in a wind tunnel, in such a manner that the forces on them can be accurately measured. The angle of incidence is varied, and the velocity of the air in the tunnel may also be varied. In this way the "characteristics," as they are called, of the section are very accurately determined.

Before this accurate method of experiment was devised, it had been discovered that curved wing sections had many advantages as compared with the flat. The present methods of experiment have confirmed this. It has already been explained that the flow on the upper surface is of a different nature to that on the lower. It is reasonable, then, to assume that improvement can be effected by shaping the two surfaces differently. As curved sections are now universally adopted, the characteristics of these only will be discussed. Fig. 23 shows a typical modern plane section. This section is of a general streamline nature, which, of course, is necessary in order to keep the value of K_d low. A curious point in connection with such a section is the effect of the steep angle at A. The natural assumption would be that a considerable positive pressure would occur at this point, which would have the effect of increasing K_d and reducing K_l. The actual condition of affairs is entirely different. Experiments demonstrating the nature of the flow show that the effect of this down-turned front edge is that the air is deflected upwards as it approaches the leading

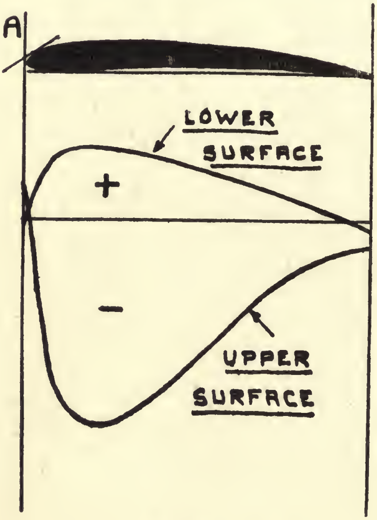


FIG. 23.

edge. This results in a high positive pressure below and a negative pressure above the leading portions of the plane. The actual resulting pressure distribution on the surface of a plane is as indicated in Fig. 23. This diagram indicates the general magnitude of the pressures to which the plane is subject, and also the comparative importance of the upper surface. In the case of a well-designed section, the top surface usually supplies three-quarters of the total lift. Fig. 24 shows the "characteristics" for a section of this nature as determined by experimenting with a model. The angles of incidence are measured on the chord.

The wing is the aeroplane. Upon its characteristics the performances of the machine at different speeds depend almost entirely. As indicating the nature of the air flow, two points should be noted. Firstly, the K_l curve shows that there is a considerable lift when the angle of incidence of the chord is zero. This fact is due to the effect of the shape of the leading edge. Secondly, at an angle of about 14°, the value of the lift begins to decline, and that of the drag to increase, rather suddenly. This indicates a change in the general nature of the flow. The curves of the section being designed to induce the desired type of flow at normal angles of incidence, it is natural to expect that, as the angle is increased abnormally, this condition of flow cannot continue. Now let the effects of these characteristics on an actual aeroplane be considered. Suppose a machine is to be built with planes of this type. With a certain load, the speed in horizontal flight will vary as the angle of incidence is increased or decreased. The base line may therefore, to a certain extent, be regarded as a scale of aeroplane speed.

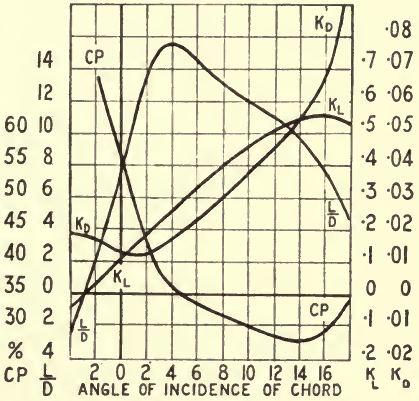


FIG. 24.

Particulars :—
Aspect ratio 6, chord 3″, V 40′ per sec.

Consider first the movements of the centre of pressure. It will be seen that it does not move very much when the angle of incidence is above about 4°. At lesser angles it may move very rapidly. This means that if the aeroplane flies with a very small angle of incidence, the fore and aft control will be sensitive. It appears, then, that the machine should not normally fly with a very small angle of incidence. The result of this is that, if high power and speed are desired, the size of the planes must be small.

Let the K_l curve be examined. The value of K_l increases steadily up to a maximum at about 15°, where it commences to decrease fairly rapidly. This means that the load which the planes will support at a given speed increases up to 15° and then decreases. Conversely, the speed at which a certain load can be carried decreases as the angle is increased. Therefore, at 15° the machine is flying at the lowest possible speed at which it will support its load. This speed should be as low as possible, as it is the minimum landing speed of the machine.

The force or power required to propel the machine may be studied from the K_d curve. In the case of an actual machine, the tractive force of the propeller is absorbed in overcoming the drag forces on the planes, to which must be added the total head resistance of the remaining parts of the machine. It will be noted that K_d does not alter very much up to 4°. At that point it begins to increase steadily up to about 15°, where the increase becomes much more marked.

As has previously been pointed out, the lift drag ratio is a measure of the efficiency of the plane as a weight carrier. It will be noted that this rises to a very pronounced maximum in the neighbourhood of 4°. The aeroplane must then be so designed that its normal speeds shall be at an angle of incidence near to this value. It must be remembered that when the efficiency of the complete aeroplane is considered, the drift resistance of the body, etc., must be added to that of the planes.

The practical importance of the aforegoing may perhaps be most effectively demonstrated by applying it to the solution of an actual problem. Suppose that a biplane is to be made, using the wing section for which the characteristics are shown in Fig. 24. Assume that the cross sectional area of the machine (less the planes) in the direction of flight is 30 square feet, and that the average value of K for these portions is 0·1. Assume the total weight to be 3000 lbs., also the maximum efficiency to be desired at a speed of 60 m.p.h. (88 feet per sec.). When considering the most efficient speed of an aeroplane, body resistance must naturally be considered in addition to that of the wings. However, as the following is to be regarded as an illustration rather than a design, it will be assumed that the efficiency is maximum when $\frac{K_l}{K_d}$ for the planes is greatest. This is at an incidence of 4°.

$$P = K_l A \rho V^2, \text{ or } A = \frac{W}{K_l \rho V^2} = 326 \text{ square feet.}$$

$W = 3000$, K_l (from curve) $\cdot 50$, $\rho = \cdot 00237$ (standard).
$V = 88$.

In the case of a biplane, interference between the planes is found to reduce their efficiency. The efficiency is about ·85, that of a single plane. The plane area must therefore be 384 square feet.

Let the power required now be calculated.

$$\left.\begin{array}{l}\text{Force to propel body, struts, etc.} = K_b A_b \rho V^2 = 55{\cdot}5 \\ \text{Force to overcome drift of planes} = K_d A \rho V^2 = 112{\cdot}5\end{array}\right\} 167$$

At 88 feet per sec., this will require 26·7 h.p.

Let the landing speed now be calculated. The maximum value of K_l is 1·1.

Thus :

$$W = K_l A \rho V^2, \text{ or } V = \sqrt{\frac{W}{K_l \rho A}} = 55 \text{ feet per sec.}$$
$$= 37{\cdot}4 \text{ m.p.h.}$$

Suppose that the power necessary to fly at 80 m.p.h. is required.

$$P = K A \rho V^2 = K_l = \frac{W}{A \rho V^2} = \cdot 24$$

The angle of incidence is therefore about 0·4° and $K_d = \cdot 013$.

Total head resistance $= (K_b A_b + K_d A)\rho V^2 = 262$.

The horse-power required is therefore 56.

The actual design of an aeroplane is very much a matter of trial and error. First a guess is made as to the ultimate weights, head resistance, etc. This guess, being based on figures relating to other machines, is usually fairly correct. From it the general dimensions are worked out. It is then possible roughly to design the machine. More accurate figures can then replace the original guess, and the necessary alterations are made. Practical limitations, such as the safe normal loading per square foot of wing surface (usually between 5 and 10 lbs.), have to take precedence over considerations of purely aerodynamic efficiency. The aforegoing discussions do not pretend to equip the reader with knowledge sufficient to design. It is hoped, however, that they will make clear to him the principles on which design is based, and enable him to appreciate the influence of characteristics, the conditions conducive to efficiency, and the limitations of an aerofoil section in satisfying them.

It is now possible to investigate the performance of an aeroplane. The conditions first to be assumed are those of horizontal flight near to the ground. The horizontal forces acting on the machine are the drag components of the air reaction on the planes and the head resistance of other parts of the machine. These are overcome by the tractive force of the propeller. Let Fig. 25 now be examined. The curve W shows the resistance offered by the wings ($K_dA\rho V^2$). The resistance of the other parts may be divided into two: the resistance of those parts in the slip stream which is fairly high, even at low speeds, and does not increase greatly with the speed of the machine (shown by I), and the resistance of the other parts which increases as the square of the speed (shown by II). The sum of these two represented by R is then the total resistance of parts other than the wings. The sum of R and W gives the total resistance of the machine at any speed (shown by RW).

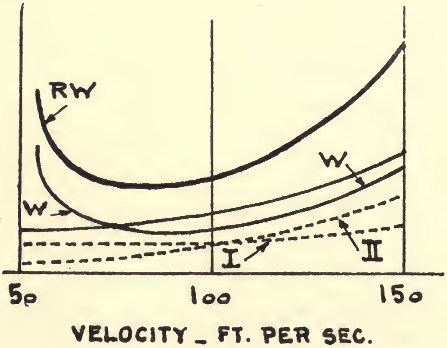


Fig. 25.

Let the power unit, consisting of the engine and propeller, now be considered. It is necessary to consider them also relative to the speed of the machine. Owing to the varying slip (see Chapter XI) the efficiency of the propeller varies considerably. The variation is much as shown by A in Figure 26. Now let a curve be drawn showing the tractive effort of the engine. If the propeller were of 100 per cent. efficiency at any point PM × OM would be proportional to H-P—i.e. constant. The curve E is drawn in this manner. If the ordinates of this curve be reduced in proportion to the efficiency of the propeller, the curve TE of tractive effort is obtained.

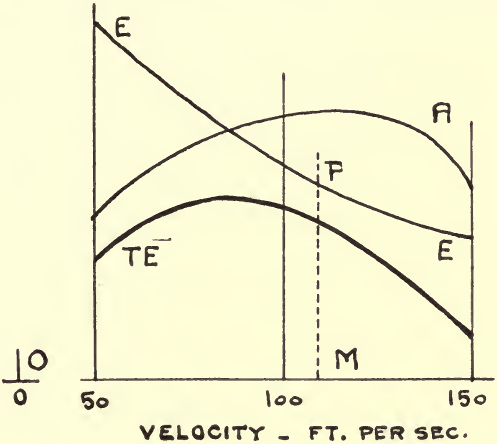


FIG. 26.

Let the curves TE and RW now be drawn to the same scale on the same diagram, as has been done in Fig. 27. It will be noted that at A the curves cross, i.e. after this point the maximum tractive effort which the propeller can exert becomes less than the head resistance. This, then, represents the maximum speed to which the machine can attain in horizontal flight. Consider now any other vertical, say, CDE. At this point (75 miles per hour) the head resistance of the machine is represented by CD, and the maximum tractive effort which the power unit can exert is CE. That is to say, for horizontal flight only a part of the available power is required. The surplus power is available to climb with. If the weight of the machine is W and the velocity of climb V, then if the maximum power be exerted the speed

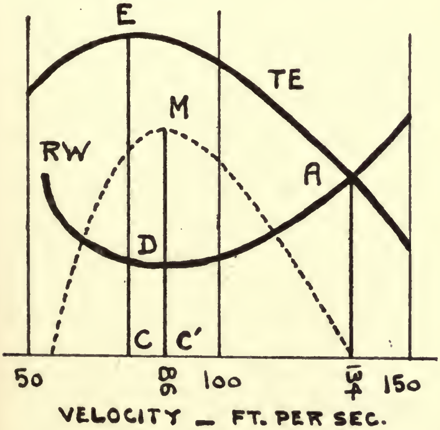
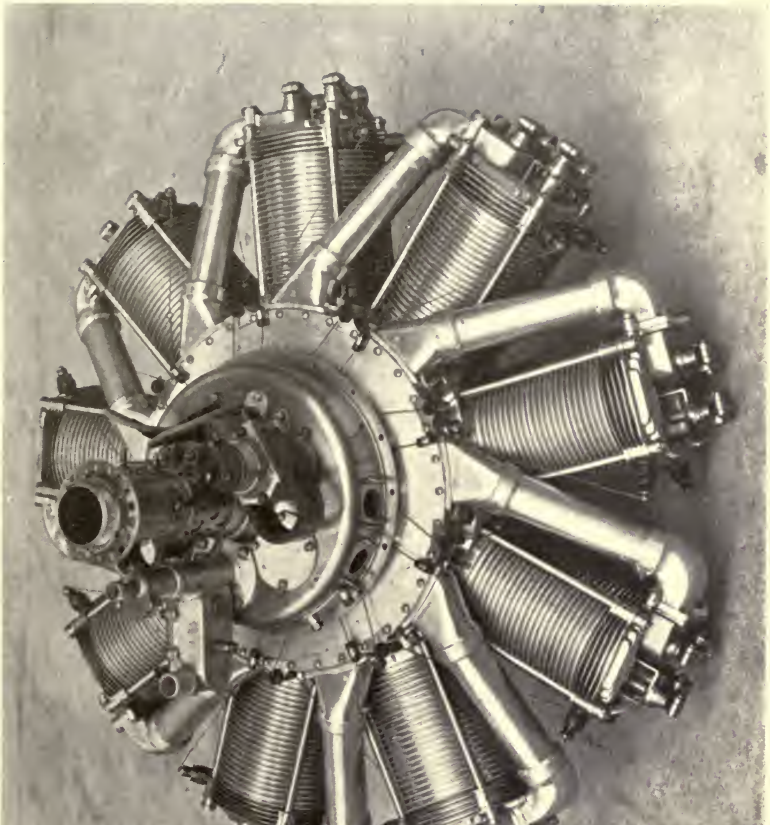


FIG. 27.

of climb at a speed OC will be $\frac{OC \times DE}{W}$. Taking a series of ordinates such as CDE, a curve (shown dotted in Fig. 27) may be drawn showing the rate of climb at any speed. This curve rises to a maximum point at M. This, then, gives the greatest rate of climb to which the machine can attain. OC represents the speed at which the machine achieves this. As the machine climbs conditions are of course altered by the changing density of the atmosphere. This is dealt with in a subsequent chapter.

The effect of varying the different controlling factors is an investigation not without interest. It is, however, left to the reader to follow this line of study for himself.



BENTLEY ROTARY ENGINE—200 HORSE-POWER

CHAPTER V

MATERIALS OF CONSTRUCTION

BEFORE considering the various materials used in the construction of aircraft the mechanical properties of solid matters generally may be examined. These may be most simply studied by considering the phases through which a material passes when continuously loaded, say, in tension, until rupture takes place. Mild steel may be taken as an example.

If a steel bar is subject to an increasing load it at first stretches almost imperceptibly; if during this period the load be removed, it returns to exactly its original length. Thus it acts practically as an exceedingly stiff spring. During this phase it obeys Hook's Law, which states that stress is proportional to strain. This law is usually written $f=Ed$ where f is the stress in pounds per square inch, d the strain expressed as a fraction of the original length, and E is the ratio termed the "Modulus of Elasticity." Suppose that the load be continuously increased. A point is necessarily reached when the law breaks down. This is called the Yield Point. Up to the yield point the material is elastic, and on removal of the load reverts to its original size. Loads occasioning stresses beyond the yield point, however, cause the materials to take a permanent set. A stress termed the Ultimate Stress, considerably greater than the yield stress, has to be applied before the material ruptures. Elongation between yield point and fracture may be very considerable, depending upon the nature of the material. Failure finally occurs owing to local contraction at the weakest section.

A material which stretches considerably between the elastic limit and the point of ultimate failure is said to be ductile. This property is of great importance. Although the stresses in material under normal working conditions are well below the elastic limit, when excessive stresses occur which are liable to cause failure, the effect of ductility is felt. A ductile material has to give considerably before failure, and in so doing may avert failure by throwing part of its load on to other members of the structure. Where sudden loads are anticipated ductility is essential. Cast metals have as a rule little ductility. They fail immediately after the yield point is reached. A cast-iron pot having practically no ductility, if hit with a hammer, is broken. A mild steel one, being ductile, is permanently dinged. An india-rubber one, which is capable of very considerable deformation before reaching its elastic limit, is dented and springs back to its original shape.

The effect of stressing materials beyond their elastic limit is of interest. It is usually to harden them, i.e. to raise the yield stress and to reduce their ductility. This effect is made use of in the manufacture of wire and sheet. These are rolled down from billets, the material being annealed from time to time to soften it. If the finished sheet is not finally annealed it will be much harder than the original material. Fine steel wires may have an ultimate strength of well over 100 tons per square inch. Aluminium sheet likewise may have a strength of 15 tons per square inch, though the same material annealed would only stand 6 or 7 tons per square inch. A copper pipe that is bent or hammered is affected in exactly the same way. The ductility of materials can usually be restored by means of suitable heat treatment—steels by annealing, copper by quenching. The effect of heat on the mechanical properties of metals is exceedingly important, particularly in the case of alloy steels. As working and heat have so great an effect on the properties of materials, care must always be exercised in subjecting parts to either. If a special steel axle tube, for example, be brazed, its mechanical strength at the point heated may be reduced by half.

When materials are subjected to constantly alternating stresses they become "fatigued." Engine parts are particularly liable to fatigue. A constantly vibrating wire is another example. Alternating stresses much below the yield stress of the material cause a gradual crystallisation or coarsening of the structure of the material, which reduces its strength considerably and robs it entirely of its ductility. Provided that a sufficiently low stress is used, however, it appears that an indefinite number of alternations of stress are possible without ill-effect.

The mechanical properties of materials are very intimately connected with their internal structure. Their uniform behaviour depends to a great extent on the homogeneity of the latter. The theory of elasticity is based on the assumption of homogeneity of structure. Exact results are not to be expected when it is applied to such materials as wood and fabric. These have different properties in different directions. By suitable reservations with regard to their use it is, however, possible to apply the same theories and formulæ to them as are used in the case of metals.

In the following remarks on the materials used, little reference is made to actual figures relating to strengths, etc. These will be found tabulated in the Appendix.

Steels of all grades find a place in the manufacture of aircraft. For purposes of discussion they may be divided into two classes: carbon steels and alloy steels. Carbon steels consist of almost pure iron alloyed with a small percentage of carbon. What is known as mild steel has about ·15 per cent of carbon, so-called carbon steels having more. The effect of carbon is to harden steel and to render it very susceptible to heat treatment. The higher carbon steels which have little application in aircraft construction, if heated to a dull red and quenched, become sufficiently hard to cut glass. Mild steel is little affected by heat treatment. For this reason it is used for parts where welding is required. The process of welding consists of cementing together parts by means of pure iron melted in the oxy-acetylene flame of a blow-lamp. As the welding material is pure iron, there is, as a rule, little object in welding special high-tensile steels with it. Furthermore the heating would adversely affect their mechanical properties. Mild steel is an exceedingly homogeneous and reliable material, and is extremely ductile, giving an extension of up to 40 per cent before rupture. Where greater strength is required, somewhat higher carbon steels are employed containing up to about ·4 per cent carbon. These are used for wires, tubes, etc., where special strength is desirable. Their ultimate strength may be raised considerably by either tempering or cold working. Streamline wires, for example, are rolled down from rods. Tubes may be hardened by cold rolling, or by heat treatment. Steels so treated will withstand a load of 50 or 60 tons per square inch, but are not nearly so ductile as mild steel. Similar steel rolled down to wire for piano wire or stranded cables has an ultimate strength of from 80 to 120 tons per square inch, the finest wires being the strongest.

The alloy steels commonly used consist of iron alloyed with carbon and one or more other metals, the most common of which are nickel and chromium. They rely to a great extent upon special heat treatment for their mechanical properties. They are not necessarily much stronger than high carbon steels, but are capable of combining ductility with strength, and are thus more satisfactory for withstanding shocks and alternating loads. They are at present chiefly used for the construction of engine parts. Many engine parts have to combine toughness with a hard-wearing surface. The heat treatment necessary to harden carbon steels involves a sudden cooling. This is very apt to distort the part, and also to set up serious internal cooling strains. Some alloy steels are what is termed " self-hardening," that is to say, that in the normal process of slow cooling they harden themselves, and they are therefore not so liable to internal cooling strains. Alloy steels may combine an ultimate strength of 100 tons per square inch with an elongation of 20 per cent. Various special alloy steels are used for valves and other parts which work under more specialised conditions. Space does not, however, admit of any detailed consideration of them.

Mild steel, when broken, should show a very fine fibrous fracture with a considerable reduction of area at the point of rupture. Any crystalline appearance points to fatigue. Carbon steels all show a very fine grey fracture, but lack the silky appearance apparent in the case of mild steels. The amount of local reduction of area decreases as the steel becomes harder. Hard steel such as ball races will show no reduction, and exhibit a very finely granular fracture. Alloy steels show similar fractures. Any fractures showing a coarsely crystalline grain or any lack of homogeneity indicate defective material.

Of the non-ferrous metals and alloys, aluminium is the most important. Pure aluminium is used chiefly in the form of tubes for conducting cables, etc., and also as sheet for engine cowling, etc. Aluminium, however, finds its greatest application in the alloy form, either cast or forged. Duralumin and magnalium are examples of alloys capable of being rolled into sheet, tube, and wire. Magnalium is an alloy of magnesium and aluminium, which is lighter than aluminium and considerably stronger. Duralumin is a still stronger alloy of a somewhat complicated composition. It is nearly as strong as mild steel, and little heavier than aluminium. The chief disadvantage of these alloys is their susceptibility to heat treatment and cold working. Their strength may be halved by improper handling. They are also very liable to corrosion. A certain amount of conservatism and suspicion at present limits their application. It is probable that they will be much more widely used in the future. Duralumin is very largely used in the construction of the framework of rigid airships. Cast alloys find many uses in engine construction on account of their lightness. Suitable alloys have been produced, from which pistons and cylinders have been cast. One of the chief difficulties experienced with cast aluminium is its shrinkage on cooling, combined with its weakness at that time. The design and casting of complicated parts calls for considerable skill to prevent their cracking during the cooling process. The coefficient of expansion with heat for aluminium is very high, which fact leads to a certain amount of difficulty when it is used in conjunction with other metals in situations subject to high temperatures. Aluminium and its alloys do not readily oxidise. The latter are, however, usually very liable to electrolytic corrosion, and for this reason are not ordinarily suitable for use where contact with sea-water is liable to take place.

The chief non-ferrous metals used, other than aluminium, are copper, gun-metal, phosphor bronze, and babbit. Pure copper is chiefly used for pipe work. It is eminently suitable for this work on account of its ductility, being easy to bend. A further advantage it possesses is that of being easily sweated or brazed to unions and other pipe fittings, whereas aluminium in the same position would require to be welded. Aluminium, however, scores considerably from the point of view of weight. It is probable that in due course aluminium and its alloys will take the place of copper almost entirely.

Gun-metal is an alloy of copper, zinc, and tin; it may also contain a small amount of lead. It may be cast or rolled. It is largely used for small engine fittings, petrol cocks, and pipe fittings. It is a tough metal, easily machined, and not liable to corrosion. Here again the lighter aluminium alloys compete. Their chief drawback in this field, however, is their tendency to bind. An aluminium tapered cock, for example, would have a great tendency to stick if working in an aluminium body. Phosphor bronze is an alloy similar to gun-metal, but containing no zinc and about 8 per cent of phosphorus. It is largely used for the linings of bearings subject to heavy loads. It is cast in bars and machined to the required size. A good phosphor bronze when broken exhibits a very finely granular pinkish-grey fracture.

Babbit is white metal alloy containing antimony and lead. It is used for the lining of larger bearings. If examined microscopically, it appears to consist of a soft matrix bearing crystals of metal of a harder nature, the harder element providing a good wearing surface, whilst the softer matrix allows it to bed down to its work.

The most important non-metallic substances are wood and fabric. The chief woods are spruce, ash, walnut, mahogany, and birch ply-wood. Spruce is obtainable in pieces of considerable size with a good straight grain. It is light in weight and easily procured. Ash is a heavier and harder wood. It is difficult to obtain it in long pieces of even grain. Walnut and mahogany are very tough and strong; they are expensive, and are practically only used for propellers. Birch ply-wood consists of three or more laminæ or veneers of wood glued together in such a manner that the grain in the different plies runs at right angles. The finished board is very strong in all directions owing to the crossing of the grain. Three ply is used as a covering material, and combines lightness with toughness. Engine bearer frames and similar parts are commonly made from wood consisting of seven or more laminæ.

Wood consists of a fibrous structure impregnated with oily and resinous matter. It is liable to blemishes such as knots, cracks, twisted grain, or flaws such as resin pockets. Pieces must be chosen carefully with a view to avoiding any of these.

The chief trouble to which wood is liable is warping. This depends very much on the processes of conversion and seasoning.

Conversion consists of sawing the log into planks of suitable size. As a log dries it contracts circumferentially, thus tending to develop cracks, as indicated in Fig. 28 (I). A piece of timber with the graining as indicated in Fig. 29 (I) would shrink to the shape shown. The planks therefore should be so sawn as to have their grain running as nearly as possible as shown in Fig. 29 (II). This involves radial conversion of the log, as shown in Fig. 28 (II). The converted timber must be thoroughly seasoned or dried by exposure to the air before being made up. Natural seasoning is always best, but this is sometimes accelerated by resorting to kiln seasoning by artificial heat. The danger of this latter process is that, if the heat is too high, a portion of the lighter hydrocarbons which constitute the filling of the fibrous structure may be driven off and the timber rendered brittle. If a piece of wood is broken by bending, a "short" fracture will indicate brittleness. In a good fracture the grain should break short on the compression side of the bend, but on the tension side long splinters should be left. So long as the grain of a finished strut or spar is straight and even, the part is usually satisfactory. Twisted grain must be carefully avoided. It is often difficult to identify in the finished part. It is usually apparent, however, in the course of manufacture. The end grain in finished parts should run as nearly as possible as indicated in Fig. 29 (III). Wood has comparatively little strength across the grain; consequently, where loads other than tensile or compressive are to be supported, ply-wood is used. The laminæ are made of birch, and vary in thickness from $\frac{1}{40}$ to $\frac{1}{10}$ of an inch. They are usually cut by rotating the log between centres against

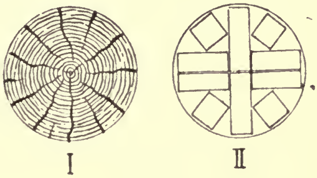


FIG. 28.

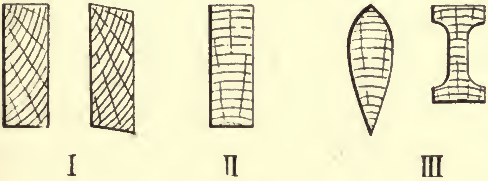


FIG. 29.

a wide knife-edge, the wood thus being cut spirally in the form of a thin sheet. In all woodwork involving gluing, the question of moisture is an important one. Parts to be glued together, as, for example, the laminæ of built-up spars, must be of similar moisture content, otherwise warping of the finished part or structure will result.

The fabric used to cover the planes and other parts is woven of linen. Cotton fabric may, however, be used for covering parts such as the fuselage which are not subject to very severe air loads. Linen fabric has a breaking strength of about 90 lbs. per inch width, and is slightly stronger on the warp direction than the weft. The weft is the width direction of the fabric as it comes off the loom. The strength of the fabric is considerably increased by the application of "dope," which commonly consists of a solution of cellulose in acetone. The increase in strength is from 15 to 25 per cent. The effect of the dope is to tighten the fabric and to render it smooth and waterproof. Fabric weighs about 4 oz. per square yard, to which about 2 oz. must be added for the dope.

The only other material of any importance used on aeroplanes is india-rubber. The reason that this finds favour as a shock absorber is that it is capable of absorbing a considerable amount of energy for its weight. It is in this respect much superior to steel springs. The energy absorbed by a shock-absorbing device depends upon the stress to which it is subject and the strain of which it is capable. Rubber as a material does not stand a very high stress, but can be strained to a very great extent without passing its elastic limit, and it is consequently capable of absorbing a considerable shock.

CHAPTER VI

PRINCIPLES OF CONSTRUCTION

THE basic principle of aeroplane construction is that the maximum of strength should be attained with the minimum weight of material. The attainment of this object is limited by such considerations as cost of materials and economy in manufacturing processes. Questions such as the durability and reliability of materials have also to be considered. The principle of strength for weight must, however, occupy the most prominent position.

The first problem of the designer is to determine as accurately as possible the maximum loads which may be encountered by the different portions of the machine. The second is to provide a structural arrangement capable of sustaining these and constructed in the lightest manner possible. It is proposed only to discuss the second of these problems. The first is somewhat too complicated for adequate treatment in the available space. Also its solution frequently demands the application of comparatively advanced mathematics.

To return to the second—consider the conditions under which members of the structure of an aeroplane may be loaded. The stress to which a material is subject is the load per certain area which it supports. It may be tensile, compressive, or shearing. Examples of materials stressed in tension are bracing wires. Struts are stressed compressively. The bodies of the pins attaching the bracing wires to the wiring plates are examples of material subject to shearing stress.

The different ways in which material can support a load should at all times be studied. The ideal is that every particle of material shall be employed as near its safe capacity as possible.

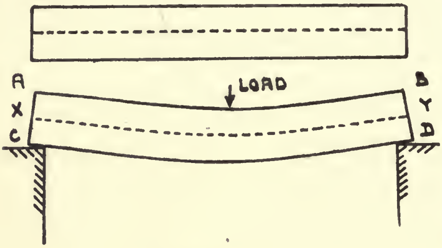


FIG. 30.

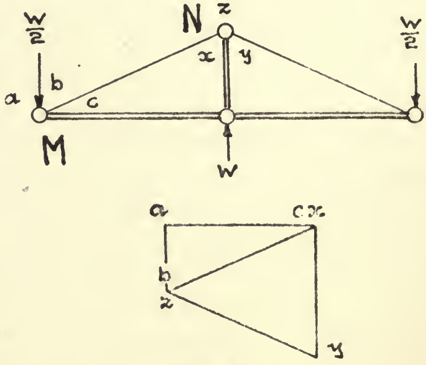


FIG. 31.

The case of a rod or wire in direct tension provides an admirable example of the ideal aimed at. The stress is evenly distributed throughout the whole of the section. Consider now a member subject to bending. Fig. 30 shows a loaded beam, the strain being greatly exaggerated. An element on the line XY has been neither extended nor compressed, whereas an element on CD has been extended the maximum amount. Stress being proportional to the strain, it is obvious that the material on the line XY is not subjected to any stress. The intermediate material is also only subject to stresses smaller than those found in the outer fibres. Furthermore the bending moment being a maximum at the centre of the span, the stresses also increase from the ends having a maximum value at this point. The beam will fail as soon as the stress in the outer fibres at the centre of the span has reached the maximum which the material will resist. Here, then, we have an example of uneconomical employment of material. Bending stresses must therefore be avoided wherever possible. This being the case, how is a load of this nature supported? The braced structure is resorted to. It might be constructed as indicated in Fig. 31. The beam is replaced by three struts in direct compression and two wires in tension. The stresses in a structure of this kind are readily obtained by the use of vector diagrams, one being drawn first for the joint M and then a second for the joint N. The diagrams for the particular case are shown in the figure. It will be noted that in the figure the two triangles have been drawn as one diagram, the vector common to both triangles only being drawn once. This combined figure is what is called a "stress diagram" for the structure. Stress diagrams of this nature may be drawn for any structure, there being a vector in the diagram representing the stress, or more accurately the load, for each member of the structure. As a matter of fact, a strut cannot, unless very short, be subjected to the maximum compressive stress which the material will sustain. In spite of this, the braced structure is considerably stronger for weight than is a solid one where bending loads are to be supported.

Struts being so essential a factor in aeroplane construction, it is desirable to study in some detail the conditions which govern their strength. The theory of the strength of struts is somewhat complicated. The general aspect of the question may, however, be considered and the results of the more scientific theory quoted. It is evident that a very short, stiff strut will fail only when the load has exceeded the ultimate compressive stress of the material. Now consider how a long strut fails. If a long strut is compressed, what happens? It supports the load until such time as it commences to bend at the centre. If the load continues to be applied, it fails at the centre by bending. There is therefore a gradual transition from the very long strut which fails by bending to the very short one which fails by direct compression. Another factor which exerts a great influence is the nature of the end supports. The free-ended strut, e.g. the inter-plane strut, fails, as indicated in Fig. 32 (I). The type of strut where the ends are supported from bending, e.g. the continuous longeron strut, fails, as indicated in Fig. 32 (II), and is much stronger. The strut most economical of material is bellied at the centre to strengthen it against failure at this point. The results of a mathematical treatment of the above ideas yield the following formulæ for the crippling loads of long struts. For a strut with unsupported ends:

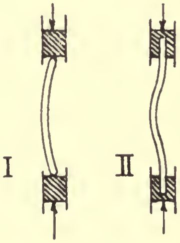


FIG. 32.

$$L = \frac{\pi^2 EI}{l^2}$$

for a strut with ends supported:

$$L = \frac{4\pi^2 EI}{l^2}$$

Where L is the crippling load in lbs.
π is 3·142.
E is the modulus of elasticity of the material (tabulated in the Appendix).
I is the moment of inertia of the section (tabulated in the Appendix).
l is the length in inches.

It will be noted that the effect of supporting the ends against bending is to multiply the strength by four.

The Moment of Inertia of a section is a function of considerable importance. Primarily it is a measure of its strength to resist bending. Its presence in the strut formula is due to the fact that final failure is anticipated by bending. As has already been explained in connection with bending, it is the metal most remote from the neutral axis which is chiefly effective. It can be readily shown that the efficiency of any element varies as the square of its distance from the neutral axis (XY in Fig. 30). "I" for a section is the sum of the areas of the different elements of the section multiplied by the square of their respective distances from the neutral axis. To obtain a large I, then, with a given cross sectional area the material must be distributed as much as possible in the outer layers. An ideal example is the tube. A further excellent example is the strut shown in Fig. 55.

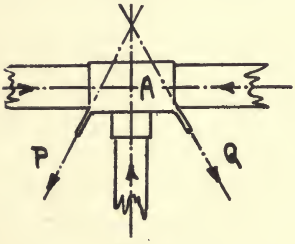


FIG. 33.

A strut commences to fail as soon as it begins to bend. It is evident, then, that struts should be straight and true since any lack of alignment predisposes them to bend. There is in this connection another important point. A strut must never be subject to a load tending to bend it. This fact leads to a consideration of the design of the joints.

In a well-designed joint the lines of action of all the loads should meet at a point. It will be noted that this is the case in the joint in Fig. 2. Now take the example of a joint poorly designed in this respect, as shown in Fig. 33. The main forces at the joint intersect at a point A. The force P on the bracing wire does not, however, pass through this point. It imposes a bending moment on the strut, thereby supplying it with an initial tendency to bend and considerably weakening it. This point is often given too little attention in the design of joints.

Fig. 34 shows a method by which long struts may be considerably strengthened, and it is also illustrative of the application of several of the principles already discussed. It is obvious that a streamline strut will fail by bending on the axis AB and not XY (Fig. 35), the moment of inertia being much greater about XY than AB. The strut will buckle at a point near the centre of its span. The mode of strengthening is indicated in Fig. 34. Were the wires and king-posts, as the small auxiliary struts are called, sufficiently strong, they would have the effect of entirely preventing bending at the centre of the span, and virtually dividing the strut into two struts of half the length, thus increasing the strength four times. As a matter of fact, only comparatively light wires are usually applied as the complete strengthening would be somewhat cumbersome.

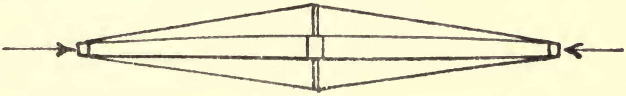


FIG. 34.

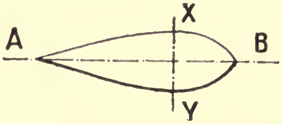


FIG. 35.

The safety of any structure depends entirely upon how nearly the maximum stresses in the various members approach the ultimate stresses which the materials they are made of will stand. The ratio $\frac{\text{Breaking Load}}{\text{Working Load}}$ in a member is called the Factor of Safety. The factor of safety which should be allowed in various parts of an aeroplane is very difficult to fix, as the conditions of loading in special circumstances are extremely hard to anticipate.

The man who is concerned with the flying or the maintenance of machines is not usually in a position to work out the stresses in the various parts. He must take these very much on trust from the designer. It is, however, necessary that he should understand the general principles of design, as from time to time he is called upon to make alterations or to strengthen parts, whereupon he himself becomes, as it were, on a small scale a designer. It is then essential that he should do his work in such a way that it be structurally sound, and also (a point of great importance) that the modifications should not have any adverse effect upon the strength of the other parts of the existing design. Before touching any part of the structure he should first satisfy himself that he thoroughly understands its functions, and he should then make sure that whatever modification he is about to introduce or substitute will adequately answer the same purpose.

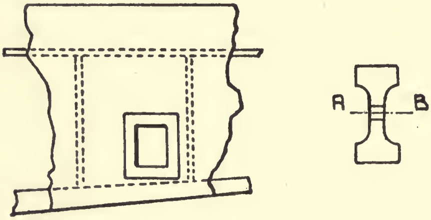


FIG. 36.

Two very simple examples may be taken. Suppose it be found necessary to cut an inspection door in the side of the three-ply fuselage covering. The function of this three ply may be to act as do the bracing wires in the parts where the fuselage is fabric covered. The result of cutting the hole would be to weaken this diagonal bracing. The effect of this alteration might be overcome by fitting an ample doubling strip round the opening, as indicated in Fig. 36. As a further example suppose it necessary to lead, say, a petrol pipe through one of the bottom cross struts of the fuselage of section, as shown in Fig. 36. Consider the formula for the crippling load of struts :

$$L = \frac{\pi^2 EI}{l^2}$$

The only factor affected is I. It is then evident that the hole should be cut as near the neutral axis AB as possible. In this position it will have scarcely any effect on the strength of the member.

The question of torsional loads has not been considered. The chief parts of the machine supporting torsional loads are the bracing of the fuselage, also minor portions such as parts of the control system. Their calculation offers certain difficulties, and their discussion is beyond the scope of this volume.

The principles involved in the design and construction of engine parts has not been dealt with; they are, generally speaking, very complex and may be left to the engine expert. The resulting engine is as much the outcome of practical experience as of theoretical design. In any case the airman is seldom if ever called upon either to make or to modify the engine of to-day.

A very useful exercise is to take the various portions of a machine at random and, considering the loads to which they are subject, decide the nature of the stresses in them. The shape of the part concerned may then be discussed from the point of view of its adequacy to meet them. As an excellent if somewhat complicated example—the conditions obtaining in the plane spars of a biplane may be examined (see Fig. 37). Consider the spars of the lower plane between the struts. They are subject to bending by reason of their transmitting the lift of the fabric to the points where the struts are attached. They are also subject to tension by reason of their position as part of the braced structure transmitting the general lift to the fuselage. Furthermore they may be subject to tension in the case of the front and compression in the case of the rear because they must maintain the plane against the drift forces due to its being propelled through the air.

Examples of this nature may be multiplied to any extent The constant studying of parts from this standpoint will help most airmen to a much more thorough and sympathetic understanding of their machines.

CHAPTER VII

THE MAIN PLANES

THE biplane arrangement has now supplanted the monoplane for practically all classes of machines. The chief advantages resulting from the use of more than one plane are as follows. It is possible to increase the available lifting surface considerably without unduly increasing the span. The biplane arrangement is very much more rigid, the spars, interplane struts, compression ribs, and wire bracings forming a braced structure of considerable strength. This point is illustrated by Fig. 37. Here is shown the skeleton framework of the planes, the covering and its supports having been removed. A further advantage of the biplane is that owing to the reduced span the weights of the planes are concentrated nearer the axis of lateral rotation, thus rendering it considerably quicker on lateral control. Owing to interference the plane surfaces are not quite so efficient in the case of the biplane. Since the top surface of a plane provides the bulk

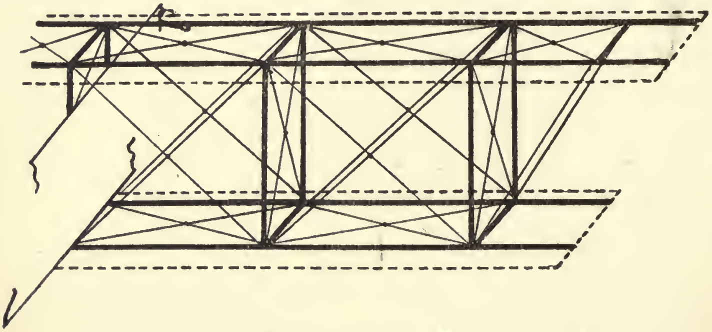


FIG. 37.

AIRCO 18 COMMERCIAL AEROPLANE—NAPIER LION ENGINE

of the lift, it follows that the lower plane will be the one most affected. The efficiency of the lifting surfaces in a biplane is usually about 85 per cent that of a monoplane, the loss occurring almost entirely on the lower plane. This efficiency may be slightly increased by staggering the planes. Fig. 38 illustrates staggered planes, the dimension S denoting the amount of stagger. Stagger is commonly resorted to with a view to increasing the pilot's field of vision, rather than increasing the lifting efficiency. Visibility is generally a point in favour of the biplane. The usual monoplane arrangement is very bad in this respect, although the "parasol" monoplane, where the plane is situated above the level of the pilot's head, allows him a particularly good range of vision. In the case of very large machines designed for weight-carrying, and where the provision of large lifting area is necessary, the triplane arrangement is sometimes adopted.

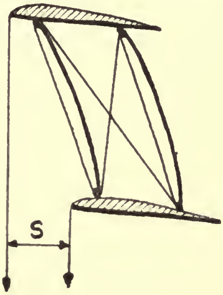


FIG. 38.

The plane bracing in the case of a monoplane is shown in Fig. 39. King-posts or "pylons" A and B are mounted on the fuselage and the planes are braced from them by wires.

The bracing of the planes in the case of a biplane varies to some extent with the size of the machine, the number of struts used being increased according to the span of the planes. A typical arrangement is shown in Fig. 40. The port or left-hand side of the machine, which is the side on the pilot's left when he is seated, is shown. The names by which the various struts and wires are known are as follows:

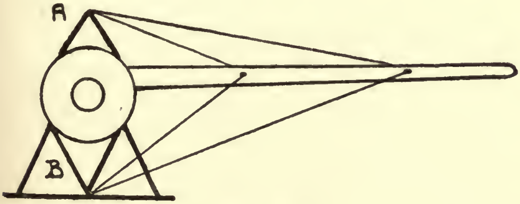


FIG. 39

1 and 2.—Inner and Outer Bay Front (and Rear) Lift Wires.

3.—Extension Front (and Rear) Lift Wires.

4 and 5.—Inner and Outer Bay Front (and Rear) Landing Wires.
6 and 7.—Inner and Outer Bay Front (and Rear) Interplane Struts.
8 and 9.—Front and Rear Spars.
10 and 11.—Incidence or Stagger Wires.

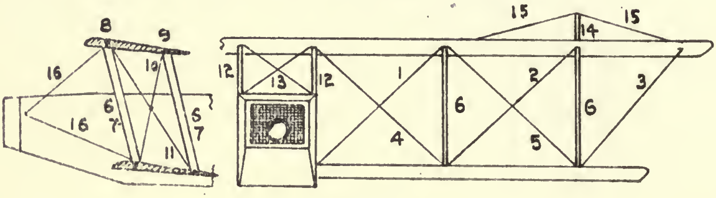


Fig. 40.

12.—Centre Section Struts.
13.—Centre Section Cross Bracing.
14.—Extension King-post.
15.—Extension Landing (or King-post Bracing) Wires.
16.—Main Plane Drift or Drag Wires.

It will be noted that the flying wires transmit the lift to the fuselage when the machine is in the air. The landing wires support the weight of the planes when the machine is on the ground, or the lift if it is flying on its back. The length of the incidence wires controls the incidence. The drift wires support the planes against the drift forces to which they are subject when in flight. The centre section wires ensure the truth of the main plane system relative to the fuselage.

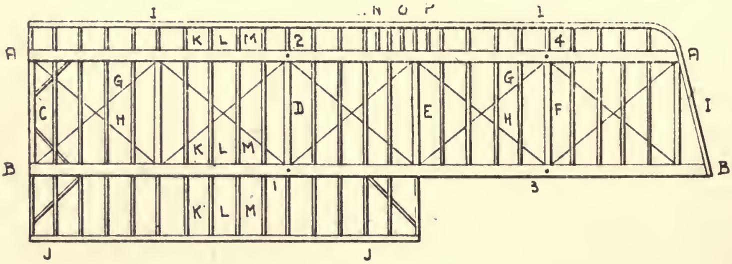


Fig. 41.

Fig. 41 shows a typical biplane wing stripped of its covering so as to demonstrate its internal structure. A and B are the front and rear spars. The interplane struts are attached at the points 1, 2, 3, and 4. Between the spars are situated the compression ribs CDEF. The structure formed by the spars and compression ribs is braced by a series of wires GH. This girder structure supports the plane against the drift forces to which it is subject. The wires H are called drift or drag wires as they support the drag in normal flight. The wires G are anti-drag wires and only become stressed during a tail slide or other abnormal manœuvre. Strips II and JJ form the leading and trailing edges. The camber ribs KLM which run from the leading to the trailing edge, support the fabric covering against the air pressure to which it is subject, and maintain the profile of the wing section.

The spars are usually made of spruce and are of H or box section for the sake of lightness. Fig. 42 shows some sections commonly used. The H section is by far the most common. This may be solid as in (*a*) or built up of glued laminæ as in (*c*). This latter arrangement is resorted to when it is necessary to economise timber. The box section (*b*) also relies on glue, but may in addition be bound with fabric. A good glued joint can be nearly as strong as the timber itself. It has, however, the disadvantage that it may become very much weakened by the effect of moisture. The spar is first made as a solid square section, the lightening then being cut out. At points where bolts pass through the spar for the attachment of interplane fittings, the web is left solid. It is likewise left solid where any splice occurs. Splices are often necessary owing to the difficulty of obtaining suitably grained wood of sufficient length for a complete spar. Fig. 43 shows an ordinary scarfed and pegged splice. The pegs normally detract from rather than add to the strength, but, in event of failure of the glue, serve to hold the splice together. The surface of the splice is arranged vertically, in the spar, and should be tapered at about 1 in 10. The splice is lapped with glued and varnished fabric. In connection with the lapping and covering of wood parts with fabric it may be pointed out that this practice is not always to be recommended. The lapping

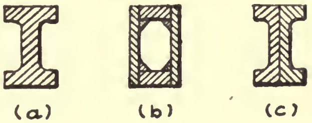


FIG. 42.

undoubtedly adds to the strength. The danger of the practice, however, lies in the fact that any failure developing within the covering may be entirely hidden. For this reason, where lapping is resorted to, it should be applied in bands rather than continuously.

The compression ribs are usually made of spruce. They are of profile similar to the camber ribs, so that they also serve in that capacity. They must be securely jointed to the spars. Wiring plates are provided at the joints for the attachment of the internal drift and anti-drift wires. These are usually of piano wire. On some machines inspection doors are provided in the covering for inspection and adjustment of these wires. Owing to the movements of the wooden structure of the plane with varying weather, these wires have a great tendency to work slack. Where inspection doors do not exist the slackness of the wires may be detected by banging heavily on the spar with the fist, whereupon, provided that they are not taped together at their intersection, they will be heard to jangle.

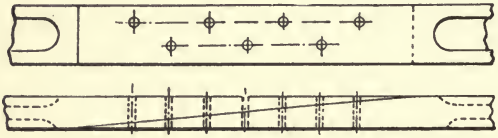


FIG. 43.

The camber or intermediate ribs of the plane serve to maintain its shape and to transmit the air loads on the fabric to the spars. They are therefore loaded chiefly as beams. They are also subject to compression owing to the tension on the covering fabric. The leading portion of the ribs, specially on high-speed machines, has to be particularly carefully constructed, since in the case of steep dives it may be very heavily loaded. In some cases, as shown at N O P in Fig. 41, extra intermediate ribs are fitted at the leading edge. The ribs are usually spaced at about 12 or 14 inches. Fig. 45 illustrates two forms of construction, (*b*) being suitable for small machines and (*a*) for larger. The flange is usually made from a strip of spruce suitably grooved to receive the web.

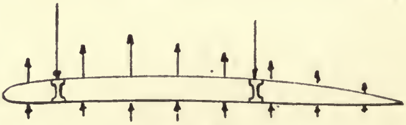


FIG. 44.

The web in ribs of smaller sizes is generally made from one piece of three ply suitably lightened, and in the larger-sized ribs it consists of small spruce struts and ties. The whole is tacked and glued together. The webs are made continuous over the spars. Particular attention must be paid to the secure attachment of the ribs to the spars. When the planes are covered the fabric is always sewn to the ribs with string. Thus they are supported to a great extent against secondary failure by buckling.

The leading and trailing edges are made of spruce where they are straight, ash being spliced on to them at their bent portions. The bent portions are steamed and bent to the correct curvature. The main function of these parts is to support the tension of the fabric.

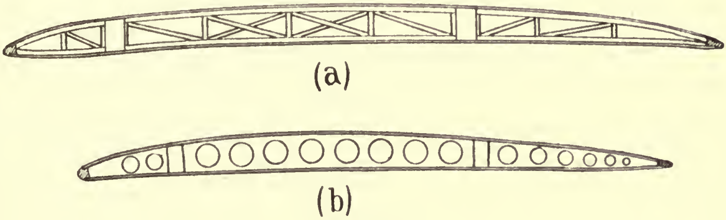


FIG. 45.

Linen is almost universally used for the covering of planes. Metal has been used, but not with any great success. Owing to the metal necessarily being very thin, it is usually corrugated when put to this use, in order to give it sufficient stiffness. Fabric is stitched on to the framework and then laced to the ribs with thin cord. It is then doped, which renders it waterproof, gives it a smooth surface, and also tightens it. The dope also adds considerably to its strength. The successful doping of planes calls for a certain amount of experience, without which the fabric may be so tightened as to distort the plane. Usually four or five separate dopings are required thoroughly to impregnate the fabric and give it a good surface. The surface may be further improved by varnishing. Over the ribs where the lacing occurs extra strips about 1½ inches wide are doped on. The leading and the trailing edges are likewise doubled. When strips or patches are doped on, the edges must always be frayed out for about $\frac{3}{16}$ of an inch. This gives them a more secure hold and prevents them from working loose. Doping must never be done in a cold atmosphere. Doped fabric is considerably affected by weather conditions. A plane that appears tight on a warm day will be very slack on a cold, damp one.

The maintenance of the planes calls for periodical cleaning and occasional repair work. The most satisfactory method of cleaning is with lukewarm water and soap. Oil is particularly injurious to fabric work and must never be allowed to remain on it. The occasional repairs may involve simply the patching of small holes or tears in the fabric, or, in some cases, small carpentry repairs to the internal structure.

In order to repair a hole or a rent in the fabric, the surrounding dope must first be thoroughly cleaned off. This is commonly done with acetone. Next the rent is stitched together. A patch somewhat larger than the hole is then prepared, its edges being frayed out preparatory to applying it. This is lightly doped on. A second patch of still larger dimensions is usually fixed over this in the same manner. Three or four coats of dope are now applied to the whole. A patch made in this manner will be stronger than the original fabric, and will present a smooth surface. If some minor structural damage to a rib or the leading edge has occurred, it is necessary to strip a larger area of fabric in order to expose the work. This is repaired in exactly the same manner, the fabric, if possible, being so slit that it can easily be rejoined; patching strips are doped on the seam. If satisfactory work is to be done, a warm, dry day must be chosen.

If the machine has suffered such damage as to render it necessary to remove any one of the planes for complete repair, the other planes should be treated with very great suspicion. Actual or incipient cracks may be present in the spars or other vital members, and may be difficult to detect unless the plane is completely stripped. The spars, being the most essential members, must be very carefully examined. The points most liable to damage naturally vary with different machines and also with the nature of the accident to which they have been subject. Perhaps the point most often injured is where the outer interplane struts join the spars, or at splices, if these exist. Defects of this nature can often be detected by applying upward and downward pressure to the extreme end of the spar and listening carefully along its length for any undue creaking which would indicate a sprung splice or an internal split. A further rough guide also is obtained by comparing the force required to deform the spar a certain amount with the force required to produce a similar distortion in another similar spar known to be sound. The condition of the rigging of the machine will usually be a clue to the nature of possible plane damage.

CHAPTER VIII

THE CONTROL SYSTEM

THE normal inherently stable aeroplane, if absolutely correctly rigged, will itself adopt and continue in a condition of straight flight. The use of the rudder, elevators, and ailerons in controlling the speed and direction of flight has already been discussed. A point which has not been touched upon and one which should not be passed over without mention is the effect of the propeller slip stream on the controls. On nearly all machines all the control surfaces, with the exception of the ailerons, are situated in the slip stream. This has a great effect on them. The velocity of the air in the slip stream is much greater than the velocity affecting other parts. As the air reactions induced vary as the square of the air speed, this has the effect of increasing their power considerably. It must also be noted that when the machine is gliding and the slip stream is not present the rudder and elevators must be used much more vigorously to achieve the same results as in normal flight.

It is here proposed to describe the mechanism by which the control surfaces are actuated. Its all-importance cannot be exaggerated. Its principles of action and construction are very simple, and the various components always have a very large factor of safety. The pilot must not, however, allow these facts to lull him into any false sense of security, for a very minor failure in some part of the mechanism may lead to disaster. The principle which has been standardised is that a movement of any control in any direction produces a corresponding movement on the part of the machine. A pressure with the left foot on the rudder bar causes the machine to swing to the left ; a forward movement of the control pillar causes the machine to dive, and so on.

Fig. 46 illustrates diagrammatically the system most generally adopted. The principles are the same on nearly all machines. The actual method of coupling the several control flaps to the control levers, however, necessarily varies to some extent in different aeroplanes. A is the main control pillar. It was early nicknamed the "joy-stick." This term has since been so universally adopted that it has come to be accepted practically as a technical term. The movement of this pillar controls both the elevators and the ailerons. The rudder is controlled

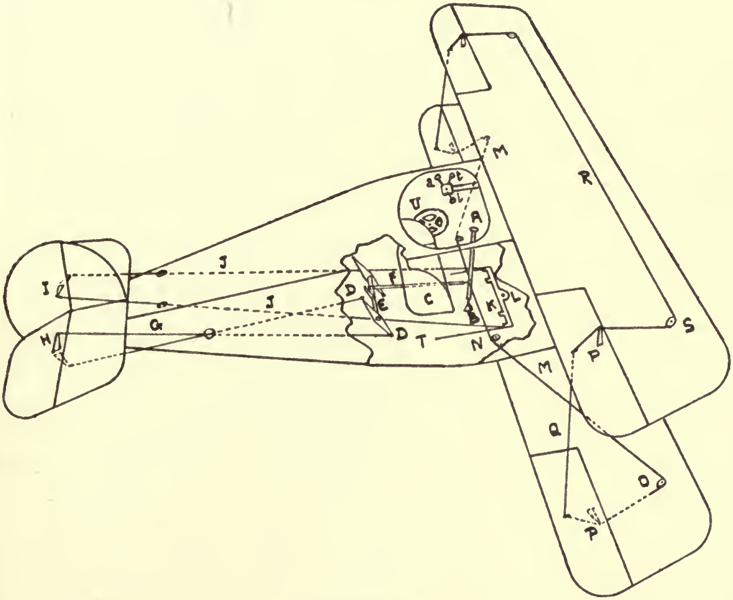


FIG. 46.

by the rudder bar K, on which the pilot rests his feet. The pilot's seat C is so arranged that he sits in comfort with his feet on the rudder bar, the control pillar being so placed that it projects upwards between his legs in such a position that he can hold it comfortably with the right hand. Any manœuvre of the machine usually calls for a combined movement of the hands and feet. This may at first seem somewhat complicated. In practice, however, the movements become entirely automatic and instinctive. It is only during his earlier training that the pilot has to split up and analyse his various movements.

The control pillar is pivoted at B in such a manner as to allow it complete freedom of movement in all directions. A rod F couples it to the rocking shaft E, which is usually carried in bearings fixed to the vertical struts of the fuselage. This rocking shaft carries two double-ended levers D to which the elevator wires are coupled. These elevator wires are coupled to king-posts on the elevators. Any fore or aft movement of the control pillar then causes a movement of the elevators. It is necessary that when the control lever is moved forward the machine should increase its speed or dive. In order that it may do this, the angle of incidence of the main planes must be decreased by raising the tail, which is effected by the depression of the elevators. With the arrangements shown in the figure it is evident that the forward movement of the control pillar causes a forward movement of the top half of the levers D on the rocking shaft. The top ends of the levers D must therefore be connected with the lower king-posts of the elevators and the elevator wires G crossed. The rod F is so jointed as not to interfere with the lateral movement of the control pillar. It will be noted that lateral movements of the pillar have no appreciable effect on the elevators.

In the figure a very simple method of coupling the ailerons is illustrated. To the control pillar are attached two wires M. Let the course of one of these be followed. It passes first over a pulley N, so situated that the fore and aft movements of the control pillar will not appreciably affect the aileron control. It passes thence to a guide pulley O fixed on the front main spar of the lower plane. The pulley O guides it to the king-post P situated on the lower surface of the aileron. The aileron on the top plane is actuated by the inter-aileron wire Q. As the control pillar is pushed over to the left-hand side the two ailerons on the right-hand side are depressed. This increases the incidence and lift on the right-hand side and causes the machine to bank to the left. The power of the lateral control is increased by the addition of the " balance wire " R. The top plane ailerons are fitted with king-posts P. The wire R, which passes over guide pulleys S fitted to the front spar of the top plane, connects these king-posts. The effect of this wire is that, when (say) the right-hand ailerons are depressed, they raise those on the left by means of the balance wire, thus doubling the effect.

The rudder control is very simple. To the rudder bar K, which is pivoted on the floor of the cock-pit at L, are connected two wires JJ. These are led directly to the rudder king-posts II. The tail skid (not shown in the figure) is also commonly controlled from the rudder bar. This greatly facilitates steering the machine when taxying. Extra wires T are run from the rudder bar for this purpose. These wires are usually fitted at some point in their length with fairly strong tension springs. When turning on rough ground the tail skid is subject to a certain amount of jarring; these springs serve the purpose of shock absorbers, insulating the rudder bar and the rudder controls from this vibration.

Other controls are the engine controls, switches, and tail adjustment. These are usually situated on the left-hand side so that the pilot need not remove his right hand from the main control pillar in order to operate them.

The engine controls normally consist of three levers—the throttle, the altitude control, and the ignition control—*a*, *t*, and *i* in the figure. These are always arranged to open or advance by causing the lever to move in a forward direction. Switches are always arranged to be "on" when in the up position, and "off" when in the downward position. Most propeller accidents are the result of men swinging when the switch has been left on, and for this reason it is advisable that the main switch should if possible be situated in such a position that the men swinging the propeller can see it.

A tail plane control is fitted on most modern machines. It consists of a wheel or lever by means of which the incidence of the tail plane can be varied. To alter the speed of a machine which is not so fitted, the incidence of the main planes must be varied by depressing or raising the elevators. With modern machines which have a sufficient margin of engine power to fly at varying speeds and rates of climb, it is not desirable that the pilot should be compelled continuously to hold the control pillar in a position corresponding to the speed at which he wishes to travel. An adjustable tail plane is therefore provided. With this device to increase the speed he simply increases the tail plane incidence by turning its control wheel forward the requisite amount. The standard arrangement is that the top of the wheel or control lever, as the case may be, moves in the same direction as would the top of the main control pillar to achieve the same result.

Reasonable "lightness" of control is desirable. In the single-seater machine the control surfaces are comparatively small. No great effort is therefore demanded of the pilot to move them. In the case of a larger machine, especially if the speed be high, the pressure on the surfaces becomes much heavier, and the machine is correspondingly "heavy" on control Were he not aided in some manner, a super-man would be necessary to control some of the newer types of multi-seater machines. This aid is provided by partially balancing the control surfaces. Consider the force required to turn an ordinary rudder (Fig. 47 (I)) about its hinge AB. This depends upon the total air pressure and the distance of the centre pressure C from the hinge. Fig. 47 (II) shows the same rudder, but partially balanced by a portion X situated forward of the hinge. The rudder may now be divided by a line ZY into two parts, such that the centre of pressure of the upper portion is situated on the line on the hinge. No force whatever need be applied to turn this. The force applied to the rudder is then simply that necessary to turn the lower portion, which has its centre pressure at C_2. Thus the new balanced rudder, whilst having a larger surface, requires less force to turn it. Control surfaces may be as completely balanced as the designer wishes. An

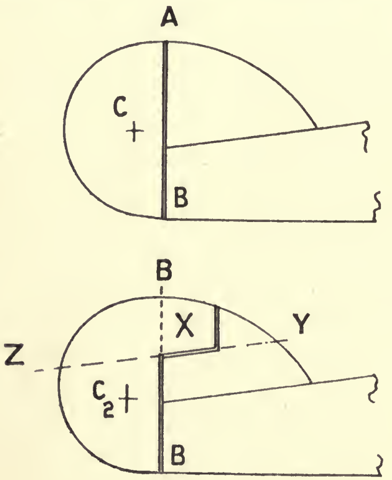


FIG. 47.

over-balanced control, however, is a source of danger. The pilot could introduce excessively high controlling forces without himself using undue force. These might be quite sufficient to break some part of the machine. He would also be robbed to a great extent of the power to "feel" the condition of the machine.

Before turning to the consideration of the detail of the controls a word may be said concerning the extreme importance of standardisation. The standard arrangement must never in any circumstances be deviated from. The pilot always flies instinctively, and, even if it be possible for him normally to remember on some particular machine he is flying that some special detail is not according to standard, if he is suddenly placed in some emergency, he will most certainly act instinctively and use it wrongly.

On most larger machines of the multi-engined types the ailerons are not controlled by a lateral movement of the control pillar, but by a hand wheel placed upon it, as shown in Fig. 48. The control movements in the machines of this type need not be so rapid. Moreover, the forces required to control the ailerons are much greater. The control pillar is allowed only to swing in a fore and aft direction, the pilot turning the wheel for lateral control. The wheel carries a drum to which the aileron control cables are led.

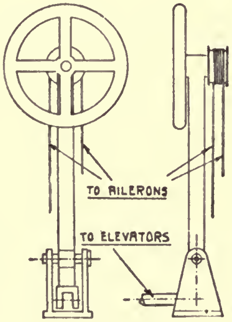


FIG. 48.

Reliability is the main object aimed at by the designers of the various parts of the control system. The rudder control wires are always duplicated. This control is perhaps the one which the pilot can least afford to do without. The elevator controls are already virtually duplicated, sufficient emergency control being usually obtainable from one elevator alone in event of the other for some reason becoming inoperative. A machine with normal dihedral angle can, in steady weather, usually be flown without using the lateral control. Breakage or jambing of control gear is, however, an exceedingly rare occurrence, and, if the machine is well looked after, should be impossible. The loads on the control wires are never very great. They can never be greater than the pilot can exert upon them. Stranded cable, of breaking strength usually from 10 to 15 cwt., is nearly always used. The chief reason for using cable is that it has a fair amount of "give" in it, and also that it shows signs of wear before it breaks.

The control wires have frequently to be led round pulleys or through fairleads. This, of course, renders a flexible cable essential. Fairleads, as they are called, are often used to guide cables where they turn through very slight angles or where they need simply to be steadied. These are sometimes made from copper tube. Fibre blocks suitably drilled are more commonly used, and are rather better than metals as they do not chafe the cable so much. Fairleads should, however, always be avoided when possible. They chafe the cable and ultimately cause failure. Guide pulleys are better, but these again always cause a certain amount of wear. The points on the cables where they pass through fairleads or over pulleys must be inspected very frequently. A stranded cable usually breaks more or less gradually, the most highly stressed strands going first. If the fingers are run along the cable the presence of broken strands will easily be detected. Cables should always be kept greased, and any points subject to special wear must be particularly well covered. As soon as any point in the cable shows signs of wear the whole cable or the defective part should immediately be replaced. At points where cables cross one another or pass through fairleads which do not bend them they should be armoured in some manner. A satisfactory method is to slip a piece of copper tube over them, fixing it with a spot of solder at one end.

All the moving parts of the system should be readily accessible for inspection. All the nuts, turnbuckles, etc., must be properly locked.

Turnbuckles (see p. 76) are spliced into all the main cables so that they may be accurately adjusted in the first instance and so that the gradual stretch which always occurs in use may be taken up as necessary. The adjustment of the control cables is always a matter of great importance. The tendency is invariably to make them too tight. If they are tight, friction on the various bearings is introduced, and all delicate feel of the machine is lost to the pilot. Furthermore after the controls have been coupled they must always be tried in all positions since on nearly all machines their tightness will vary to some extent with the position of the levers. In this connection the adjustable tail is frequently a source of danger ; in some machines movement in the tail plane involves a slight alteration in the lengths of the elevator controls. If these be rigged tightly in what may be called the slack position of the tail plane they will tend to jamb when it is moved.

In machines designed for high speed the control cables are as far as possible situated inside the fuselage and the planes. This is conducive to a smooth exterior of low resistance, but often means that these parts are not as easily accessible as they should be.

The wise pilot will make a point of periodically inspecting the control system himself, thus guarding against the very unpleasant possibilities which may attend upon its failure.

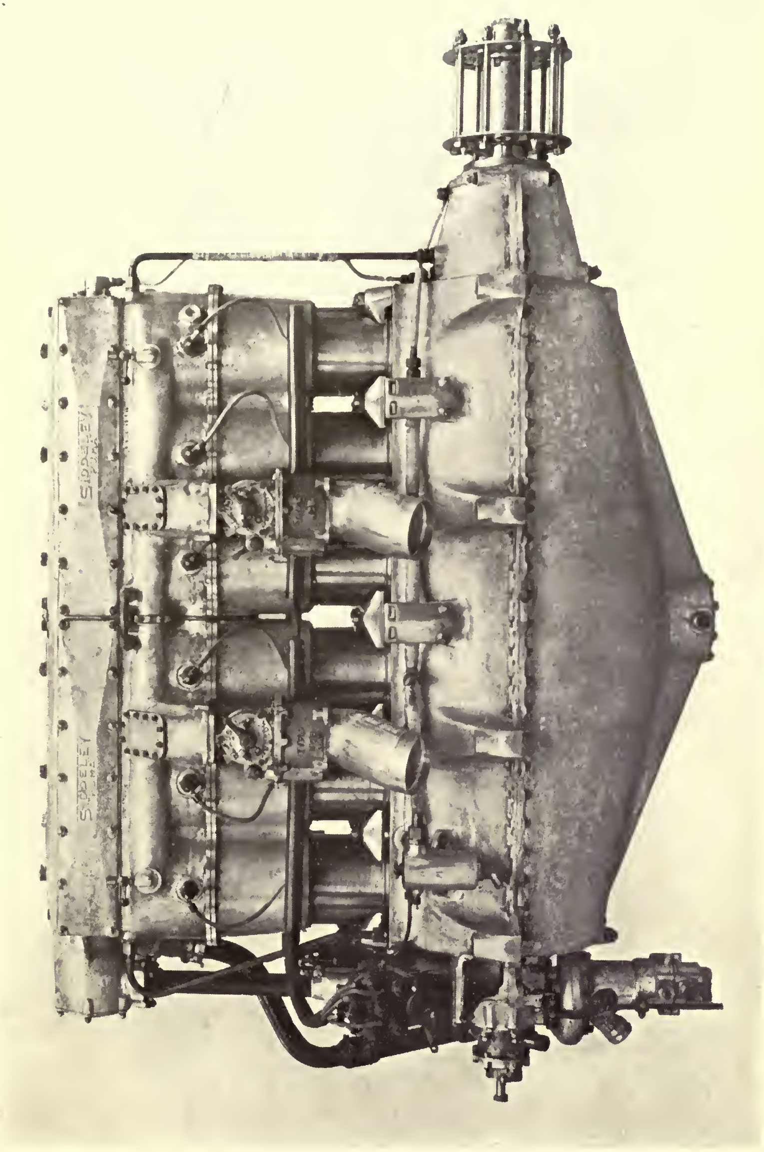
CHAPTER IX

THE FUSELAGE

THE fuselage of an aeroplane acts as a basis for attachment of all other parts. Its chief aerodynamic function is to support the tail. What may be termed its general utility functions include carrying the engine, petrol tanks, pilot, control gear, etc. It may be considered under two headings, the general utility part, and the cantilever part which carries the tail. In the single engine pusher aeroplanes, the latter part is replaced by a "nacelle," the rear portion consisting of booms. In the case of large multiple engine machines the engines are commonly situated between the planes, as shown in Plate I. The fuselage then serves for the accommodation of passengers or load, petrol tanks, centralised control, etc. The flying boat type of seaplane utilises the boat portion as the fuselage.

Various forms of construction are adopted. The simple fuselage of the ordinary pusher usually consists of hollow section wood or steel tube booms, suitably braced with streamline section struts and wires. Practically all the large multi-engine machines have wood longerons and struts cross-braced with wire, the whole externally covered with fabric or three-ply wood. "Longeron" is the name given to the continuous fore and aft members which form the corners of the structure. The commonest form of fuselage is that used in the ordinary tractor biplane. It is proposed to discuss this type in detail. Other types are, generally speaking, in some respect, a simplification of this. In any case, he who thoroughly understands this type will find little difficulty in inferring for himself the effects of the modifications which occur in others.

The general arrangement of the various parts is shown in Fig. 49, which represents the fuselage of a long-distance two or



SIDDELEY-DEASY PUMA ENGINE—240 HORSE-POWER

more seater tractor. A is the radiator which forms the nose of the machine. B are the engine bearers to which the engine is bolted, and which are carried by strong cross frames attached to the longerons. This part of the framework must be particularly well braced against torsional vibrations which may occur if the engine is not running smoothly. The longerons CC and DD are continuous throughout the length of the machine. E is the undercarriage. The points where this is attached to the lower longerons must be specially strong as they may be subjected to very severe shocks. F is the oil tank, and G G the main petrol tanks. These are situated as near to the centre of gravity of the machine as possible, so that their weight variations during flight will not affect the balance of the machine. H and I are the control column and the rudder bar, which are situated in the pilot's cockpit. J is the instrument board. K and L are the pilot's and passengers' seats. All this constitutes the utility portion of the fuselage. It will be noted that the large weights are all concentrated as near the centre of gravity of the machine as possible. This portion of the fuselage is often covered with three-ply wood, which assists the diagonal bracing wires, and is more durable than fabric. This arrangement, however, renders the structure comparatively rigid. The after portion is entirely relied upon for adjustment, and is for this reason covered with fabric which is laced on. The after part of the fuselage acts as a cantilever supporting the controlling forces induced by the operation of the tail. Also owing to the non-symmetrical arrangement of the fin and rudder, it is subject to a certain amount of torsion. Other loads are introduced when landing by the tail skid M. If the machine is taxied over rough ground these may be quite severe. N is simply a

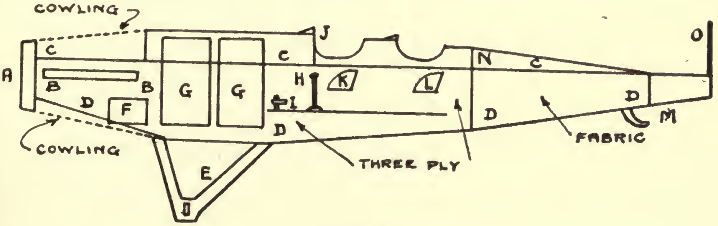


FIG. 49.

light fairing fitted to streamline off the back of the passengers' seat. O is the rudder post to which the fin and rudder are attached and from which the tail plane is braced.

In the arrangement of the cockpit the comfort of the pilot and passengers must be studied. The machine designed as a passenger carrier may make very comfortable provision for the latter; the pilot's seat is, however, necessarily somewhat exposed. It must always be so situated as to give him easy vision in all directions whilst sitting in his normal position. A suitably designed wind screen may protect him from the wind. For warmth he must rely upon clothing, although different machines, according to their engine arrangement, vary considerably in this respect A point sometimes neglected is that the exhaust fumes should be carried well clear of the pilot. Otherwise he may be very seriously affected by them.

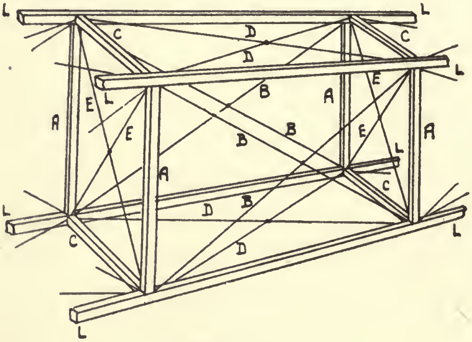


Fig. 50.

The internal structural arrangement of the after portion is as indicated in Fig. 50, one bay only being shown. The longerons LI. are called upon to support a tensile or compressive load according to the direction of the air reaction acting on the tail plane. They are therefore made continuous. The side struts AA and wires BB are stressed by the upward and downward tail loads, the cross struts CC and wires DD by the lateral loads. The conditions introduced by the torsional loads are somewhat complicated. The torsional truth of the fuselage, however, depends on the adjustment of the wires EE of the internal bays. A form of the joint plate used is illustrated in Fig. 57.

Successful all-steel fuselages have been made, the wood struts and longerons in the type already described being replaced by steel tubes. The joints are made by welding, suitable wiring lugs being welded on. An exceedingly strong and durable structure may be built in this manner. It need not be very much heavier than the wood-strut type. In difficult climatic conditions a construction of this nature has very obvious advantages. As the question of durability comes more to the fore, the application of metal in the place of wood will become much more usual in many parts of the aeroplane. A disadvantage of the welded steel construction is that it is somewhat difficult to repair if damaged.

A form of fuselage construction worthy of note is the all three-ply round or oval section commonly known as the "monocoque." This is made in a manner somewhat similar to the hull of a flying boat. It consists essentially of an oval tube of three-ply wood stiffened internally with light ribs. The resulting fuselage can be made of a particularly neat streamline shape. It may be made entirely free from internal cross-bracings, and is very stiff. Its application is limited, as it is somewhat expensive. The flying boat shown in Plate XV exemplifies the neat external lines which are obtainable by this mode of construction. It is not easily repaired if damaged in any way.

The fuselage as a whole must be thoroughly examined from time to time to ensure that no bracings are working slack or signs of failure showing in any of the wood parts. The continually varying loads, to which the different parts are subject in service, will always cause certain members to require occasional adjustment. The parts usually most affected are the bracing wires transmitting the landing shocks. These parts should always be particularly examined after a heavy landing. It is landing and taxying that is responsible for most of the fuselage wear and tear. If the shock absorber on the wheels and tail skid are too tight, the whole structure may be subject to a great deal of unnecessary jarring. A certain amount of care is also necessary when man-handling a machine. The main point of importance is that lifts must be applied at the joints of the structure, and not at points in between them, as in the latter case the parts handled are subject to severe bending loads. A practice to be recommended is the fitting of special handles, which need be neither heavy nor unsightly, at the lower joints near the tail. Care must also be taken when doping the fabric covering, otherwise the resulting shrinkage will bend the longerons inwards, thus predisposing them to failure when in compression. It must always be made a rule that the cockpits and interior be kept thoroughly clean, otherwise dirt or cleaning rags, etc., may work into a position such that some vital control becomes jambed.

The landing gear or undercarriage in the case of the ordinary tractor machine is fixed to the fuselage. In the case of the larger multiple engine machines, where the engines are situated between the planes, a separate landing gear is usually provided beneath each engine. Fig. 51 shows diagrammatically some of the arrangements commonly adopted. The fundamental desiderata of the undercarriage are as follows: It must be sufficiently strong to resist a reasonably heavy landing. It should not however, be excessively strong, otherwise rather than give way itself, it will break some other part of the machine more difficult to replace. It must insulate the machine from the shocks due to landing and to the unevenness of the ground when taxying. It must be of sufficient height to allow the planes to assume their maximum lift angle before the tail skid comes in contact with the ground, and also to provide a sufficient ground clearance for the propeller, when the tail is lifted. The wheels must be situated forward of the centre of gravity of the machine. They must also be sufficiently far apart to ensure the lateral stability of the machine on uneven ground.

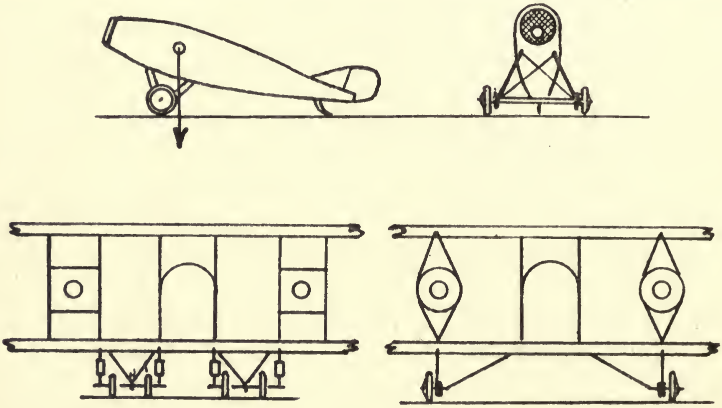


FIG. 51.

The simple "V" type of undercarriage is now almost universal for single engine tractor machines. The undercarriages on larger machines are usually similar in principle, but somewhat more complicated in detail. The V struts are made of wood or steel. Steel undercarriages are built up from streamline section tubes welded together, or from a single bent circular section tube fitted with light wooden streamlining. The upper ends of the struts are either bolted to lugs or fitted into sockets provided on the lower longerons. The V's in the case of a single undercarriage are usually splayed outwards in order to give the wheels a sufficiently wide track. They are joined at their lower extremity by a strut which is generally utilised to provide a fairing for the axle. Cross-bracing is added to render the undercarriage laterally rigid.

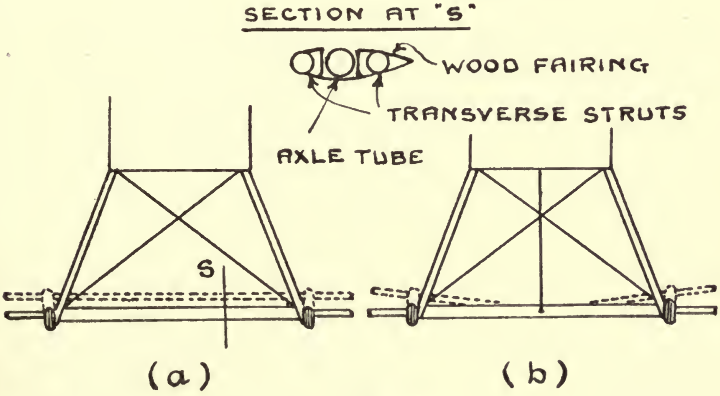


FIG. 52.

The wheels rotate on a steel tubular axle, which lies in the point of the "V." This axle is attached to the "V" struts by some shock-absorbing device. The commonest arrangements consist simply of a lashing of stranded rubber cord. Another form sometimes used, known as the "Oleo" type, consists of a combination of spiral springs, and an oil dash-pot. The load in this latter type is transmitted to a piston in an oil cylinder, the piston forcing the oil out of the cylinder through a constricted passage. As the load is relieved the springs return the piston, sucking the oil into the cylinder again, thus preparing it to receive another shock.

The commonest arrangement is for rubber cord, or shock absorber as it is usually called, to be applied at each end of the solid axles as shown in Fig. 52 (*a*). In some cases, however, the axle is jointed in the centre, moving as indicated in Fig. 52 (*b*). More detailed diagrams of the method in which the shock absorber is applied are shown in Fig. 53. The shock absorber is always wound on with an initial tension sufficient to hold the axle in its lowest position when the machine is standing, thus leaving its maximum amount of play available for the absorption of shocks. The harshness in operation may be adjusted by varying the length of the cord wound on, and the initial tension at which it is wound. The more shock absorber used, and the greater the initial tension, the harsher will it be, and the greater landing shock will it absorb. Only experience can teach the correct length of cord for each particular type of machine.

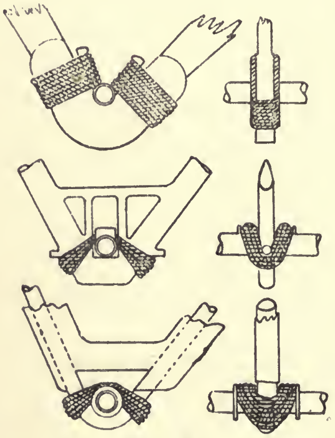


FIG. 53.

The wheels used on aeroplanes are always of the wire spoke type. These are considerably lighter than other types, because the load is transmitted from the rim to the hub by a direct tension of the upper spokes, this condition allowing of the most economical use of material. The hubs are fitted with phosphor-bronze bushes which run on the axle tube. The hubs are made fairly long so that the spokes may be set at a sufficient angle to support the side loads to which the wheels may become subject if the machine is moving in a slightly crab-wise manner relative to the ground when it lands. Fabric discs are fitted to the wheels to lessen their air resistance. The tubes and tyres are similar to those used on a car, but are made very much lighter. The tyres transmit no drive, and only run along the ground for short distances. They are therefore subject to very little wear. Punctures are infrequent. When they do occur, however, they must always be very soundly repaired. A tyre which goes down in the course of a flight may very easily be the cause of a mishap on landing. It is usual to keep spare wheels complete, inflated ready for use. It is then known for certain that the tyres are sound.

The wheel fixing usually consists simply of a cap which fits over the end of the axle, and which is fixed by means of a large split pin or bolt, passing diametrically through it. This arrangement is very simple and proves entirely satisfactory in service. The fixings must be inspected from time to time to ensure that they are sound. If the fixing is by means of split pins, the same pin should never be used more than once. The fact that it has already been bent once renders it very apt to snap off if used again. If a wheel does come off, the consequences are bound to be disastrous.

The undercarriage requires comparatively little attention in use beyond the occasional greasing of the wheels and a periodical general inspection. It should be specially carefully scrutinised after a heavy landing. The points where failure is most likely to occur are the join of the " V," the axle, and the fittings to the fuselage. A bent axle is usually sufficiently obvious. If the bend is only very slight it may be allowed to remain untouched until it shows signs of getting worse. As axle tubes are generally made of specially hardened steel it is not ordinarily wise to attempt to straighten them. If the undercarriage is seriously strained, it will usually be made evident by the slackening of one of the cross-bracing wires. One of the most useful tests to apply is to sight the undercarriage from the side. If either of the " V " struts is failing, it will probably appear to have moved forward slightly relative to the other.

The tail skid supports the weight of the after part of the machine when it is standing or landing. The load which it has to bear depends on the distance the wheels are placed forward of the centre of gravity of the machine. Any load on the tail skid has to be supported by the cantilever portion of the fuselage; it is therefore desirable that it should not be greater than necessary. This fact to a great extent controls the fore and aft position of the wheels, making it desirable that they should be placed only so far forward as is essential to prevent the machine tipping on its nose when taxying. The tail skid is usually provided with a cross bar at the top, coupled to the rudder bar, the skid thus being made to act as a kind of land rudder. A further function of the tail skid is to act as a brake. At the point where it makes contact with the ground it is shoed with steel. This shoe, which in some cases is specially shaped for the purpose, exerts a braking effect on the machine, thus reducing the distance which it takes to pull up after having landed. Brakes have been tried on the wheels for this purpose. The scheme has, however, been abandoned owing to the fact that application of the brakes proved very apt to throw the machine on its nose, since the wheels are situated so nearly under the centre of gravity of the machine.

In use the tail skid calls only for occasional re-shoeing, and a certain amount of consideration on the part of the pilot. When the machine is taxying with its tail on the ground, the tail skid, and what is more important, the after part of the fuselage, is subject to a considerable amount of jarring. The pilot must, so far as he is able, minimise this. This point is of particular importance in frosty weather. Whilst taxying, the control lever should be held well forward, thus providing an air reaction on the underside of the tail, which greatly relieves the load on the tail skid. A further point of some importance is the manner in which a machine is swung round on the ground. When this swinging is assisted by men on the wing tips it may be very rapid. The effect of this, especially if the point of contact of the skid and the ground is some distance from the centre line of the fuselage, is to impose very serious torsional strains on the structure of the latter.

CHAPTER X

STRUTS AND WIRES

ONE of the great advantages of the strut and tie form of construction adopted in aeroplanes is its flexibility. By slightly adjusting the lengths of the various members, the shape of the structure, after approximate erection, is brought into exact truth. The slight deformation resulting from wear and tear may also be corrected. Although machines have been built with struts of adjustable length, this is not common. The usual practice is for the struts to be of fixed length, the ties or wires being relied upon for adjustment. In order that it may be correctly tuned up to take its fair share of the load, every wire in the structure must be provided with some adjusting device. All that is required by the struts, then, is some form of end-fixing which will transmit their compression load to them and at the same time be incapable of subjecting them to any bending load, the latter point being of particular importance in the case of the longer struts.

The internal structure of the planes and fuselage has already been dealt with, and it is proposed to devote this chapter chiefly to the consideration of the external struts and wires. Most of what is said in this connection is, however, of very general application. In particular, the common forms of wiring adjustment and fittings are collectively described here, although the streamline form of wire has now become practically universal for all external wiring.

The inter-plane struts, which are always of streamline section, are usually made of solid wood. As considerations of strength only demand the maximum, the section near the centre, these struts are usually tapered towards their ends. Tapering the ends also admits of a neater end fitting and one which will not unduly interfere with the attachment of the various wires. Figs. 54 and 56 show typical forms of end fittings for interplane struts together with the wiring plates. It will be noted that the compressive load is transmitted to the strut by the pressure of a pin which fits an eyed or fork-ended bolt. Steel struts are commonly used for undercarriages and in some cases for interplane struts. They consist of either solid drawn tubes fitted with a light fairing which is bound on with fabric, or of steel tubes of streamline section. The former type is lighter, but the latter offers many advantages for small sizes. The all-steel strut has the great advantage of being unaffected by climatic conditions.

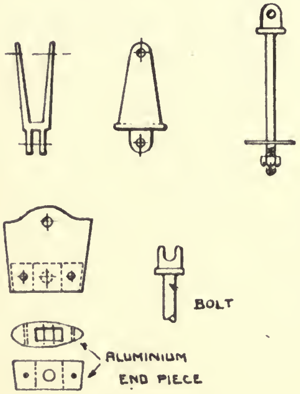


FIG. 54.

In the case of large machines the solid wood strut becomes somewhat heavy, and considerable economy results from the adopting of a built-up or a composite section. Fig. 55 illustrates a built-up wood section. Here the built-up box section takes the load, a light wood fairing being fixed to it. A strut of this nature would be lapped externally with glued and varnished fabric. The composite section strut is one which relies on both metal and wood for its strength. Such a section is also illustrated in Fig. 55. Here an H section metal core is stiffened against failure in its weaker direction by the wood, which also acts as a fairing.

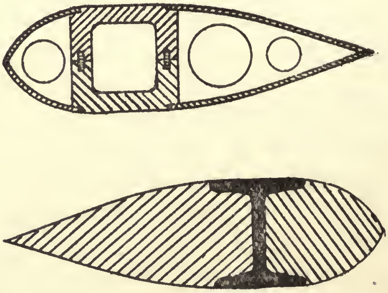


FIG. 55.

Although wooden struts are at present very largely used in British machines, as considerations of durability come more to the fore it is probable that metal will be much more generally adopted. The commercial machine will be designed to do a great many more air-hours than the normal war machine does. It will also have to be so designed as not to demand the constant attention and adjustment which are necessary in the case of a structure, the various members of which are differently affected by variations of temperature and moisture. Fig. 57 shows a typical fitting used for the internal structure of the fuselage, the point shown being where a vertical and cross strut join the longeron.

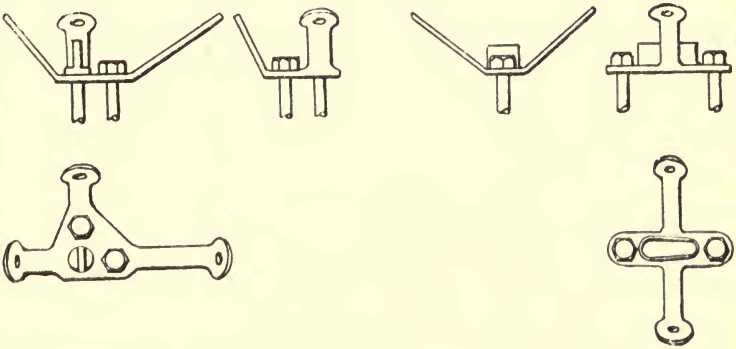


FIG. 56.

There are four types of tension bracing in common use: the piano wire, the swaged wire, the flexible cable, and the streamline wire. The piano wire, which was universally used on the earliest types of aeroplane, is now only used for internal bracings. It is very strong, but has not much "give." The swaged circular section wire, which is screwed at each end, has largely taken the place of the piano wire for internal fuselage and other short bracings where a considerable number of wires of one length are required. It obviates the use of a turnbuckle. Cable is used where flexibility is required or where sudden shock is likely to be encountered. It gives considerably before finally breaking,

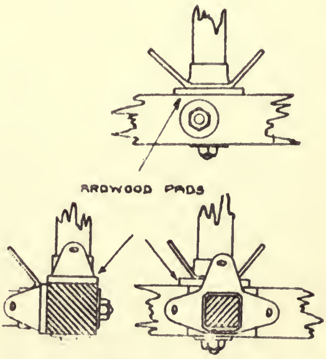


FIG. 57.

which in case of sudden shock is often very desirable. The streamline wire is a solid wire screwed at the ends and rolled to a streamline section throughout the remainder of its length. Its application considerably reduces the head resistance of a machine. It is therefore practically universally used for external wiring. Swaged and streamline wires are manufactured by rolling down to the desired section a wire of diameter sufficient to form the end threads.

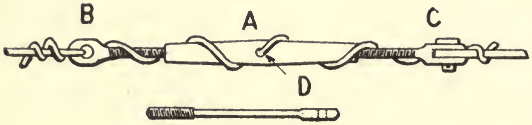


FIG. 58.

In the case of the piano wire and the flexible cable, turnbuckles are jointed or spliced into the wire to provide for its adjustment. Fig. 58 illustrates a typical turnbuckle. It consists of a bronze barrel A into which screw the two steel end pieces B and C, which may be fork or eye-ended. These two ends are oppositely threaded so that they are drawn together as the barrel is rotated. The barrel is provided with a small tommy hole D into which may be inserted a spike to turn it. When a turnbuckle has been adjusted it must always be locked to prevent it from slacking back. This is done by passing a piece of soft iron wire through the tommyhole and twisting it as indicated in the figure. Where turnbuckles are used care must always be taken that the screwed parts are sufficiently buried in the barrel, i.e. that sufficient threads are engaged. For this reason the end pieces are often shaped as indicated in the figure, it then being necessary that the whole of the threaded portion should be hidden from view.

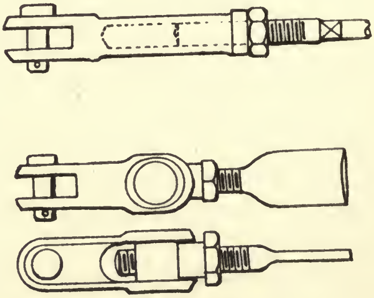


FIG. 59.

In the case of swaged and streamline wires, the two end pieces are oppositely screwed and fit into suitable end fittings attached to the wiring plates by means of pins. Two common forms of fittings are shown in Fig. 59. In the first form the wire is locked by means of a small nut. The screw thread on a wire is always made of such dimensions that the diameter of the metal at the bottom of the threads is at least equal to the diameter of the body of the wire. In connection with the locking of screwed wires, it must always be remembered that the nut imposes a stress over and above that to which the working load subjects the metal, and for this reason it must never be screwed up more tightly than is absolutely necessary. Swaged wires have a small square section formed near the ends, as shown in the figure, for the purpose of applying a spanner to adjust them. The second form of end fitting shown is self-aligning and is commonly used on long streamline wires subject to vibration. This type has the advantage that it can adapt itself to any slight lack of truth which may exist in the wiring lug.

The joints in flexible cables must be made by splicing. A metal "thimble" is always fitted inside the loop of the splice. This serves the double purpose of preventing the cable from being bent too sharply and also of protecting it from chafing. The splice is usually served with waxed thread, or in some cases sweated with solder to prevent the ends working loose. The practice of sweating the splice is not altogether to be recommended, since if it is unskilfully done it is apt to result in overheating and consequently weakening of the cable. Splices subject to heavy loads should be examined from time to time; they are the weakest part of the cable and will give out first.

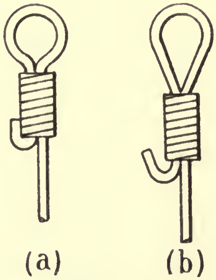


FIG. 60.

The joints in piano wire are very simply and quickly made by using ferrules, as shown in Fig. 60. These ferrules are usually made of twisted wire and are of oval shape suitable for the gauge of wire to which they are to be applied. The points of most importance in forming these joints are that the loops should be small and round and that the end piece should be turned sharply back. Fig. (*a*) shows a good end, and Fig. (*b*) a bad loop. The whole joint may be considerably strengthened by soldering.

Swaged and streamline wires have the advantage that by suitably designing the end fittings the strength of the ends may be equal to that of the body of the wire. In the case of the spliced cable and the piano wire the strength is usually reduced by 20 per cent. The strengths of stranded wires and cables are tabulated in the Appendix.

The fittings or wiring plates, which are situated at the various joints of the structure, are usually made from mild steel stampings pressed to the correct shape and in some cases welded. Fig. 56 illustrates wiring plates as used for the main plane bracings. Fig. 57 shows a form of joint used in the fuselage. The fittings must be so shaped as to cause the lines of action of the various forces to pass as nearly as possible through a common point. The importance of this has already been explained in Chapter VI. Where fittings of any kind are bolted to soft wood, care must be taken that they have sufficient bearing or, in the case of bolts, that a sufficiently large washer is used to prevent the wood being injured. In some cases hard wood pads are placed between the fitting and the softer wood. Fig. 61 illustrates a point which must be avoided. A wiring lug bent as shown in (*a*) would fail by bending at A. The fitting should be bent as shown in (*b*). If for some reason it is necessary to carry out the wiring plate as in (*a*), then a stiff washer, as shown in (*c*), must be fitted. Care must always be taken that the lugs are properly aligned with the wires attached to them.

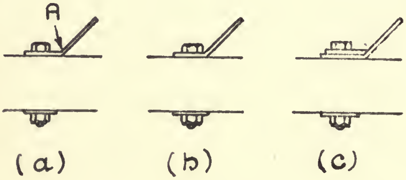


FIG. 61.

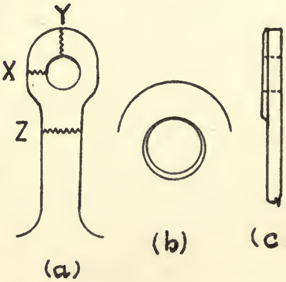


FIG. 62.

A wiring lug may fail by fracturing at X, Y, or Z, as shown in Fig. 62. At Z it is subject to simple tension and is sufficiently strong when made equal in strength to the wire which loads it. The metal at X and Y is, however, also subject to a certain amount of bending, and for this reason must be more amply proportioned. The enlarged and exaggerated section in Fig. 62 (*b*) illustrates how this occurs. The maximum stresses occur at Y. The lug should thus be shaped as indicated. There is one other form of weakness from which the lug may suffer. If it be made too thin, the bearing pressure on the pin may exceed the crushing strength of the material. This will result in either the lug or the pin, whichever is softer, failing. For this reason an extra thickness of metal, as shown in Fig. 62 (*c*), is sometimes brazed on.

Where bracing wires cross one another, and are liable to chafe, they must be protected. This is chiefly necessary at points where the external streamline wires cross as they are there edge to edge. The most satisfactory arrangement is to fit a small hardwood or fibre streamline bobbin between them. Two types of these are shown in Fig. 63. This arrangement has the added advantage that it steadies them against vibration, to which they are very liable. Vibration in a wire usually indicates that it is rigged too slack, or, in the case of a streamline wire, that it is not set quite correctly relative to the air flow. Any wire noted to be vibrating must be adjusted, since the vibration may add considerably to the stress to which it is subject. Cables and piano wires of any length are commonly taped with adhesive tape at their intersection.

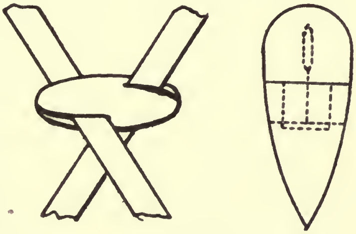


FIG. 63.

Apart from occasional rigging adjustments which are dealt with elsewhere, the only attention required by the struts and wires in service is periodical cleaning. Struts, the surface of which is usually varnished, require nothing more than an occasional wipe down. If their varnish shows signs of wear they should be revarnished to prevent ingress of moisture. Wires must be thoroughly cleaned and lightly greased periodically. Once they have been properly cleaned a periodical wipe over with an oily rag will keep them in good condition. Paint and anti-rust preparations are generally to be avoided as it is usually found that the rust, commencing at some exposed spot, eats its way under the covering. Internal wires are commonly painted white. These are not exposed to the weather or any form of abrasion, and the white paint serves as a protection and also immediately shows up any tendency to rust. When greasing wires special attention must be paid to the end fittings and screw threads. In overhaul work generally it must be made a rule that all screw threads are thoroughly greased. Otherwise they will become rusted in service and consequently difficult or even impossible to unscrew.

PLATE VI

SOPWITH CAMEL AEROPLANE—BENTLEY ROTARY ENGINE

CHAPTER XI

THE PROPELLER

THE aeroplane propeller is simply a development of the propeller as used in water. Before the advent of the aeroplane the windmill and the rotary fan were practically the only applications of the principle to the production or utilising of air motion. One of the most difficult problems with which the pioneer airman was faced was the production of efficient propellers. The ordinary fan provided him with a principle, but with very little practical data upon which to work it out. He was called on to produce a fan as light as possible and capable of efficiently converting a very considerable horse-power into an air thrust.

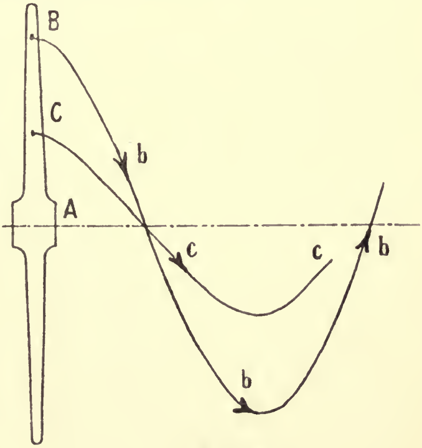


FIG. 64.

Let the conditions under which the propeller works be analysed. It rotates at a certain number of revolutions per second, and at the same time travels forward with a certain translational velocity which is the speed of the machine. Consider a small part of the blade at B, the flight path, for so it may be termed, is the helix *b b b* (Fig. 64). Likewise the flight path of the element C is the helix *c c c*.

Fig. 65 shows a plan view of Fig. 64, the size of the propeller being somewhat exaggerated for purposes of demonstration.

The blade is shown sectioned at the point B. Suppose that this section makes an angle θ with its flight path; then, owing to its motion through the air, it will be subject to an air reaction P. This force P may be resolved into two forces, namely, T parallel to the direction of motion and E at right angles to it. Here, then, is the principle of the propeller. By applying a turning moment equal to E multiplied by the distance A B (Fig. 64) to the section B of the propeller, a pull equal to T is produced in the direction of flight.

A point thoroughly to be grasped is that the section B is subject to exactly the same conditions as the wing of an aeroplane. In order to make the propeller as efficient as possible, it is necessary that T should be large compared with E for each section. It must be borne in mind, however, that the efficiency is the ratio of work done by the engine on the propeller to the work done by the propeller on the machine. It is therefore $\frac{TV_m}{EV_r}$, where V_m and V_r are the velocities of the section in the direction of flight and at right angles to the direction of flight respectively. It may be proved that the efficiency is greatest when θ has a value near to 45°.

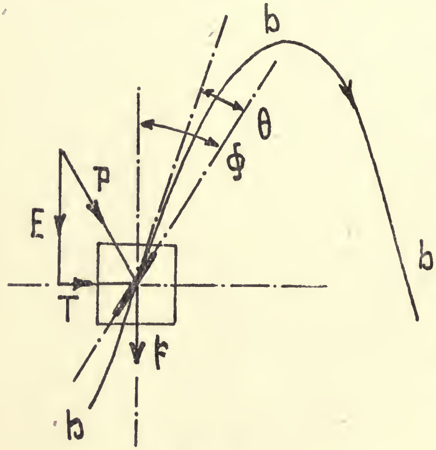


Fig. 65.

Using the same nomenclature as in the case of an ordinary wing section, the angle θ is the angle of incidence. Suppose that this is altered. Referring to Fig. 65, it is evident that as θ is increased the ratio $\frac{E}{T}$ is also increased, i.e. the efficiency of the propeller is reduced. Its efficiency is then increased by reducing the angle of incidence of the blade. If the angle D is, however, reduced to zero, P will become purely a drag force and no pull will be exerted by the propeller. There is therefore some small angle at which the section is most efficient. This, as in the case of a wing section, is found to be about 4°. As the section of the propeller blade is acting under the same conditions as a wing section, it is made of similar shape. Fig. 66 shows an enlarged view of Fig. 65, the section of the blade and the angle of incidence being approximately those adopted in practice.

So far only the section at the point B has been considered. The same argument exactly applies to any other section C. It will be noted, however, that the section at C must offer a 4° angle of incidence to the particular flight path at that radius. The blade of the propeller must therefore be more and more inclined, i.e. the angle ϕ in Fig. 65 becomes greater and greater as the boss is approached.

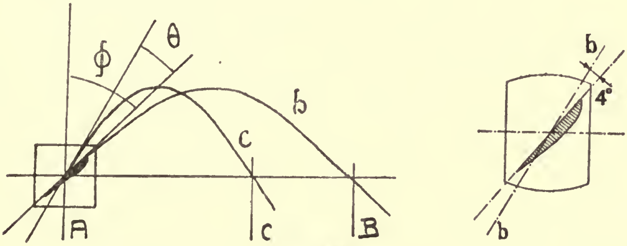


FIG. 66.

The following technical terms are commonly met with. The Angle of Incidence of the blade is the angle which the chord of the section at any point makes with its path through the air. Referring to Fig. 65, it is the angle θ. The Pitch of the propeller is the distance which it travels forward per revolution if the angle of incidence is zero, or more accurately when the section has a "no lift" angle of incidence. In the case of a curved blade section this would demand a slight negative angle of incidence as measured on the chord (see K_L curve in Fig. 24). Supposing that in these circumstances the section follows the path shown by the line A*b* in Fig. 66, the pitch is the distance AB × 2. The pitch angle of the blade is the angle ϕ. It must be remembered that this approaches 90° as the boss is approached. In order to exert a pull the blade must necessarily have a certain angle of incidence. It then travels forward a distance of only AC × 2 per revolution. The distance CB is termed the Slip, and the Slip

Ratio, as it is called, is CB/AB. It will be noted that as the slip ratio varies so does the angle of incidence, and consequently the efficiency.

In all actual propellers the angle of the blade over the more effective part of its length is less than 45°. It is evident then that for the same forward velocity a slowly revolving propeller is more efficient than one of the same diameter revolving more rapidly. Similarly one of small diameter will be more efficient. The absorption of the necessary horse-power forces the designer to adopt a diameter greater than the most efficient one. A limit in size is imposed by centrifugal stresses in the timber.

The general principles upon which the propeller works now being understood, it is possible to proceed to discuss the various factors controlling its actual design.

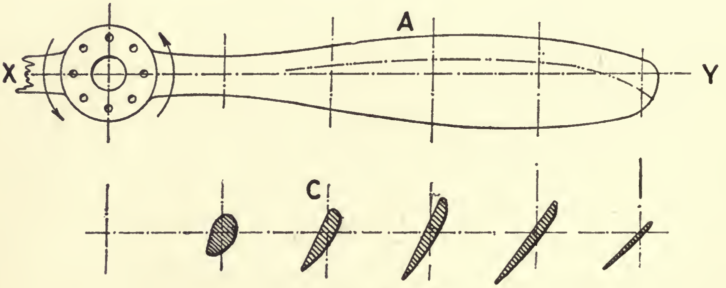


Fig. 67.

The load on the blade due to the air reaction at any point is equal to $KA\rho V^2$. The important point to be noted here is that the velocity of any point on the blade is proportional to its distance from the centre of the propeller. The air forces on the blade therefore increase very rapidly as the maximum diameter is approached.

Fig. 67 shows a typical propeller blade, cross sections at different radii being drawn. The reasons for the varying shape of these cross sections may be examined. There are two principal factors which control the disposition of the material: firstly, considerations of aerodynamic efficiency in producing thrust, and, secondly, the stresses to which the material is subjected by the loading.

It has been shown that the effectiveness and efficiency of the blade increase as the tip is approached. The blade is therefore commonly shaped so that the face is wider in these parts. The extreme tip is, however, subject to "end effects" in exactly the same way as are the tips of wings. It is therefore shaped away in a similar manner. The cross section of the outer parts, which travel at the highest speed and contribute the bulk of the propelling force, must be as aerodynamically efficient as possible. A section approximating to that of an efficient wing section is therefore made use of. In the case of a propeller a flat lower surface is nearly always adopted; the gain in efficiency due to hollowing it is not great, and would also add considerably to the difficulties of manufacture. Another factor which has to be considered in deciding the general shape is the position of the centre of pressure. The centre of pressure of the efficiently sectioned portions lies about one-third of the chord distant from the leading edge. As the less efficient portions near the boss are approached it recedes. It likewise recedes (as in the case of the wing) at the tip. Its position at various sections is indicated by the broken line in Fig. 67. Supposing that the centre of pressure were at all points on one side of the neutral axis XY of the blade, then, the propeller being a comparatively flexible wooden structure, the result would be that in use the blade would twist, altering its pitch angle. The blade should be so shaped that the loads at each side of the axis balance one another, thus having no tendency to twist the blade.

FIG. 68.

The disposition of the material to resist the mechanical loads on the blade may now be considered. The two loads to which the blade is subject are the load due to the air reaction and that due to the centrifugal force. The air reaction load on the blade is as indicated by Fig. 68. This subjects the blade to bending stresses. The bending moment increases as the boss is approached; consequently, the moment of inertia of the cross section must increase correspondingly. The centrifugal forces cause a tensile stress in the material; this likewise increases towards the boss. Owing to the curved shape of the blade centrifugal loads also introduce bending stresses; these may be utilised to balance those due to air loading. The varying cross sections shown in Fig. 67 are now readily understood. The sections near the tip are not subject to great mechanical stress; it is therefore possible to make them fairly light and of an efficient aerofoil section. A section such as C nearer the boss is subject to considerable stresses, and a corresponding amount of material must be so disposed in it as efficiently to support them. The section is therefore a compromise between aerodynamic and mechanical efficiency. As the boss is approached the sections become less and less aerodynamically efficient. These portions are travelling comparatively slowly. Therefore, though they do little else but churn air, the resulting losses are not necessarily great.

In some cases the centre portion of the propeller is fitted with a streamline cowl or " spinner " (as indicated in Fig. 69). This shields the inefficient centre portion. The gain in speed is in some cases quite considerable. The cowl may be shaped to the lines of the fuselage, which certainly gives the machine a very clean appearance.

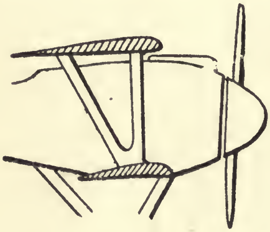


FIG. 69.

Propellers are commonly made with either two or four blades. The design of either type is exactly the same. A four-bladed propeller would absorb twice the power of a two-blader of similar dimensions. Actually, however, the maximum diameter being usually the controlling factor, the four-blader can be geared down to a slower speed and run slightly more efficiently. The gain in propeller efficiency, however, would probably be lost again in the gearing. Run on the same shaft the four-bladed propeller could be made of less diameter and give more ground clearance, which in many machines is a point of great value. A four-bladed propeller is usually better balanced than a propeller with two blades. It is also less likely to get out of balance in use. The four-bladed propeller is, however, usually weaker at the boss, owing to its construction. On account of the extra timber and the increased amount of work required in its manufacture, it is considerably more expensive.

The boss of the propeller serves simply to couple it to the engine shaft and to transmit the torque to the blades. A steel liner designed to fit the engine shaft is bolted in. Fig. 70 shows a typical boss. The drive is not transmitted from the wood to the metal by shear on the bolts, but by the frictional grip of the plates on the wood. For this reason the bolts must always be kept very tight. They should also be locked in some way. This is usually done either by split pins or spring washers. The drive is usually transmitted from the shaft to the steel boss by serrations, as shown at B; these must be a very good fit. In order to locate the boss endwise there is commonly a cone, as at C, which fits a corresponding cone on the end of the shaft. A large nut on the engine shaft is screwed up against the face F, holding the whole solid. This nut again must be carefully locked.

Propellers are usually made of walnut or mahogany, or sometimes a combination of the two. These woods combine toughness and elasticity with considerable mechanical strength. The use of inferior woods would entail the adopting of larger cross sections and a consequent sacrifice of efficiency. A hard wood is necessary to resist the wear and abrasion to which the propeller is subject. In the most recent designs, however, this is provided against by sheathing the propeller with varnished fabric or even metal. Metal sheathing is usually confined to the tips; it has, however, in some cases been applied to the whole of the leading edge. Propellers for seaplanes must be particularly well sheathed on account of the abrasive action of spray.

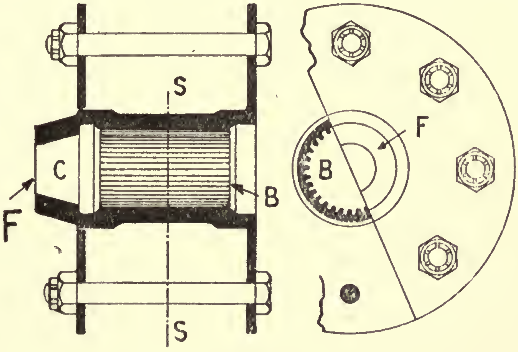


FIG. 70.

Propellers are always laminated, i.e. built up from a number of boards glued together. The thickness of the laminations is usually about $\frac{7}{8}$ inch. By adopting this form of construction it is possible to use specially selected smaller pieces of wood with suitable grain. A well-glued joint is as strong as the timber.

This method of manufacture, besides providing for greater strength, is also economical of timber as the laminations are so shaped before being glued that comparatively little material has to be cut away in the final shaping. The surface-finishing of a propeller is a matter requiring considerable care. The surface is usually French polished or varnished. In addition to being smooth and hard it must be moisture-proof, otherwise the glue between the laminations becomes softened by damp or oil. In the finishing, particular attention must be paid to the balance. As the propeller is rotating at such a high speed, balance is a matter of extreme importance. This may be well illustrated by considering an example. Suppose that the tip of one blade of a propeller 9 feet in diameter running normally at 1600 r.p.m. becomes chipped, the chip removed weighing ½ oz. The out-of-balance force introduced will be :

$$\frac{WV^2}{gr} = \frac{\frac{1}{32} \times \left(\frac{1600}{60} \times 2\pi \times 4\frac{1}{2}\right)^2}{32 \times 4\frac{1}{2}}$$

$$= \text{about } 123 \text{ lbs.}$$

This unbalanced force would cause vibrations which might be attended by serious results.

The chief factor controlling the size of most aeroplane propellers is ground clearance. When a machine is taking off it may lift its tail practically to flying position before its wheels leave the ground. It is therefore necessary that in this position the propeller tips shall be given an adequate clearance. Landings have frequently to be made in comparatively long grass, and a clearance sufficient to prevent the tips touching this is desirable. In the case of airships the propellers are commonly made of much greater diameter in order that they may be efficient at the comparatively slow speed of the ship.

All-steel propellers have recently been manufactured. They are made from sheet metal pressed to a shape similar to that of a wood propeller. The steel sections are assembled by welding. The resulting propeller is both weatherproof and durable.

Propellers are comparatively costly things and are easily damaged. A few remarks on their care will therefore, perhaps, not be out of place. When not in use the blades should have covers put on them to protect them from moisture. An engine should never be run up on a dusty or gritty patch of ground. The propeller draws up the grit and even small stones, the surface becoming abraded or bruised as a result. When it is necessary to take a machine off in long grass the tail should not be lifted higher than need be before leaving the ground, otherwise the tips will be damaged by contact with the grass. Rain should never be flown through when it can be avoided. It causes serious abrasion of the leading edge of the propeller. A long flight through rain, in fact, usually renders a propeller useless for further service.

Propellers should be examined periodically for damage. The points to be given special attention are abrasion of the surface, failure of the glued joints, chips or bruises caused by small stones, etc. Any failure of the glued joints can usually be detected by bending the blades. Creaking will indicate trouble of this nature. If the surface generally has become seriously worn the propeller should be returned to the makers to be done up. If the surface is fabric covered, the air, having once damaged the covering, will soon make its way between it and the wood. Moisture is then driven in and the glue affected. Repair work of this nature is certain to have considerable effect on the balance, and it must therefore be done where facilities exist for testing. Small chips or bruises may be repaired by cutting away the small damaged portion and neatly dovetailing and gluing in a new piece of similar wood. This work must be done very carefully so as not to disturb the balance.

Propellers when not in use should be kept in a dry place. They should be supported by the boss, so that there is no weight on the blades such as would tend in time to warp them and alter their pitch. The whole propeller should from time to time be turned so that the blades become subject to exactly the same influences, and any slight warp which may take place may be evenly distributed.

CHAPTER XII

THE AERO-ENGINE

THE aeroplane was rendered possible by the advent of the petrol motor, which provided a power unit of light weight capable of developing considerable horse-power despite its lightness. Modern aero-engines are built in powers ranging from 35 to 600, and weigh complete from about $1\frac{3}{4}$ to 3 lbs. per brake horse-power.

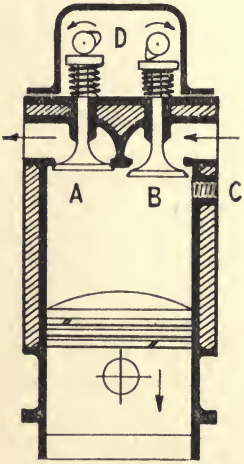


Fig. 71.

Practically all the engines in use work on the four-stroke or Otto cycle. This may be very briefly described. Fig. 71 shows a cylinder designed to work on this cycle. A is the inlet valve which admits the explosive gas generated in the carburettor, and B the exhaust valve through which the products of combustion are discharged. C is the sparking plug at which the magneto produces a spark to ignite the mixture.

The cycle occupies four strokes of the piston or two revolutions of the crankshaft. Suppose the piston to be at the top of its stroke. As it travels downwards the inlet valve A, which is normally held closed by the spring, is opened by the action of the cam D on the "half-time" shaft. The "half-time" shaft is so called because it is rotated at half the speed of the crankshaft, this being necessary as the complete cycle occupies two revolutions of the latter. As the piston travels downwards it sucks into the cylinder a supply of gas. When the bottom of this stroke, called the "suction stroke," is reached the valve closes. The piston now travels upwards, compressing this supply of gas to about one-fifth of its original volume; this stroke is called the "compression stroke." When the piston reaches the top of its travel a spark is produced by the magneto, which is suitably geared from the engine, at the sparking plug C. The mixture explodes, and the pressure rises, forcing the piston down; this is called the "working stroke." When the piston nears the bottom of this working stroke another cam on the half-time shaft opens the exhaust valve. As the piston travels upwards the burnt gases are discharged, the exhaust valve closing at the top of the stroke; this is called the "exhaust stroke." The cycle is then repeated. Actually owing to the inertia of the gases, the time taken to ignite them, and other causes, the timing of the valves and ignition is as shown in Fig. 72. The time lag which takes place in these operations is readily understood when it is considered that the whole of the cycle described takes place in about $\frac{1}{15}$ of a second.

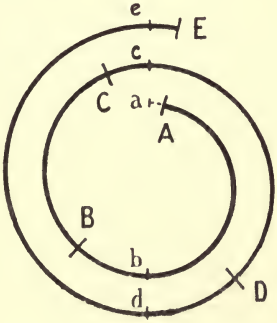


FIG. 72.

At A. Inlet valve opens; ab is suction stroke.
At B. Inlet valve closes; bc is compression stroke.
At C. Spark occurs; cd is working stroke.
At D. Exhaust valve opens; de is exhaust stroke.
At E. Exhaust valve closes.

Consider now the torque on the crankshaft. Only during the working stroke, or for half a revolution in every two, is work being supplied to it. During the remaining one and a half revolution it is itself supplying a certain amount of work to the piston. In order to obtain a more or less steady torque on the crankshaft it is necessary to use a considerable number of cylinders acting either on cranks at different angles or set at different angles to the crankshaft. There are a variety of ways in which these cylinders may be arranged, and engines are commonly categorised according to the cylinder arrangement adopted. There are two main controlling factors which decide the crank angles, numbers, and arrangement of cylinders in the different types. First, balance—that is, the mechanical balancing of the various reciprocating and rotating masses amongst themselves. Secondly, evenness of torque, which calls for an even series of explosions or working strokes. The latter factor controls the firing order of the cylinders. Unfortunately space does not permit of any very detailed discussion of these matters.

The main types of engine are as follows :

The first is the six-cylinder vertical. Here the crankshaft has six cranks disposed at 120°. Examples of this type of construction are : the Beardmore, the Siddeley-Deasy Puma (see Plate V), the Mercédès, the Benz, and most other German engines.

The second type is the " V " type. This is a development of the vertical, resulting from the call for more power. Many difficulties arise when the power per cylinder is increased abnormally. The weight of the large parts necessitated, moving at high speed, introduces excessive inertia loads on the bearings ; the piston speed also becomes excessive, which leads to lubrication difficulties. An obvious solution is to adopt more than one bank of cylinders, acting on the same crankshaft. In the case of the V engine the cylinders are arranged as indicated in Plate II. The inlet manifolds are usually arranged between the cylinders and the exhaust manifolds externally. Examples of this type are : the Rolls Royce, the Liberty, and the Renault.

The " Fan " type of engine is simply a further development, yet a third bank of cylinders being inserted vertically between the two banks of the V type. The Fan type of engine is commonly made with three banks of four cylinders, although engines with four banks have recently been constructed. The engine is consequently shorter. The advantage of this is that the crank-case structure is stiffer and lighter. Further the crankshaft, being made shorter, is less liable to torsional strain. It will be understood that in the case of a six-throw crankshaft the torsional deflection may be quite appreciable when the explosion force of an end cylinder is being transmitted to the propeller. Examples of the Fan type are : the Napier Lion (see Plate XIV) and the Sunbeam.

The " Radial " type of engine which was much used in the early days of aviation and which, after a period of comparative disuse, is again coming to the fore, has the cylinders equally disposed round the circumference of a circular crank-case. Plate IX indicates the arrangement. The number of cylinders is always odd, this being rendered necessary by considerations of firing order. There may be one or more circles of cylinders, all the cylinders of a circle working on the same crank. The radial engine is particularly light in relation to the horse-power developed. The form of construction, as compared with the vertical or V types, requires a very short crankshaft and crank-case, the result being a considerable saving in weight. Examples of this type of construction are: the Anzani, Canton Uné, ABC, and Cosmos.

A type of engine particularly suitable where only a small power is required is the horizontal twin. This has two cylinders acting on separate cranks at 180°. It is particularly well balanced and should prove very useful in the lighter single-seated type of aeroplane. As at present constructed it has many features in common with the radial types. Examples are: the ABC Gnat, and the Siddeley-Deasy.

The last type of engine is the "Rotary." The conception of how the rotary engine works sometimes presents a little difficulty, though it is not really difficult to understand. In the case of a radial engine the crank-case is mounted in the machine and the propeller is carried by the crankshaft. In the case of the rotary engine the crankshaft is fixed, with the result that the engine has to go round. To it is attached the propeller. The rotary is very similar in appearance to the radial. All the existing types are air cooled, the motion of the cylinders through the air being sufficient to maintain them at a suitable working temperature. The rotary engine has the same advantage as the radial as far as saving in weight is concerned. It has also the advantage of fly-wheel effect. As the horse-power and weight of these engines have increased, however, this fly-wheel effect has come to be a disadvantage on account of the gyroscopic action which it exerts. The gyroscopic effect causes the machine to tend to dive when turning in one direction, or to climb when turning in the opposite one. On account of its comparative lightness the rotary engine has been largely adopted for small high-speed machines. Here the gyroscopic action is particularly felt, and it is this factor which is largely responsible for the present tendency to readopt the radial type. The rotary engine, on account of the fact that the mixture is sucked through the crank-case, and also owing to the difficulty of oiling the overhead valve gear, presents a certain problem as regards lubrication. Castor oil, which does not mix so readily as mineral oil with petrol, has to be used. The rate of consumption is very high. Examples of the type are: the Gnome, the Le Rhone, the Clerget, and the Bentley.

The two-stroke cycle engine, which is exceedingly simple, being without valves, will probably be developed in the future for aero purposes. Up to the present time its development in the larger sizes has not got beyond the experimental stage.

The principal desiderata of an aero-engine are low weight per horse-power, reliability and smoothness of running, low fuel and oil consumption, compactness, simplicity of construction, ease of overhaul, reasonable initial cost, and freedom from liability to fire.

The question of weight does not end with the engine itself. All the accessories must be included. In the case of the water-cooled engine the weight of the radiator and cooling water must be added. Separate special accessories, such as petrol pressure pumps, controls, etc., must be considered. Another important factor in the weight problem is fuel economy. An engine designed to be of minimum weight per horse-power is usually less economical in oil and petrol. For flights of short duration the combined weight of engine and fuel would be less with the light engine. For prolonged flights, however, a heavier engine and a more economical one would be ultimately the lighter combination.

Reliability is a subject on which a very great deal might be said. Given skilful piloting, probably nine-tenths of the accidents which occur are attributable to engine trouble. The commercial value of reliability is, therefore, obvious. If difficult country is to be traversed or bad weather to be encountered, nothing but the best is good enough. The development of aero-engines during the past three or four years in this respect has been remarkable. It is the result of the immense amount of experiment and experience provided by the war.

The strength of any chain is measured by that of its weakest link. After the most skilful designer has done his utmost to bring the various parts to a standard of safety, tests only, either on the bench or in the air, can be relied upon to effect further improvements. Questions of wear, for instance, are chiefly matters of test. In any new engine certain parts will be found to wear out unduly in use. The designer must take this matter in hand, substituting more durable materials for those originally used in these parts, improving their lubrication, or increasing their dimensions as may be advisable. Overloading is certain to occur sooner or later, and when an engine is sufficiently overloaded something inevitably breaks. This reveals the engine's weakest spot, and when the latter has been strengthened the next weakest fails. Thus by a process of constant experiment with its resulting eliminations, a chain is obtained in which all links are equally strong. As a matter of fact the engine having no weak point is in the nature of an ideal. The practical engine is purposely designed with certain weaker points, the object being to localise any damage which may occur owing to an excessive overload to some particular replaceable member; this acts in a way as a safety valve for the rest of the structure. Although a very great deal depends on the original design, it is only by subsequent lavish experiment that the maximum reliability is reached.

A few of the most important factors which contribute to reliability of running may be discussed.

Perhaps the commonest cause of failure is faulty lubrication. Any failing in this direction is felt immediately by an engine working under the severe conditions of loading which obtain in aero-practice. Failures are commonly caused by dirty oil, which causes choking of the smaller oilways and thus cuts off the parts fed by them from any oil supply. Oil should always be filtered and the oiling system should be flushed periodically. Indirectly the oiling is affected by excessive wear, inasmuch as the oil escapes so readily from the worn bearings that others, less worn, do not get an adequate supply.

Ignition systems cause a certain amount of trouble. On most larger engines, however, the ignition is usually duplicated and complete failure therefore seldom occurs. The general problem of ignition is dealt with in the chapter on that subject.

Dirt, moisture, and oil are the most frequent causes of trouble. Ignition troubles due to oiling are most prevalent in the case of rotary engines because of the large amount of oil consumed. If the plugs are cleaned periodically and tested, and the distributors and contact breakers are kept clean, little trouble is experienced. The effects of damp are usually only met with after an engine has been laid up for some time.

A third common form of trouble is carburation, which, again, is nearly always caused by dirt, or water. This, however, should seldom be met with if all petrol is passed through chamois leather before being put into the tanks.

Mechanical breakages, unless they be the result of oiling troubles, usually occur amongst the minor parts of the engine, such as valves and their details. They may be the result of faulty material or design, and can only be guarded against by constant inspection.

Reliability and simplicity are very nearly related. Every additional part of an engine provides a possible source of breakdown. Furthermore, the more complicated an engine is, the more difficult it is to clean and to examine. It is during the routine cleaning and examination that the distortion of parts, the wear, the loose nuts, and other common causes of failure are discovered. Some engines are so complicated that the exposure of parts which should be subject to frequent examination is a matter of considerable difficulty. Consequently they rarely receive the attention they should. The moving parts, such as valve operating gear, etc., should, where possible, be enclosed in oil-tight casings, allowing for their adequate lubrication and at the same time giving the engine a clean external appearance. They should, however, be readily accessible.

Accessibility is always a very difficult problem to the designer as he has so many things to fit into the space available. The following parts in the order named should always be easy to get at: sparking plugs, carburettor jets and filters, magneto contact breakers and distributors, oil filters, valve tappet adjustment, switch wiring, and control levers.

In the foregoing discussion the question of cleanliness has perhaps been somewhat laboured, but it is of extreme importance. There is, however, another matter which exerts almost as great an influence on reliability, and that is the pilot's attitude towards his engine. The pilot who feels for his engine, runs it up carefully, never overloads it unnecessarily, and, when it is not working its best, nurses it, is very seldom faced with serious engine trouble.

Smooth running is essential. All vibration and roughness mean excessive wear somewhere and consequently affect reliability adversely.

Compactness of design is a *sine qua non.* The space available for the engine is very limited. Low cross sectional area in the direction of flight is important, especially in the case of machines where the engine is not built into the fuselage.

Many of the early types of engine were prone to catch fire. The chief cause of fire in engines is back-firing in the carburettor. A broken valve, or too weak a mixture (which commonly results from water or dirt in the jets), may cause a back-fire. This may ignite the petrol in the mixture chamber. For this reason the carburettor intakes should be carried clear of anything inflammable. Petrol pipes liable to breakage should also be kept as clear of the carburettor intakes or exhaust outlets as is possible. Carburettor fires are usually quickly extinguished by being sucked through the engine. In event of an engine fire the last thing the pilot should do is switch off. The correct procedure is to turn off the petrol and open the throttle, thus sucking the carburettors dry and also preventing the fire from being supplied with petrol if one of the pipes has cracked or burned.

Oil and petrol economy, apart from weight considerations, are of considerable importance in the commercial aeroplane. These items will constitute a large proportion of the running expenses. The vertical engine with large cylinders is at present the most economical. Fuel economy depends on the compression ratio, a high compression being most economical. With the present system of induction the power of the engine falls off very greatly when the machine is flying at considerable altitude. Systems of forced induction promise considerable improvement both in power and economy at varying heights.

The cost of aeroplane engines is a matter of quantity production. It need not be high. The war has provided sufficient data for standardisation. The aeroplane designer need have little difficulty in selecting a suitable engine. Whatever machine it is for, proved reliability is the first essential. This taken for granted, a commercial balance, taking into consideration weight per horse-power, economy of running, and overhaul, and prime cost, will have to be struck.

Conservatism will always have to be reckoned with. Before any new engine is readily accepted by pilots very complete proof of its reliability will have to be forthcoming. The comfort of having an engine with a reputation for never failing is inestimable.

CHAPTER XIII

ENGINE DETAILS

THE space available in this book does not allow of any comprehensive discussion of the more detailed construction of aero-engines. The subject cannot, however, be passed over without some brief description of the more salient points concerning their design. What follows must necessarily take the form of a series of somewhat disjointed remarks. These will offer no information that is not the common knowledge of every engine expert, and are designed solely to help those with little knowledge and experience to acquire a useful smattering of the essential features of engine construction and to point the way to a more detailed study of these matters.

The designer of the motor-car engine is chiefly concerned with the production of a device which shall be "foolproof" and shall require as little attention as possible. He is not hampered to any appreciable extent by considerations of weight. The designer of the aero-engine on the other hand has to exert every effort to obtain the maximum horse-power for the minimum weight. The result is a more delicate mechanism requiring more skilful handling and also continuous skilled attention to keep it tuned up to its highest output. The parts of an aero-engine are so designed as to resist the loads to which they are subject when working, and it is seldom practicable to give them a sufficient margin of strength to cover possible abuses by unskilled workmen. Examples illustrating this point are the tightening up of the cylinder holding down bolts or the fitting of a gudgeon pin. In the one case uneven tightening would distort the cylinder; in the other the driving in of a pin too tightly would distort the piston. Either form of bad workmanship would probably ultimately result in a seizure.

The lubrication of practically all stationary engines is on the "dry sump" system. That is to say, the oil drains to a sump beneath the crankshaft, which sump is continually pumped dry by a special "scavenging" pump. To ensure the complete clearing of the sump this pump is usually made of greater capacity than the one which feeds the bearings, etc. The dry sump system is necessary in the case of an aero-engine, as the working of the engine has to be as independent of position as possible. The presence of considerable quantities of oil in the sump of an engine called upon to fly upside down for a few moments might lead to serious results.

The most usual type of oil pump used is the gear pump. The principle on which this works is indicated in Fig. 73. The pump is usually driven from the half-time gear by means of a suitable extension shaft. As the gears rotate the oil, entering as indicated by the arrow, is carried round between the gear teeth and the casing and is discharged as shown. It will be noted that the satisfactory working of this type of pump depends entirely on the good fit between the gears and the casing both at the tips of the teeth and on the side faces of the wheels. A pump of this nature is quite satisfactory for a viscous fluid like oil, but on account of leakage it would not deal satisfactorily with a lighter liquid. A gear pump cannot pump air. If it runs dry it must be "primed" or flooded with oil before it will begin pumping. For this reason the oil pump is always placed at the lowest possible level, thus ensuring that it shall always be full of oil. Two pumps are usually provided—the scavenging pump, which draws the oil away from the sump (whence it drains after having done its work) and delivers it back to the supply tank, and the pressure pump, which draws cool oil from the tank and delivers it under pressure to the bearings. It will be noted that in this way the oil is used over and over again, only such oil as works its way up into the combustion space of the cylinders being actually consumed. To increase its capacity the scavenging pump is usually made with somewhat wider teeth than the pressure pump.

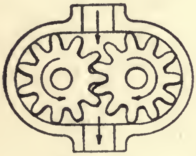
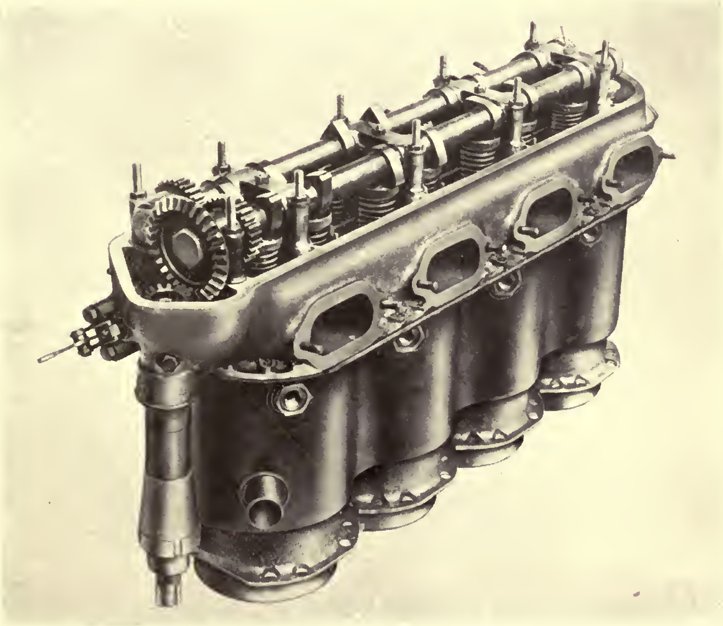


FIG. 73.

In order to regulate the oil consumption it is necessary to

BRITISH THOMSON HOUSTON—TYPE A V 12 MAGNETO



CYLINDER BLOCK SHOWING VALVE GEARING—NAPIER LION ENGINE

control the pressure at which it is supplied to the bearings. Were the pressure not regulated, both the pressure and the quantity of oil delivered would depend entirely on the temperature, the viscosity of the oil, and the clearances or wear allowing leakage in the pump. A relief valve is provided on the pressure side of the pump, and the pump is made of such capacity that it can, under all conditions, supply an excess of oil. Fig. 74 shows a typical relief valve. By means of a cap A, which is locked by the nut B, the pressure of the spring C on the valve D is so regulated that the valve lifts at the desired pressure. Any excess supply of oil is then bi-passed back to the supply tank through the branch E.

The manner in which the various parts are generally lubricated in a stationary engine is as follows: the oil is led to the main crankshaft bearings in which suitable oil-ways are cut. The crankshaft itself is hollow and is drilled with radial holes at the main bearings. The oil therefore enters it at these points. At the crank necks other oil holes are drilled and the oil within the shaft forces its way out of these, thus lubricating the connecting rod big ends. The oil is thrown out from the ends of the big-end bearings and forms a mist in crank-case, which oils the cylinder walls and gudgeon pins. In some engines small-bore steel tubes are led up the webs of the connecting rods, conveying oil to the gudgeon pin bearings in exactly the same way that the hollow crankshaft delivers it to the big ends. The valve gear is usually oiled from the main supply either through a constricted opening which limits the amount delivered or through a special relief valve at a lower pressure. The cam shaft is made hollow and the oil is led into it at one end. Holes are drilled at various points from which the oil escapes and lubricates the cams and other gear. Other special leads deliver oil to the gearing, to the thrust bearings, and to other parts requiring lubrication.

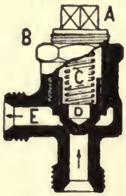


FIG. 74.

Rotary engines frequently employ a reciprocating type of pump. Here the main oil lead must necessarily enter the engine through the hollow crankshaft, which serves also as the carburettor intake. This pipe is then usually divided, one part of the supply going to the main big-end bearing and the remainder to the thrust bearing, valve gearing, etc. All the oil subsequently reaches the crank-case, where, in the form of a mist, it lubricates the cylinder walls and other parts. This mist is sucked into the cylinders with the gas, which also passes through the crank-case, and is there either burnt or discharged through the exhaust valves. The use of castor oil is essential in rotary machines, since it is not readily miscible with petrol.

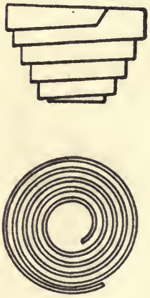


Fig. 75.

All aero-engines have valves of the mushroom type, as shown in Fig. 71. These are practically always situated in the head of the cylinder, an arrangement allowing of a high compression ratio and of the least constricted form of entry and exit for the gases. There are two, three, or four valves per cylinder, so arranged as to provide the largest and freest area of ingress and egress for the gases. The valves work under very trying conditions, particularly the exhaust valves, which may be practically red hot. Very special steels are necessary to stand up to this work, nickel, chromium, or tungsten alloys being used. Chromium is somewhat less liable to burn than nickel. Tungsten alloy steel retains its mechanical properties in a remarkable manner at very high temperatures; valves of this alloy have, however, a tendency to flake. Valves are ground on to their seats in order to secure a gas-tight joint. The seats are either steel or phosphor-bronze, the latter alloy being used where they are fitted into an aluminium cylinder head. The reason for this is that both have a similar coefficient of expansion, and the repeated heating and cooling of the head does not cause the seat to work loose. The valve springs which hold them on their seats are usually either spiral or volute. Where spiral springs are employed two springs of different outside diameter arranged concentrically are commonly used in order to obtain the maximum strength for a given bulk of spring. Volute springs are spirally wound of flat-section wire, as shown in Fig. 75. They have the advantage of a long range of compression relative to the length of the spring. The stem of the valve must be a fairly free fit in its guide as it may expand considerably when heated. If it does begin to bind, it tends to distort in such a manner as to aggravate the trouble. The tension of the valve springs in a rotary engine is usually very light, as centrifugal force when the engine is in motion tends to hold the valves on their seats.

The half-time shaft or cam shaft in stationary engines is usually arranged to run along the heads of the cylinders, thus bringing the cams close to the valves. Plate VII, which shows a block of cylinders with the valve gearing casing removed, is typical of modern design. In this case separate half-time cam shafts operate the inlet and exhaust valves, of which there are two each per cylinder. The section of these cylinders is not dissimilar to the section shown in Fig. 71. In some cases the cams act directly upon the stems of the valves; in others, rockers are provided and pivoted in such a manner that one end of the rocker is actuated by the cam, and the other end operates the valve Cam shafts arranged in this manner are usually driven by vertical shafts and bevel gears from the crankshaft. The cam shaft is usually enclosed in an oil-tight casing, oil being continuously supplied through the hollow shaft. In the case of rotary and radial engines the cam shaft is usually concentric with the crankshaft round which it rotates. It is then driven by epicyclic gearing, as indicated by Fig. 76, where A is the crankshaft, B the sleeve-shaped cam shaft, C a valve tappet, and D the epicyclic gearing consisting of planet pinions rotating on pins E, which are fixed to the crank-case of the engine.

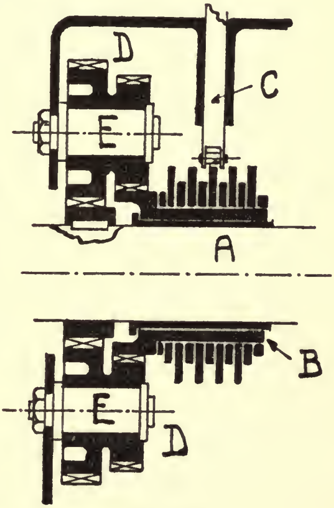


FIG. 76.

The magnetos in modern engines are usually driven by a special shaft and gearing from the crankshaft, the speed of rotation being arranged according to the number of sparks to be provided per revolution. The fine adjustment of their timing is commonly provided for by a vernier plate. The principle of this is illustrated in Fig. 77. A plate A having, say, 24 holes is keyed to the magneto shaft, and another having only 22 holes to the engine shaft. The moving of the two coupling bolts by one hole causes an adjustment of only about 3° on the magneto shaft in the timing.

The various bearings are made either of white metal or phosphor-bronze, or are of either the ball or roller type. The connecting rod big ends are practically always white metal, and the small ends phosphor-bronze. White metal provides a good bearing where sufficient space is available to make the latter of ample proportions. The metal is usually mounted in gun-metal shells, which are fitted to the rod. When worn these may be adjusted or renewed. Phosphor-bronze does not provide such a satisfactory bearing as white metal where the surface speed of the bearing is great, but it can stand a higher load per square inch. It is therefore used for the connecting rod small-end bearings. Here the loading is greater, but the motion is oscillatory and slower. Roller bearings are sometimes used for the main crankshaft bearings, although white metal is more usual. The use of the roller bearings, which can support a very high load per inch width, allows of a shorter and stiffer crankshaft and leaves more space available for the big-end bearings. Ball bearings are frequently used for the less heavily loaded shafts, as, for example, the magneto, water pump, etc., drives. Provided they are not overloaded, they wear almost indefinitely and require little lubrication. They also run very freely. Ball bearings are very largely used in rotary engines. On account of the short length of the engine it is very difficult to make white metal bearings of sufficient width. As ball bearings are much more easily lubricated than plain, the problem of lubrication (complicated by the presence of petrol in the crank-case) is also much simplified. Ball thrust washers are almost universally employed to take the thrust or pull of the propeller.

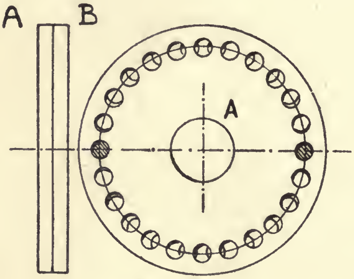


FIG. 77.

They run very freely and will support heavy loads. Owing to the small clearances allowed, ball and roller bearings are very susceptible to the effects of dirt or grit.

Few parts of an aeroplane exhibit so great a variety of form of construction as the cylinders. The barrel is practically always steel. In the case of rotaries it is commonly solid, having cooling fins turned from the solid in the course of manufacture. Composite cylinders of steel and aluminium have, however, been made, the aluminium providing the radiating surface and the steel the internal rubbing surface. In the case of stationary engines the whole head and water jackets are in some cases an aluminium casting into which the barrels are screwed. This arrangement might be expected to offer great difficulties owing to the large difference in the coefficients of expansion of the two metals. These difficulties have, however, been overcome, and the system is now largely adopted. In some cases the cylinder and jackets are made entirely of steel, the cylinders being machined from a forging and the jackets pressed from steel sheet. The whole is assembled by welding.

Aluminium alloy pistons are now almost universal. These, owing to their lightness, greatly reduce the inertia loads on the bearings and admit of higher speeds. Owing to their high coefficient of expansion they must be given a large clearance in the cylinders when cold. For this reason they must be carefully run up. They are entirely satisfactory in service.

The rapid development of design in aero-engines is chiefly due to the war, which has provided opportunity for test and experiment on a large scale. Many of the innovations introduced by the designers of aero-engines are now being applied to other types of petrol engines. Thus in a way they are repaying the debt which the aeroplane owes to the internal combustion engine.

CHAPTER XIV

THE CARBURETTOR

THE carburettor is one of the most important elements of the power plant. It is, as it were, the lungs of the engine, and as such is fundamentally essential to its efficiency. It is liable to a number of derangements, by no means the least common of which result from excessive attention. It cannot be too strongly impressed upon the reader that the carburettor is an instrument to be understood, and not a mechanism to be constantly adjusted. It should be set correctly once and for all by an expert, after which none but the slightest adjustment should ever be needed. The conditions affecting the working of the aeroplane carburettor are more complex than those normally met with in the ordinary motor-car. This arises particularly from the fact that an aeroplane engine has to work in an atmosphere of varying pressure, the pressure at 20,000 feet, for example, being approximately only half that at sea-level. The aeroplane has, however, this advantage over the motor-car that the engine is not normally expected to run at such varying speeds.

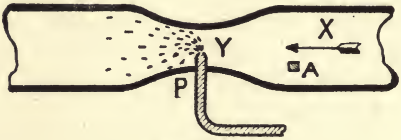


FIG. 78.

In order thoroughly to understand the working of the ordinary jet type of carburettor it is necessary to consider air flow from a point of view which up to the present has not been touched upon. Suppose air to be passing through a smooth pipe with a certain velocity and at a certain pressure. Consider any small element of the air such as A (Fig. 78). This element of the air has a certain amount of energy stored up in it. This energy or capacity for doing work is of two kinds—pressure and kinetic. The pressure energy is simply the amount of work (either positive or negative) that it could do during expansion to the pressure of the atmosphere. Its kinetic energy, which is analogous to the energy stored in a stone flying through the air, is simply dependent on its mass and the speed at which it is travelling. If the tube is assumed to be frictionless no work is done on the air in the course of its passage, and any element will therefore emerge from any section with exactly the same energy as it had stored in it when it entered. Now suppose that the element enters a narrow portion of the tube, what happens? In the first place, it must travel faster. This increases its kinetic energy. As no work is done on it, it cannot increase its total energy. In order, then, to increase its kinetic energy it must sacrifice some of its pressure energy. Consequently, referring to Fig. 78, the pressure at the point Y is less than that at X. This is the fundamental principle upon which the jet carburettor (the type now practically universal) operates.

A pipe XY is provided, communicating at X with the atmosphere and constricted at Y. Through this pipe the cylinders suck in their supply of air. At the constriction there is a nozzle or jet P. Petrol at atmospheric pressure is supplied to this jet and maintained level with its orifice. Owing to the constriction the pressure in the region of the jet falls very much below that of the atmosphere, and the petrol, being under atmospheric pressure, is forced out in the form of a spray. Petrol is a light, easily vaporised fluid, and a gaseous mixture of petrol vapour and air is formed. Liquids always vaporise more readily at low pressures. The reduced pressure therefore further aids the complete vaporisation. The effect of temperature on the vaporisation of a liquid may also be noted in this connection. A liquid vaporises more readily as the temperature rises. For this reason aero-carburettors are commonly fitted with a hot-water jacket. By suitable arrangement of the size of the jet P the strength of the resulting petrol-vapour and air mixture can be adjusted so as to bring it within the explosive range. The constricted portion of the passage is termed the "Choke."

There is another part essential to the complete carburettor, namely, a device for maintaining the petrol at constant level in the jet, and also under atmospheric pressure. This is known as the

Float Chamber, and is commonly of the form shown diagrammatically in Fig. 79. The chamber A contains a needle valve N working on a seat V. The petrol is supplied via the pipe P. The petrol is at atmospheric pressure by reason of the orifice O in the chamber cover. The level is controlled in the following manner. Surrounding the needle is an annular float F, which is usually made of very thin brass sheet. On the top of this float rest the weights of two small levers L, which are attached to the chamber cover by their pivots X. The inner ends of these levers engage a collar C on the needle valve. As the petrol enters it raises the float together with the weight of the levers. When it rises to a certain point the inner ends of the levers depress the needle valve on to its seat, thus cutting off further supply. There is a passage G communicating with the jet, the top of which is just slightly above the level at which the mechanism maintains the petrol.

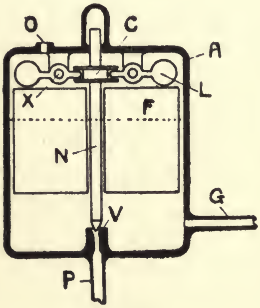


Fig. 79.

The carburettor complete in its simplest form is then as shown in Fig. 80. A throttle valve V is added in order to regulate the amount of gas passing to the engine. A carburettor of this simple type is used on motor-cycles and other small engines. It has the advantage of simplicity, but has also several inherent disadvantages. In the first place, the mixture is not constant, that is to say, the ratio of petrol to air varies with the engine speed. When discussing the principles of gas flow it was noted that the energy of the moving gas depended on its pressure and velocity These two do not vary according to the same law, the result being that as the speed increases the proportion of petrol to the air sucked in becomes greater. In this simplest form of carburettor an extra air valve is usually embodied. This admits air at a point nearer to the engine than the jet. As the engine speed increases this valve needs to be opened gradually in such a manner that the mixture is suitably diluted.

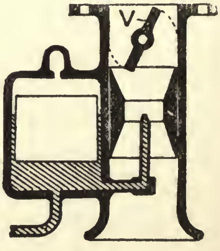


Fig. 80.

This arrangement has several disadvantages, foremost amongst which is the necessity for the continual adjusting of the carburettor as the engine speed varies. The accuracy of this adjustment depends entirely on the skill of the adjuster. A bad mixture not only decreases the power output, but may also cause mechanical damage to the engine.

Many schemes have been devised with a view to compensating this mixture change automatically. A very simple and effective means is that adopted in the Zenith Carburettor. It has already been explained that the fault lies in the fact that the increase in the rate of petrol supply through the jet is more rapid than the increase in the amount of air sucked through the carburettor. This may be compensated by reducing the size of the main jet, and adding a second jet, the discharge of which is controlled in such a manner that, as the gas velocity increases, the amount of petrol drawn in does not vary. The arrangement adopted is shown in Fig. 81. The compensating jet J, which is of comparatively large area, is connected to the float chamber by a pipe P, in which is situated a secondary jet O controlling the petrol flow. It will be noted that the effect of the air intake A, which is situated between O and the jet, is to prevent the suction at the choke acting on the orifice O. The result is that the quantity of petrol supplied through the jet J is unaffected by the engine speed. The sum of the discharges of the two jets does not therefore increase with engine speed as rapidly as would the discharge of one single larger jet arranged as in Fig. 80, and of such a size as to give the same discharge as the two at low speed. The air sucked in through A, the amount of which increases with engine speed, has also an automatic diluting effect. It will be noted that the two jets are arranged concentrically.

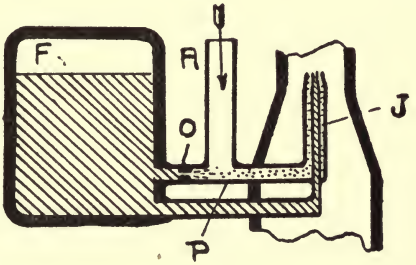


FIG. 81.

The Claudel-Hobson carburettor, which is much used on aero-engines, has a somewhat different jet system designed to achieve the same result. It is shown enlarged in Fig. 82 It consists of three concentric tubes, A, B, and C, as indicated. The inner tube A is perforated with small holes F. The second one B stands rather higher than the normal petrol level, and the space between the inner and the outer tubes communicates with the atmosphere via the ports D. Consider what happens as the engine speed increases. The resulting increase of gas velocity decreases the pressure in the choke, and the suction causes the column of petrol in the perforated tube A to rise. As the main jet J (situated at the base of A) limits the rate of flow, the rise takes place partly at the expense of the petrol between the tubes A and B. The level in B falls, uncovering some of the holes in the tube A, and allowing air to be drawn in through the outer tube C and the ports D. This air dilutes the mixture supplied to the engine. It is evident that as the gas velocity (and consequently the suction) increases, the more holes will be exposed and the larger will be the quantity of this diluting air sucked in. By suitably grading the size and position of the holes in the tube A a correct mixture can be obtained at all speeds. It will be noted that this air serves a further purpose. It is sucked through the petrol. Thus at the holes E, where the petrol joins the main air supply passing through the choke, it is delivered in the form of an emulsion of petrol and air, which considerably aids its gasification. The small central tube shown is the pilot jet, and is referred to later.

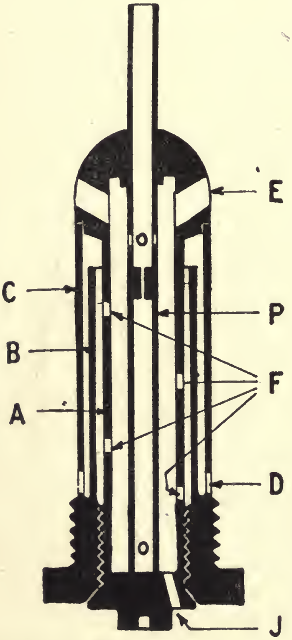


Fig. 82.

There is still another grave disadvantage to which the carburettor as so far developed is subject, and which it is necessary to compensate in all carburettors designed for use on large engines. Before the engine will start the cylinders must receive a supply of explosive gas. This must be sucked in through the carburettor. This sucking in has commonly to be done by hand, and, owing to the largeness of the engine, this can only be done very slowly. At the speed at which the engine can be turned by hand the suction in the choke, and consequently the amount of petrol drawn in, are inappreciable. The same argument applies when the engine is running slowly or "ticking over." With a carburettor large enough to supply gas for full power the choke is necessarily so large as to render slow running and starting practically impossible.

A simple way to deal with the situation is to provide an additional small carburettor, with a very small choke and a correspondingly small jet, to be used only for starting and slow running. This is in effect what is actually done. The small carburettor is, however, built as part of the larger one. This small jet is called a "pilot" jet. In considering the action of the pilot jet it is very necessary also to consider the position and effect of the throttle valve, which is built integral with the carburettor and is situated between the choke chamber and the engine. When the engine is running very slowly the throttle is almost closed. There may therefore be considerable suction on the engine side of the throttle, although there is practically none at the main choke. This fact is made use of in arranging the pilot jet. The two types of carburettor already considered may be referred to again in this connection.

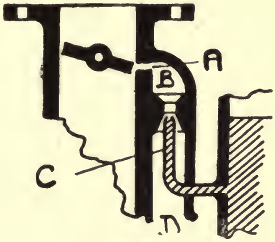


Fig. 83.

Consider first the Zenith. This has what is known as a "butterfly" throttle valve, which consists of a slightly oval plate rotated about an axis situated diametrically in the circular passage in which it works. In Fig. 83 it is shown very slightly open, i.e. the "ticking over" or "sucking in" position. It is evident that when the machine is running very slowly or even being sucked in by hand, the gas velocity at the constriction A will be considerable. At A there is therefore a very low pressure. Into the wall of the carburettor at the point A is introduced a small pipe B in which is situated the pilot jet C open to the atmosphere at D. This pipe in itself constitutes a small single jet carburettor. It will be noted that its operation is controlled by the main throttle valve in that when this is almost shut the pilot jet supplies practically all the petrol that gets to the engine, whereas as the throttle opens the effect of the pilot jet becomes insignificant.

The arrangement of the pilot jet in the Claudel-Hobson carburettor is as follows. The throttle valve is of what is called the rotary or barrel type and consists of a barrel which rotates in the outlet portion of the carburettor. The diameter of the barrel is greater than the diameter of the outlet, and through it is bored a hole of diameter equal to the outlet. The arrangement is illustrated in Fig. 84 (I) which shows a sectional view of the throttle half-way open. It is evident that rotation of the barrel opens and closes the passage. The arrangement of the pilot jet is as follows: Fig. 84 (II) shows the rotary throttle valve removed. It is shown as it appears from the choke side and in the shut position. The dotted line indicates the position of the opening in the carburettor body communicating with the choke. As the throttle lever L is rotated through 90°, the passage AA will register with this position and give a full bore opening. In the shut position there is, however, a slot S cut in the barrel through which the pilot jet projects. Fig. 84 (III) shows a sectional view of the arrangement, the throttle being in the shut position. The pilot jet J (built as part of the main jet system) consists of a tube which projects through

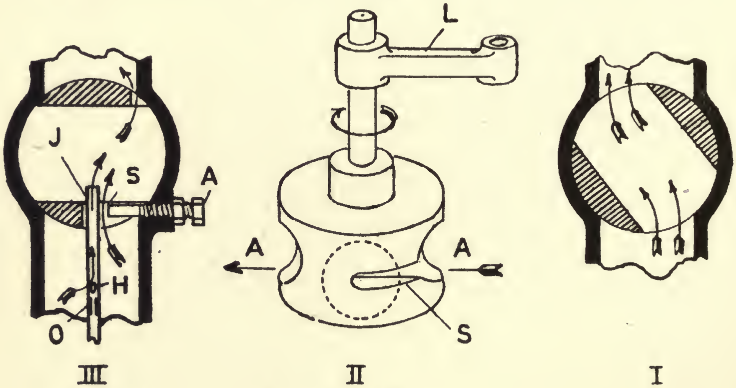


FIG. 84.

the slot. This tube has a small constriction at O which controls the petrol flow. The jet, projecting as it does through the body of the valve, is, in the shut or nearly shut position of the throttle, subject to considerable suction. The pilot jet will be noted at P in Fig. 82. Following the Claudel-Hobson practice, above the orifice or jet proper are situated small holes H. Through these air is sucked in, forming an emulsion with the petrol which issues from the jet. A further refinement is provided by the screw A which projects into the open portion of the slot S. The adjustment of this screw controls the quantity of air sucked through the slot itself, and thus provides a means of regulating the mixture supplied to the engine when the throttle is in the slow running position. It is evident here again that as the throttle opens the suction on the pilot jet is reduced, and that at considerable openings, the jet being a very small one, its effect on the mixture is practically negligible.

Rotary engines necessarily suck in their supply of gas through the hollow crankshaft. This delivers it to the crank-case, whence the induction pipes conduct it to the inlet valves. The system of carburation usually adopted is very simple. The carburettor is always constructed on the variable jet system, the petrol is supplied by a pump at a predetermined pressure. The petrol control lever in the pilot's cockpit operates a finely tapered needle valve which adjusts the jet orifice and thus the amount of petrol sucked in. A throttle valve which controls the amount of air drawn through the crankshaft is also fitted. In the case of one well-known engine the carburettor consists solely of a jet fitted within the crankpin, the flow of petrol to which is finely adjustable. In this particular case it will be noted that the engine must always run at what may be termed full throttle. In the case of rotary engines the control is almost entirely by the petrol fine adjustment lever. The throttle lever is seldom altered. The fine adjustment is so manipulated as to provide a suitable mixture. As the machine climbs it must be gradually closed, as it descends it must be opened. The control calls for rather more skill than is necessary in the case of stationary engines. The fine jet adjustment must be done with great nicety. Maladjustment of the mixture not only causes very bad running, but may also do damage to the engine or cause it to catch fire.

The principles of action of the various components of two typical and largely used aero-carburettors have been described.

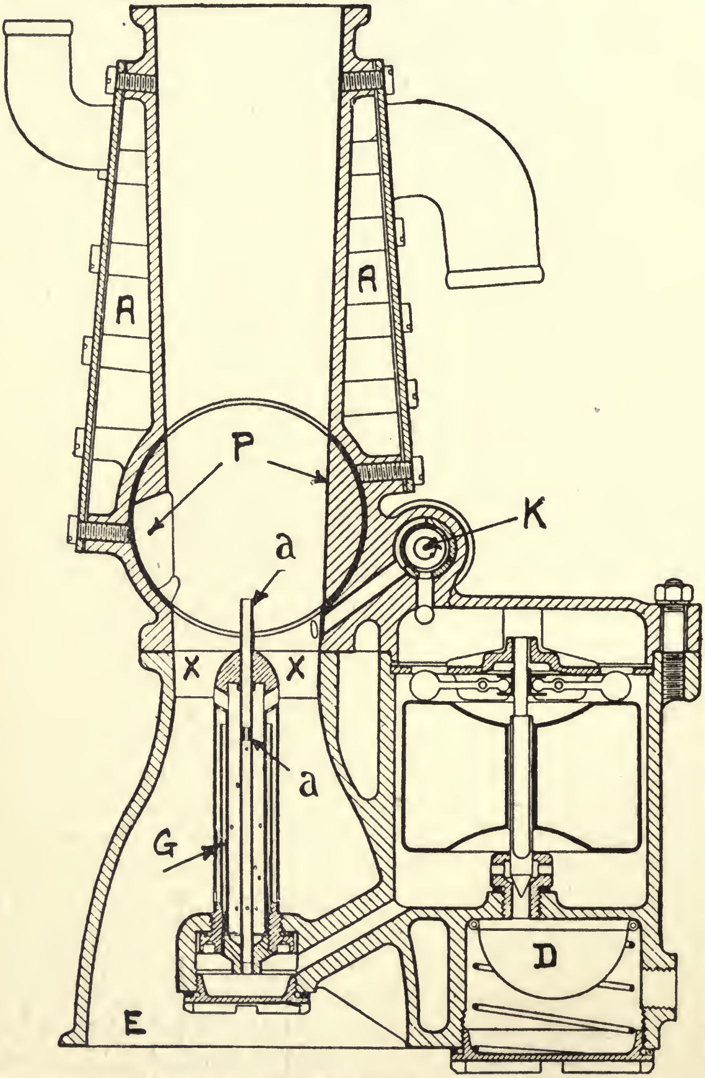


FIG. 85.—CARBURETTOR OF NAPIER LION. (Claudel-Hobson.)

Fig. 85 and Plate VIII show complete cross sections of these carburettors. These illustrations are indexed with the names of the various parts according to the appended list. The reader is advised to study these carefully, following for himself the arrangement and action of the different components. This will teach him more than any lengthy and necessarily redundant description of them.

A Hot Water Jacket.
a Pilot Jet.
b Air Inlet to Pilot Jet.
D Gauze Filter.
E Main Air Intake.
F Petrol and Air Passage to Compensating Jet.
G Main Jet.
I Compensating Jet Orifice.
K Altitude Control (see Chapter XXIX).
O Air Inlet to Compensating Jet and Pilot Jet.
P Throttle Valve.

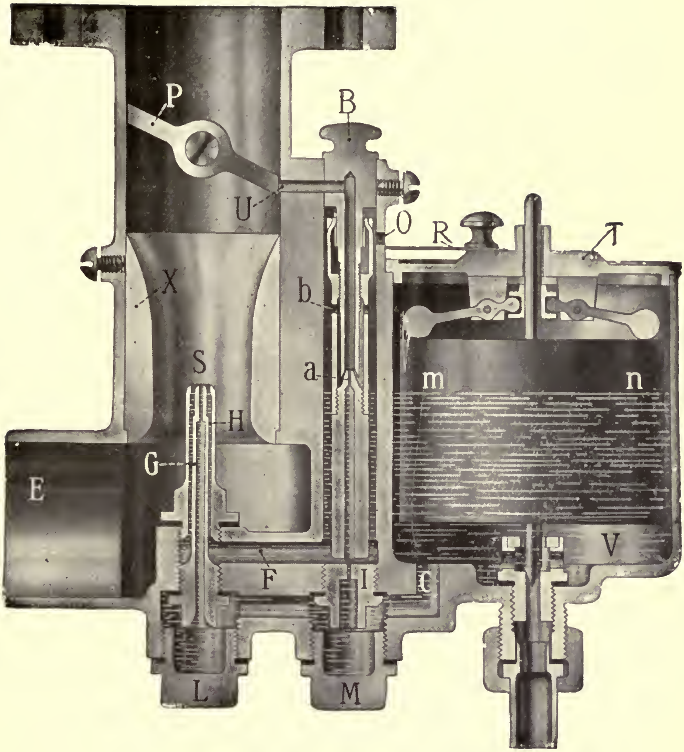
The question of carburettor troubles may here be very briefly dealt with. They arise chiefly from three causes: first, and by far the most important, dirt—dirty petrol causes three-quarters of the troubles met with in practice; secondly, wrong adjustments, usually the result of excessive "tinkering"; thirdly, mechanical breakdown or wear.

The usual troubles due to dirt are choked jets. The jets are of very small diameter and are very easily clogged. Dirt is also liable to choke the various passages in the body of the carburettor. Any grit getting on to the needle valve seating will lead to flooding and bad running as the valve is prevented from closing properly. If the fine-mesh gauze filters in the petrol system or carburettor get choked "starving" (i.e. insufficient supply) results. Together with dirt must be considered water. Water does not readily pass through such small orifices as petrol, and this again results in the choking of jets and filters.

As to the second possible cause of trouble, maladjustment, this should not often be experienced once a carburettor is properly set. The necessary adjustments consist of, first, obtaining the correct sizes for the jets and, secondly, the correct level for the petrol. The correct sizes for the jets can only be obtained by experiment, and once obtained this seldom if ever requires alteration. The petrol level is usually adjusted by altering the height of the collar on the needle valve which is actuated by the float chamber weights. It should very seldom require attention. The level is adjusted so that it is just below the jet orifices. A point sometimes overlooked in the case of large engines having various carburettors is the question of synchronisation. The several carburettors and their controls must be very carefully synchronised. Trouble due to bad synchronisation is often somewhat difficult to diagnose as the action of one carburettor masks that of the others.

Under the heading of wear and mechanical breakdown, the following are the most usual troubles. The float may become punctured. This allows petrol to get into it and the consequent increase in its weight resulting in a raised petrol level and flooding. Occasionally owing to careless reassembling after cleaning the jets or float chamber, covers, screwed plugs, etc., may be left loose. The needle valve seat is subject to wear, which may result in its not closing properly. The float balance weight pivots in some carburettors become worn. Worn or dirty throttle valves sometimes lead to the sticking of these parts.

Finally, in connection with carburettors a word may be said on the subject of induction air leaks. These are often a source of considerable trouble, particularly in starting and when running slowly. Any leaks between the carburettor and engine admit air, which dilutes the mixture. As when running slowly with the throttle almost closed the suction in these parts is particularly high and the amount of gas supplied by the carburettor comparatively small, it is just at this time that their effect is most felt. If the carburettor is to behave satisfactorily at all speeds too much attention cannot be paid to securing an induction system as airtight as possible



THE ZENITH CARBURETTOR

CHAPTER XV

IGNITION

WHEN an electric circuit is moved in such a manner as to cut the lines of force of a magnetic field, a current is generated in it. If two magnets are arranged as indicated in Fig. 86, and the wire AB, which is part of the circuit ABC, is moved through the magnetic field between their poles, the meter C will, during the movement, indicate that a current is flowing.

The units in which an electric current is measured are amperes (shortened into amps) and volts. Amps measure the amount and volts measure the pressure of electricity. The voltage necessary to force a certain number of amps round a circuit is proportional to the resistance of the circuit. Later experiments on this method of producing an electric current proved that the voltage produced in the electric circuit was proportional to the rate of cutting the magnetic lines of force. This is the fundamental law on which the design of all types of ignition apparatus is based. Suppose that the single part of the circuit AB were doubled, as indicated by the dotted line. Then in similar motion the electric circuit would cut twice as many lines of force and the voltage would be doubled. If the rate of movement of this new circuit were doubled, then the voltage induced would be multiplied by two again. So far as the electric circuit is concerned, then,

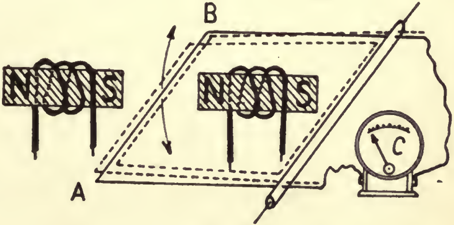


FIG. 86.

induced voltage can be increased indefinitely by increasing the number of coils.

Some attention must now be paid to the magnetic side of the question. A magnetic field may be produced by a permanent magnet or by means of an electro-magnet. An electro-magnet is an iron or steel bar excited by a current flowing in a coil which encircles it. The strength of a magnetic field is measured by the number of magnetic lines of force in a given cross-sectional area, and depends on the magnetic resistance of the circuit. Soft steel and iron have a small magnetic resistance; all other materials, including all non-ferrous metals, air, etc., have a very high magnetic resistance. Referring, then, to the system shown in Fig. 86, the magnets of which may be either permanent or electrically excited, there is a considerable resistance offered by the air gap between the pole pieces of the magnets. Suppose the poles are brought nearer together. This will reduce the magnetic resistance; there will therefore be a more intense magnetic field produced, and the voltage induced in the circuit ABC will be correspondingly increased for similar movements.

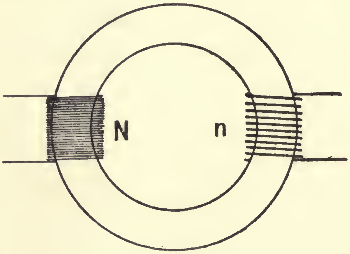


Fig. 87.

Suppose now that the magnets in Fig. 86 be electrically excited and that the currents flowing in their coils be switched off or even reversed, what happens? The magnetic field in which the electric circuit ABC is situated disappears or is reversed, as the case may be. In the course of this operation the electric circuit, without any actual movement on its own part, cuts, or rather is cut by, all the lines of force once in the first case or in the second case twice. Moreover, as this change, being due to the springing out of the lines of the magnetic field when the current is switched on, takes place very suddenly, the rate of cutting of the lines is high and the voltage induced also high.

Suppose a very low resistance magnetic circuit be provided. An iron ring offers the lowest possible (Fig. 87). Let a coil of a few turns be put round the iron ring to excite it, and let a current of comparatively low voltage be supplied to this coil. A magnetic flux, as it is termed, is produced in the ring; the strength of this flux is proportional to the number of coils and the voltage of the supply. Now, suppose that on the ring is also wound another coil with a very large number of turns. When the current is switched on in the small or low tension coil a magnetic flux suddenly cuts this other circuit. Owing to the suddenness of the rise of the magnetic flux and the large number of the coils, a very high voltage is produced. By increasing the number of coils indefinitely as high a voltage as may be desired can be induced, a limit only being imposed by the amount of insulation necessary on the wires to resist this voltage. This device is called an induction coil. The coil of few turns is called the low tension or primary winding, and the other the high tension or secondary winding.

The ordinary magneto designed to give two sparks per revolution is constructed as shown in Fig. 88. The permanent horseshoe-shaped magnet A, made of an alloy steel chosen for its property of retaining its magnetism, provides the magnetic flux. A soft steel armature D of "H" section, which is geared to the engine, rotates between the poles of the magnet. These are provided with pole shoes C designed to reduce the air gap to a minimum. Owing to the shape of the armature it can be seen that as it rotates the magnetic resistance offered varies, and thus the magnetic flux passing through it varies. Fig. 88 shows it in the position offering greatest magnetic resistance. The mounting of the magnet and bearings for the armature is the Plate B. This is made of brass or aluminium, which acts as a magnetic insulator. On the armature is wound a low tension or primary winding E, consisting of comparatively few turns. As the armature rotates the number of magnetic lines passing through it would (neglecting the effect of currents induced in the armature) vary somewhat, as shown by the curve M in Fig. 89. Owing to the reversal of the position of the armature relative to the pole pieces it will have one positive and one negative

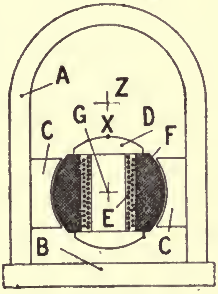


FIG. 88.

maximum value in each revolution. The effect of this is to cause a current (as shown by the curve C) to flow in the primary. It should be noted that the magnitude of this current is proportional to the rate of change (not the actual value) of the flux at any instant.

The fact that the armature rotates may now be forgotten. Its subsequent function is simply that of an induction coil having on it two coils, one E, of few turns, and one F, of a very large number. In E is generated the current C, as indicated in Fig. 89. This current may conversely be regarded as causing the magnetism in the core of the induction coil. The voltage in the secondary coil depends on the rate of change of this magnetism. In order to make this as great as possible, a device called the contact breaker is fitted. This is designed to break the primary circuit at the moments when the current flowing has maximum positive or negative values. The current flowing in the primary winding then becomes as shown by the full line parts of the curve in Fig. 89. At the point A there is then caused a very rapid change in the current and a correspondingly rapid change in the magnetic flux in the core. Consequently a wave of very high voltage is induced in the secondary winding. The high tension winding is at one end connected indirectly to the crank-case of the engine, the other being carried to a small insulated collector ring on the armature shaft on which a carbon collector brush bears. To this brush is coupled the high tension lead to the sparking plug. When this voltage rise occurs therefore a spark is produced at the plug points. A magneto which gives two sparks per revolution and serves a single-cylinder

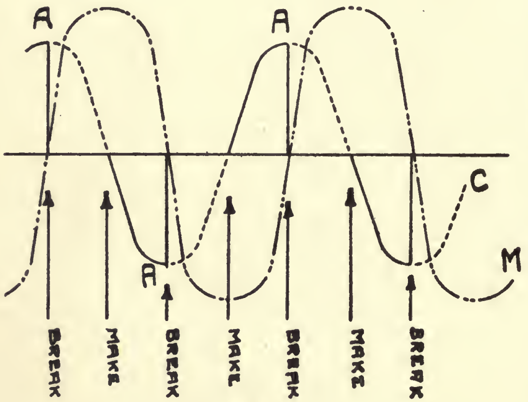


Fig. 89.

engine working on the four-stroke cycle will have to rotate at one-quarter the crankshaft speed, and its gearing will have to be so adjusted that the breaks occur at the exact moment when it is desired that the spark shall be produced in the cylinder.

The contact breaker, which breaks the primary current, is the mechanism which "times" the position of the spark. Fig. 90 shows this diagrammatically. The plate A is keyed to the end of the armature shaft and is "earthed" or connected to the framework by means of a carbon brush rotating in contact with the body of the magneto. The plate carries a pin C on which is pivoted the bell crank lever D. One end of the primary winding is connected to the plate and also, by means of the spring K, to the bell crank. At one end of the bell crank is fitted a platinum contact F. This makes and breaks contact with a similar contact E fixed in the block B. The latter is carried by the plate A, but insulated from it. To B is connected the other end of the primary winding. The bell crank is actuated as follows: at the end of one arm is a fibre block G kept in contact with the external fixed ring H by means of the leaf spring K. There are two internal cams I on this ring. It will be seen that whenever G passes over these, contact will be temporarily broken. These cams are so located that the break positions correspond approximately with the two maximum current positions, as shown in Fig. 89. In order that the timing of the spark relative to the piston position may be slightly advanced or retarded, the ring H is arranged so as to be capable of rotation through a small angle, the lug J being provided for the attachment of the ignition control.

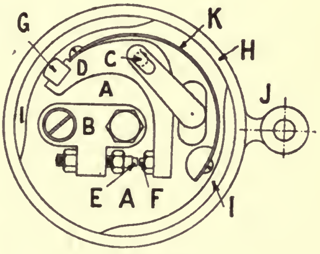


FIG. 90.

When an electric current is made and broken, sparking tends to take place at the contacts. This is why the latter are made of platinum, which has a very high melting point. The sparking can, however, be considerably reduced by the inclusion of a condenser. This does not take any current, but simply acts as a kind of electrical buffer. It is connected across the contacts and is usually built as part of the armature.

The magneto so far developed supplies two sparks per revolution, and if run at $\frac{1}{4}$-engine speed could be utilised for the ignition of a single-cylinder engine. Suppose a multiple-cylinder engine is to be served. In the case of a six-cylinder engine the magneto must provide three sparks per revolution of the engine and must distribute these to the particular cylinders according to their firing order. The first condition is readily satisfied by gearing up the magneto to run at $1\frac{1}{2}$ times engine speed; the second by the distributor. Fig. 91 shows the arrangement of this device. A is the armature shaft. This carries a gear wheel B, which engages with a second gear wheel C on the distributor shaft D. The latter is usually centred at the point Z (Fig. 88). The ratio of these gears is such that the distributor shaft rotates once per cycle (i.e. two revolutions) of the engine. The armature therefore produces six evenly timed sparks per revolution of the distributor shaft. The high tension lead from the collector ring G on the armature is led via the centre of the distributor shaft to the sparking point at the end of the rotating arm F. This point almost touches a series of insulated terminal studs, 1 to 6, in the fixed distributor cover H, and is so timed as to be directly over one of them as each spark occurs. These contacts are made fairly large in order that they may register with F whether the contact breaker is set in the advanced or retarded position. The leads to the plugs in the various cylinders are taken from these terminals. Each spark is thus distributed to the appropriate cylinder.

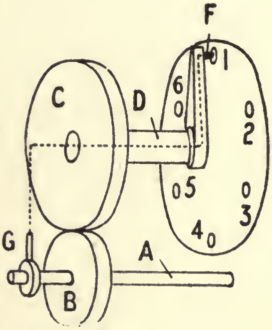


FIG. 91.

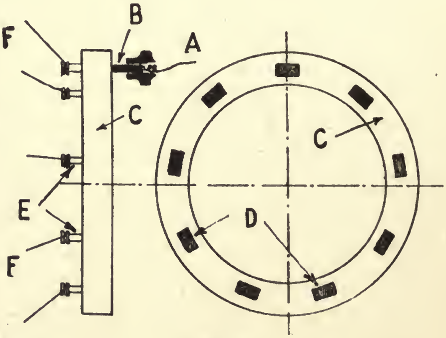


FIG. 92.

The distributing arrangements in the case of a rotary engine are particularly simple. The magneto is so geared as to give the requisite number of sparks (usually nine) per two revolutions. Its high tension lead is connected to a carbon brush B, which bears on a fibre ring C, the latter rotating with the cylinders. The ring carries a series of contacts D D, connected to terminals E E, from which the current is led to the plugs by bare wires F F. The angular location of the brush B is such that it makes contact with that stud connected to the cylinder which is at its firing point as each spark occurs.

Fig. 93 illustrates a magneto working on rather a different principle. It has a rotary " magnetic shutter " and a stationary armature. The armature A is fixed in the position shown, the flow of the magnetic flux through it being controlled by the position of the sleeve-shaped soft iron shutter B, which has two slots S cut in it. When the shutter is in the position shown in the figure, the flux through the armature is very weak owing to the large air gap (at S). If, however, the shutter be rotated through 90°, the resistance of the magnetic circuit is considerably reduced and the flux correspondingly increased. The variations of flux, low tension current, etc., in the armature are therefore varied in exactly the same manner as they would be by the rotation of the armature itself. In the case of a fixed armature the rotating high tension collector ring and brush for the collection of the high tension current are unnecessary. The contact breaker is carried on the same shaft as the shutter. The general appearance of a magneto of this type is practically the same as the more usual type already described.

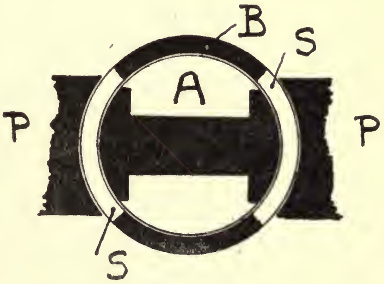


FIG. 93.

Fig. 94 illustrates a further development of this principle, i.e. the variation of the flux through a stationary armature by mechanically varying the resistance of the magnetic circuit. In this case, however, the arrangement is such that four instead of two reversals of the armature flux are obtained per revolution of the rotor. The rotor shaft in this case is arranged at right angles to the direction of the armature shaft shown in Fig. 88. It carries two soft iron plates N′ and S′, which rotate almost in contact with the N and S poles of the permanent magnet. These plates each carry two inductors N N and S S, which become similarly magnetised. The fixed armature has a horseshoe-shaped core C arranged at right angles to the axis of rotation of the rotor. The figure shows a cross-section through the centre of the rotor. It will be noted that only a 90° movement of the latter is required to induce a complete flux reversal in the armature, whereas 180° is required in the magneto as more commonly constructed. Where engines with a very large number of cylinders have to be served the speed of rotation of the ordinary magneto becomes prohibitive. This makes it necessary either to adopt a device of this nature or to use more than one magneto. A magneto of this "polar-inductor" type is shown in Plate VII.

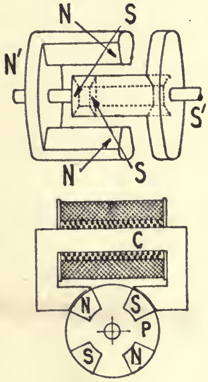


Fig. 94.

A ready means of stopping an engine is provided by switching off the ignition. This is done by short-circuiting the contact breaker. One switch wire is connected to the framework of the machine, i.e. virtually to A (Fig. 90), the other to B. It will be seen that when the switch is in the "on" (which is the "ignition off") position the effect of the contact breaker will be nullified and no sparks will be produced.

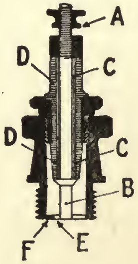


Fig. 95.

Fig. 95 shows a section of a typical aero sparking plug. A is the high tension terminal to which the insulated lead from the distributor is carried. The central electrode B, which is usually made of nickel, is insulated by a mica tube C and a series of mica washers D from the body of the plug. The latter is screwed into the cylinder. The high tension current is thus compelled to jump the gap E in the form of a spark to the electrode F, which is riveted into the body of the plug. The electrodes E and F where the spark occurs protrude into the combustion space of the cylinder. The gap from E to F should be about $\frac{15}{1000}$ of an inch. The most important part of the plug is the insulation. If this breaks down, the current will leak away by this easier path rather than leap the gap. Porcelain and mica are the most commonly used insulating materials. Porcelain is at some disadvantage owing to its brittleness. In the case of mica it is the inner tube C which provides the bulk of the insulating power. If this tube is very thin, the washers being relied on, the current tends to leak between the washers.

Systems of ignition dispensing with the magneto have recently been used with great success. They are practically an improved form of the coil and accumulator system known to older motorists. The inherent disadvantages of nearly all forms of magneto are that at slow speeds they produce a poor spark and that the spark intensity varies as the ignition is advanced or retarded. In the system illustrated in Fig. 96 the primary current is provided by an engine-driven dynamo supplemented by the accumulators at such times as the engine is stopped or running slowly. This primary current, which is sensibly constant, is made and broken by a contact breaker driven by the engine. The intermittent low tension current passes through the primary winding of an induction coil. Its sudden variations induce voltage waves in the secondary sufficient to cause sparks at the plugs. The distribution of the sparks to the plugs is effected by means of a distributor driven at the requisite speed by the engine. The timing of con-

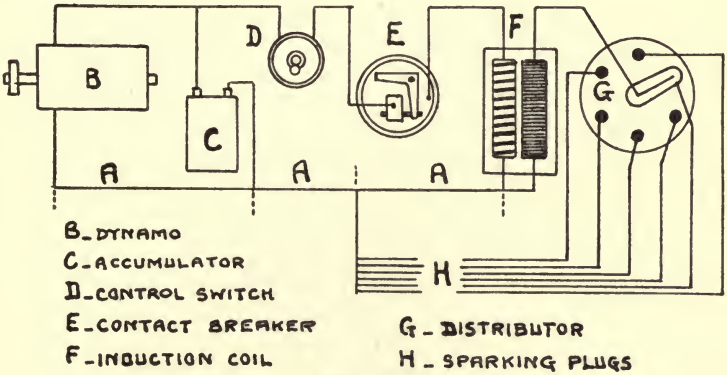


Fig. 96.

tact breakers and distributors in a system of this type is similar to the case of the magneto. It will be noted that the accumulators are so connected that when the dynamo is not developing its full voltage, they will discharge and supply the necessary current, being themselves re-charged when it has speeded up and its voltage has increased.

The wiring of the ignition system must always be carefully installed and frequently inspected when in use. Faulty running is often attributable to some minor wiring defect which is difficult to diagnose and which when diagnosed is often hard to locate. The engine itself is always utilised as the return wire for both the high and low tension currents. That is to say, the plate A (Fig. 90) is connected to the engine, and the return wire from the ignition control switch is carried back to the engine. The high tension current reaches the engine framing by jumping the plug gaps. In Fig. 96 the wire A shown is dispensed with ; the engine serves its purpose. The various dotted lines indicate connections direct or indirect to the crank-case.

The various causes of troubles encountered in the ignition system may be briefly examined. In general, oil and moisture are those most ordinarily met with. Oil in the case of the high tension circuit attacks the insulating materials. It may also prevent plugs from sparking. In the case of the low tension circuit, oil is very effective as an insulator. Moisture is a good conductor, and where present, e.g. as a film on the insulation of a plug, provides an alternative path for the high tension currents.

In the case of the magneto the main troubles experienced arise from oil, moisture, or dirt. If the magneto be over-oiled or liable to become oiled by discharges from the engine the insulation of the armature will be attacked, also the contact breaker points will become oily and fail to operate satisfactorily. Moisture in the magneto will provide a means of leakage for the high tension current. If a magneto has been standing in a damp atmosphere for any length of time, it will seldom work satisfactorily till it has been thoroughly dried. The points requiring attention on the magneto are the platinum contacts and the distributor. The former should be adjusted to a gap of about $\frac{15}{1000}$ of an inch, and should be kept thoroughly clean. A detail which sometimes gives trouble is the small fibre brush on which the contact breaker bellcrank works. Moisture causes this to swell. The lever then sticks either permanently or intermittently. Most distributors require to be thoroughly cleaned after every few hours' running. A carbon or metal trail tends to form along the track between the contacts. Although this may not appear to be of much consequence, yet with the voltages involved it can be responsible for a considerable amount of high tension leakage. In the case of rotary engines, owing to their high oil consumption, distributor oiling troubles are not uncommon. In the case of engines having more than one magneto the question of synchronisation also is important, especially when there is more than one plug in each cylinder.

Plugs require constant attention. In the case of most engines they should be taken out and cleaned after every few hours' running. The portion needing most attention is that around the centre electrode and inside the screwed part of the body. The cleaning may best be done with a wire brush and a little petrol. Paraffin must never be used on plugs with mica insulation. The points of the plug sometimes become distorted with heat; they should be adjusted to a gap of $\frac{15}{1000}$ of an inch. A plug tester, which consists of a small cylinder with a glass inspection window, is a very useful accessory. The plugs are screwed into this in turn. The pressure in the cylinder is pumped up to about 100 lbs. The plug is then tested with a hand magneto. A plug with faulty insulation will often appear to spark satisfactorily when under atmospheric pressure, whereas when subjected to the compression it will fail.

The main points in connection with wiring are that it should not be subjected to undue heat, it should be kept away from oil, and it should be prevented from chafing. Wires should wherever possible be conveyed in tubes. The portions which have necessarily to be exposed should be as short as possible so as not to be able to swing about and chafe. All connections should be made with sweated terminals. Terminal screws must be examined constantly to ensure their not slacking. Any connections not easy of access or particularly liable to slack back should be taped.

To ensure complete reliability of ignition the essential points are as elsewhere—extreme cleanliness and a conscientious care of detail.

CHAPTER XVI

PETROL, OIL, AND WATER SYSTEMS

THIS chapter is devoted to the consideration of the various tank and pipe services to the engine. There are a number of general principles applicable to all systems of this nature. It is proposed first to examine some of these and then to note their particular application to the petrol, oil, and water systems of a machine.

As regards the tanks these are usually made of tinned steel sheets of thin gauge. This material is eminently satisfactory, being strong, cheap, and easily repaired. Sheet brass or welded aluminium may also be used. The joints are usually riveted and soldered. In tanks of any kind large flat unsupported surfaces are always a source of weakness. If a tank, as indicated in Fig. 97, is subjected to internal pressure, it is the flat ends that bulge and give way. Flat surfaces, if extensive, are usually supported by ties, for example, a bolt such as AB in Fig. 97 would add very greatly to the strength. A further point which must not be overlooked when considering the possible pressure bulging of sides is its effect on the joints. The material itself will not usually fail, but successive strains will cause the corner joints to leak.

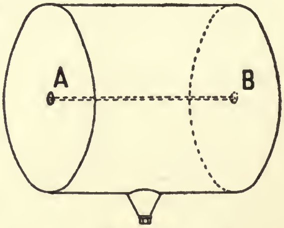


FIG. 97.

Tanks are usually attached to the machine by means of lugs soldered and riveted on them. These lugs are often a source of weakness on account of the strains to which they may be subjected. It is usual to arrange a soft felt washer between the lug and the portion of the machine framework to which they are bolted. This obviates strains which might otherwise arise from lack of truth, and it also minimises the effects of vibration. In tank work and sometimes in part of the pipe work the use of soft solder is resorted to. This makes an exceedingly strong joint when properly applied. It must, however, always be remembered that soft solder is very liable to fatigue, so that where vibration is to be expected hard solder or brazing should be used instead. Tanks of all kinds should be provided with an ample drain at their lowest point for convenience in flushing them out. It is a great advantage if this drain be situated in a small sump, as indicated in Fig. 97, as then any dirt which may find its way into the tank will settle to this point. This sump and drain is of particular advantage in the case of petrol tanks. If any water gets into the tank it will settle to this point and may then be drained off. It is particularly easy to test for water in petrol tanks so fitted. If mixed petrol and water be allowed to settle for a few moments in a glass vessel the line of demarcation between the two fluids is very apparent. Tanks of all types should be fitted with gauzes at their filling caps. These gauzes should not be relied on as filters, but should be regarded as an extra precautionary measure. Filler caps should always be attached in such a manner that they cannot be lost. They should also be shaped so that no special tool is necessary to screw them up.

Little trouble should be experienced with pipe systems once they are correctly installed. Their original arrangement, however, calls for a good deal of thought, and a number of pitfalls await the unwary fitter of pipes. The importance of extreme reliability in the pipe system is self-evident and cannot be over-emphasised.

The materials used for pipes are copper, aluminium, rubber composition, and occasionally steel. Copper is the most usual. It has the advantages of reliability, ease of bending, ease of soldering or brazing, and freedom from oxidation. Its chief disadvantages are its high weight and the fact that it is somewhat readily fatigued. Copper subject to vibration crystallises and becomes very brittle. The remedy is simple. All copper pipes liable to fatigue must be annealed periodically. This is quite easily done by heating the material to a dull red heat and quenching it in water. Prevention is, however, better than cure. This aspect of the subject is discussed farther on. Pipes made of aluminium and its alloys are not at present very much used except as conduits for electrical wiring and for the air speed indicator air tubes. Their use will, however, probably become more general. Aluminium and its alloys are not so easy to work as copper, and they have the disadvantage that all nipples, unions, etc., must be welded. Aluminium is very liable to electrolytic corrosion, and where damp, and particularly sea water, is likely to be encountered junction between it and other metals must be avoided.

Rubber composition piping is largely used to make flexible connections between tubes of other materials. Its advantage in this respect is obvious. Petrol resisting rubber composition is obtainable and is very satisfactory. Rubber composition deteriorates somewhat rapidly, especially when subject to heat and oil. These connections must therefore be inspected periodically and renewed as necessary. The joint between the rubber and the pipe to which it couples is made by means of a clip which is tightened up on the outside. One of the greatest troubles experienced with rubber, but one which can be easily guarded against by good workmanship and reasonable forethought, arises from internal chafing. Fig. 98, A, B, and C, illustrate forms of rubber connection. In the case of joint A the edges of the pipe indicated at X, especially if left sharp, will chafe the rubber and even cut it seriously. Pieces may protrude, constricting the bore at the joint, and any small pieces breaking away may choke other parts of the system. B shows an improvement on this arrangement, a bead being formed on the tubes. The scheme indicated in C is, however, best. Here an Olive, as it is called, is inserted between the two suitably expanded pipe ends. This arrangement provides a flexible joint and effectually prevents chafing of the rubber and the ingress of particles. It has the further advantage that it resists

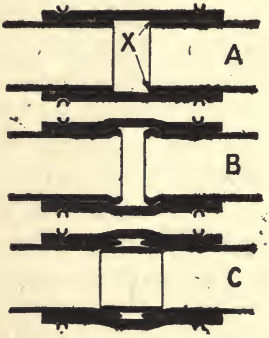
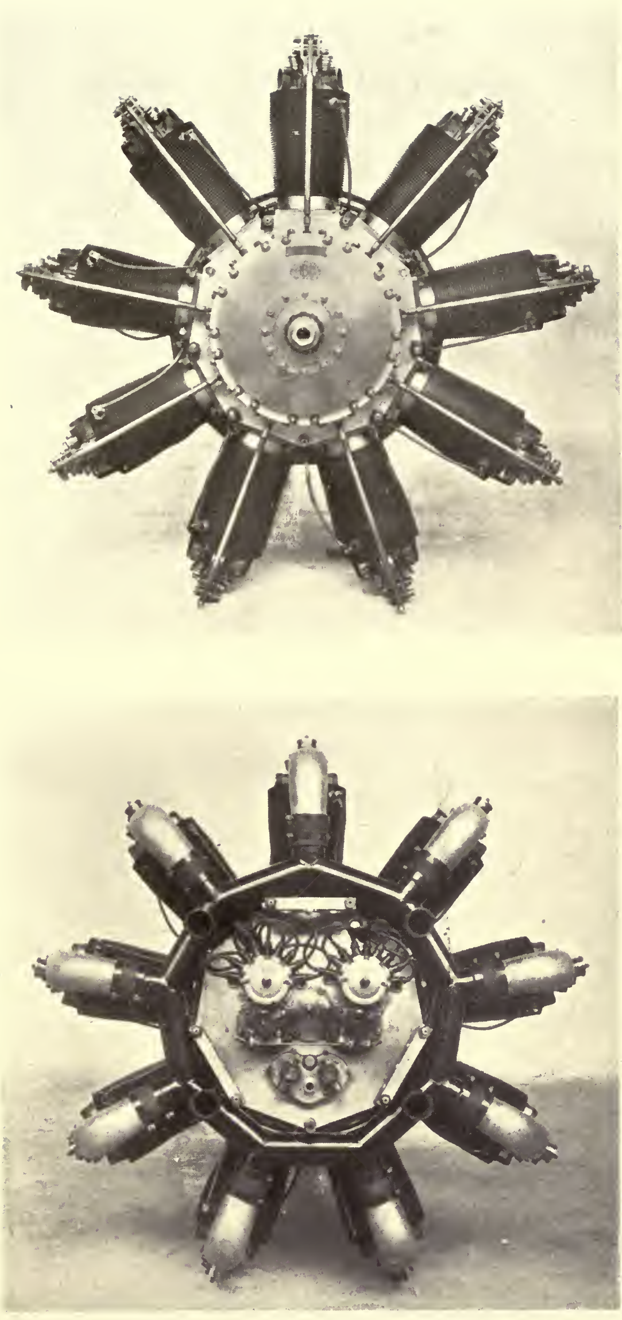


FIG. 98.

PLATE IX



A B C DRAGONFLY 1 A RADIAL ENGINE, 340 HORSE-POWER

any tendency which the material (particularly when saturated with petrol) has to swell inwards and constrict the bore.

Steel is chiefly used where the pipe serves a dual purpose by forming some structural member.

Vibration is the cause of most pipe failures on aeroplanes. The structure of the machine not being very rigid, it distorts slightly according to the load to which it is subjected. The engine bearers, owing to the slightly varying torque and the slight lack of balance in the moving parts, are subject to a continuous tremor. Owing to misfiring or other engine defects very considerable vibration may arise at times. The fatiguing effect of these movements on the various pipes must be guarded against. Referring to Fig. 99, a pipe, as shown in Fig. A, if subject to vibration, must suffer considerable stress during the deformations to which it has to conform. Straight pipes are therefore to be avoided. A pipe such as B with a single bend in it is much better. Here, though, the deformation will be localised chiefly at the bend, and this point will prove a source of weakness. A pipe such as C, in the length of which are arranged one or more complete twists of not too small radius, is more satisfactory, and can provide a considerable degree of flexibility; in arranging the coils, however, the possibility of air locks must be considered. In the case of all pipes, the bends of which are relied on for flexibility, these portions are liable to fatigue and should occasionally be annealed. All bends should be annealed after manufacture, as the bending of a pipe which naturally involves stressing it beyond its elastic limit always hardens it. Another form of flexible coupling is the rubber one shown in D; this is extremely flexible and effectually isolates the metal part of the pipe from all vibration effects. Its only disadvantage is that common to all rubber compositions, namely, lack of durability. Rubber joints should not, if it can be avoided, be placed in inaccessible positions, as they should frequently be inspected for signs of deterioration. The position of the flexible joints

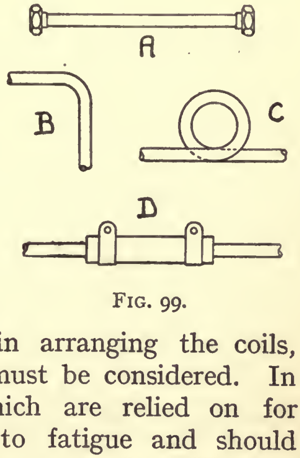


FIG. 99.

calls for a little forethought. In arranging them the aim should be to divide the length of the pipe into a number of sections which may be expected to vibrate independently. Flexibility between each section is then provided for.

Another consideration which must govern the general run of the pipe lines is the avoidance of air locks and what may be called dirt traps. If a pipe be arranged, as indicated in Fig. 100 (A), any air which may get into the system will make its way to the topmost point and, owing to its reluctance to flow downwards, will greatly interfere with the free flow of the liquid. It may even prevent it altogether. Moreover, in the case of oil systems, if the pumps draw a liquid from a tank and are of a gear type they will not suck air, and the presence of accumulated air will cause a breakdown of the supply. The danger arising from air locks depends to some extent on the pump pressures available to overcome them. Another serious form of air lock not infrequently met with is the air locking of a tank from which liquid is being drawn. If liquid is being drawn from a tank the ingress of air is necessary to take its place. There would otherwise be formed a vacuum which would increase until a negative pressure existed in the tank equal to the suction of the pumps, whereupon the flow would cease. In Fig. 101, were the pipe I of the gravity tank blocked, the tank would be entirely ineffective. Likewise in Fig. 102 it is essential that all the tanks (A1, A2, and H) should have some form of air inlet. Down bends, as indicated in Fig. 100 (B), must also be avoided. These form a harbouring place for dirt, the gradual accumulation of which may ultimately choke the system. Moreover, in the case of petrol systems water will segregate to these points, and in cold air, freezing and consequent stoppage of the pipe may ensue. The avoidance of these two troubles demands that the pipe should as far as possible have a steady upward or downward flow.

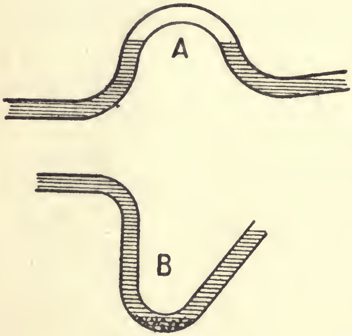


FIG. 100.

Petrol pipes should never be led near to very hot parts of the engine, otherwise the petrol in them at these points may boil and interfere with the flow. Exhaust manifolds, carburettor inlets, and other points where flame may occur must be avoided on account of fire risks in event of a breakage.

In all systems pipes of ample bore are essential. Wherever any doubt exists they must be made on the large side.

It is now proposed to describe representative types of petrol, oil, and water systems, commenting on the principles controlling their design and the advantages of alternative arrangements.

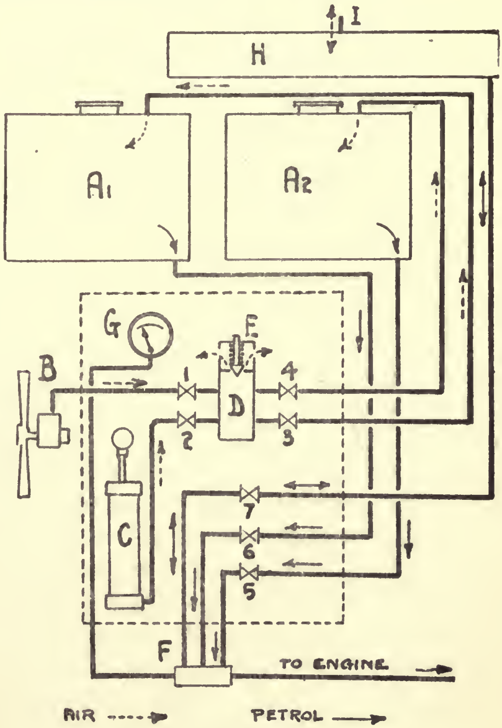


FIG. 101.

Petrol systems in general may be divided into two classes. In the first, air is pumped into the tanks and forces the petrol out. In the second, the petrol pumps are situated in the tanks and pump the petrol itself into the pipe lines. A third system, which unfortunately can seldom be adopted, consists of all gravity tanks. This demands that all the tanks should be situated above the level of the carburettors. The second system has several advantages. The most important of these is that, as the tanks are not subject to pressure, leakage is less to be feared. Also, if a crack does occur, there is no bulk of compressed air in the tank available to force the petrol out. Whichever of these systems is adopted, the pumping arrangements must be duplicated.

Nearly all systems have what is known as a gravity tank. This can supply petrol for starting up, and it also carries a sufficient supply to allow of landing under power being effected in the event of some breakdown affecting the whole of the pressure system. The gravity tank is usually situated in the top plane of the machine so that the maximum head of petrol is available.

The arrangement generally adopted in the case of the air pressure system is shown in Fig. 101. Two main and one gravity tank are shown. The arrangement is, however, capable of extension to any number of tanks. B is the mechanical air pressure pump and C is the hand pump provided as a stand-by and for starting. The pump B is commonly either driven by a fan or mechanically by the engine. When driven by a fan the pump should be so arranged as to be in the slip stream of the propeller. When driven by the engine it is usually actuated by a special cam on the half-time shaft. The air pressure pipes are coupled to the distribution box D via the taps 1 and 2. This box is provided with a relief valve E, which can readily be adjusted to the pressure of the supply. The pressure of the petrol supply on most machines is about 3 lbs. From the air distribution box pipes are led to the main tanks A1 and A2 via taps 3 and 4. The petrol flows from the main tanks via the taps 5 and 6 to the petrol collection box F. The pipe conveying the petrol to the engine is coupled to this box. A pressure gauge G is connected to the collector box F. This shows at all times the pressure of the petrol which is being supplied to the engine. The gravity tank H is also coupled to the collector box via the tap 7. The gravity tank must be provided with an air inlet I in order that it shall not become air locked. The caps on the main taps in a pressure system must be quite airtight. It will be noted that if the gravity tap 7 is left open, and if the pressure in the pressure system is great enough (which it usually is) to overcome the head to the gravity tank, the tank will refill and overflow at the air inlet. This provides a ready means of refilling the gravity tank, but demands that the tap 7 shall not be left open after it is filled. The working of the system is very simple and requires no further explanation. It is evident that by manipulation of the taps air pressure from either pump can be directed to either or both tanks, and that petrol may be directed from any tank to the engine. The parts of the system within the dotted line of the figure must be placed within easy reach of the pilot.

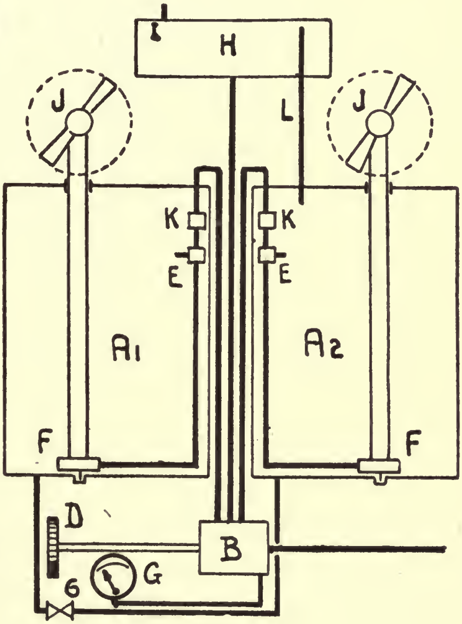


Fig. 102.

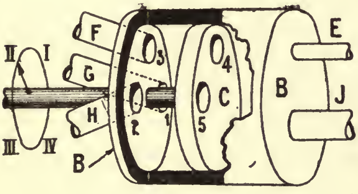


Fig. 103.

E to gauge. F to gravity tank.
G to tank A1. H to tank A1. I to engine.

A system which does not rely upon air pressure is shown in Fig. 102. This diagram shows an extremely ingenious and satisfactory arrangement which is fitted to most of the Airco machines. Rotary pumps FF driven by fans JJ are situated in the two main tanks. These deliver petrol via the release valves E (which are usually set at about 3 lbs.) and the non-return valves K (i.e. valves which allow liquid to flow in one direction only) to the main distribution valve B, which is controlled by the indicator D. This distribution valve is shown enlarged in Figure 103. Its action is as follows. The supplies are carried to orifices 1, 2, and 3 in its back plate, as indicated. The distribution is then controlled by the plate C, which is rotated by the indicator D. This plate actually works against the inside face of the back of the box, but is shown moved forward from this position to illustrate its action. It has two holes in it, 5 and 4, which can be made to register with the holes in the back plate. To consider the position II as shown, this opens up the pipe to the gravity and the pipe to the main tank

A2. If the fans are not running, as would be the case when starting up, the gravity tank supplies petrol. Then as the fan pump in A2 begins to work it gradually takes up the supply. When the fan is running strongly the pressure also forces petrol back from the distribution box to the gravity tank. The excess, however, flows back to the main tanks via the pipes L. The object of the non-return valves is to prevent the petrol flowing from the gravity tank back to the main tank when the indicator is in this position and the fans are not running. When the machine is well in the air the indicator is turned to IV; 4 then registers with 2, and 5 is blank. Only the main tank then supplies petrol. The positions I and III are similar as affecting the tank A1. A pressure gauge is coupled to the delivery side of the distributor valve. A further refinement is provided by the valve 6 coupling the two tanks. If this is opened, then, in the event of failure of one of the pumps, the other may be utilised to empty both tanks.

The oil system is usually a fairly simple one as a comparatively small tank will hold all the necessary oil. In the case of stationary engines all the oil is continuously circulated, passing many times through the engine and tank. In the case of rotaries it is continuously consumed and flung out through the exhaust. Oil pumps are usually of the gear type, as indicated in Fig. 73; since the presence of air very seriously affects their efficiency, it must be particularly guarded against. Little other trouble is experienced with the oil system. The tank should be near the engine. In some cases arrangements are made to air-cool the oil in the tank. There is, however, usually sufficient circulation to render this unnecessary. Oil tanks and pipes should be cleaned out periodically, as any gummy constituents in the oil tend to settle in them. Oil tanks should usually be placed below the level of the sump as in some engines it is possible for the oil to leak slowly into the sump, the result being that the engine becomes flooded with oil and has to be drained before it can be started. The oil pumps should be situated below the general oil level when the machine is standing; air can then never get in, and they will consequently not require to be primed for starting. The filters in the oil system must be given very frequent attention, particularly in the case of new engines. It is remarkable how much impure matter is commonly allowed to accumulate in them.

With regard to filters generally, whatever system they be situated in, the danger of placing them in inaccessible positions may here be commented on. It is sometimes found that makers place gauzes inside tanks and in other similar places, which make it practically impossible to clean them. In some cases their presence may not even be suspected. They may then become a source of considerable danger.

The water system is generally very simple, the radiator being always very close to the engines. One of the most important points in the design of the water system is the provision of efficient drains which render it possible thoroughly to clear the engine of water in frosty weather. The honeycomb type of radiator is almost universally used on account of its lightness and efficiency. This type consists of a very large number of thin brass tubes arranged parallel to the direction of air flow and soldered as indicated in Fig. 104. The water percolates between what is normally the outside of the tubes. The total area of the insides of the tubes presents a very large cooling surface. Radiators must be carefully mounted in a machine so as to avoid strains and excessive vibration, which very soon damage them. For the same reason the pipe connections to the engine must always include a flexible rubber joint. From the top of the radiator there is always an overflow tube called a steam tube. This takes any overflow which may occur if the water begins to boil, and should always be led to some point where the pilot can see it, so that his attention is immediately drawn to any undue heating. A thermometer is always fitted to the water system. In this connection it must be remembered that the water boils more readily at high altitudes. Only the purest water obtainable must be used for filling the water system, and once used it should not be changed, but only added to. Every pint of new water added has in it a certain amount of impurity, all of which is deposited in some part of the engine or water system.

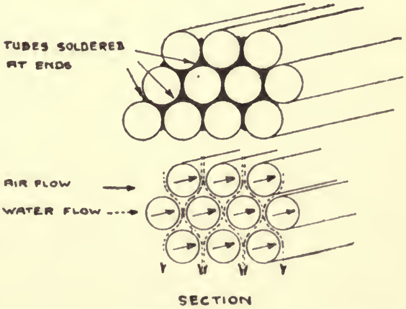


FIG. 104

CHAPTER XVII

ENGINE STARTING AND RUNNING

IN the earlier days of aviation when engines were of much smaller power than they are to-day the engine was invariably started by swinging the propeller. The process is practically the same as the starting of a car engine by means of the crank handle. The first few turns suck the gas into the cylinders, whereupon the engine begins to fire and picks up itself. In the case of the car engine the handle is mounted on a ratchet so that when the engine commences to run itself the starting handle is not carried round. As far as the person swinging the engine is concerned the sooner it starts the better he is pleased. The propeller of an aeroplane, however, cannot be so mounted, and its unexpected starting is liable to damage the person swinging it. The process must therefore be somewhat modified. With the ignition switched off the engine is first " sucked in " by swinging the propeller several turns as rapidly as possible. When it is judged that the cylinders are well charged with gas, the ignition is switched on, the propeller given one good pull over a compression, and if all is in order, the engine should fire.

The swinging of the propeller requires a certain amount of skill. When the switch is on and the engine is expected to start the situation is not without danger. If the man swinging it does not get clear as the engine takes charge he will be struck by the propeller. This accident is usually the result of carelessness born of familiarity, or in some cases it is due to a mishap such as a slip on wet ground. Its results are usually serious, a broken arm being one of the least. A further and not infrequent cause of these accidents is the inadvertent leaving of the switch in the " on " position during the process of sucking in. The engine in these circumstances unexpectedly starts up. For this reason the main switch should always be placed in such a position that it can easily be seen by the person swinging the propeller. The wise mechanic will always glance at the switch before touching the propeller. With care, and provided that the engine is kept in good condition, this method is quite satisfactory for starting up stationary engines of up to 100 h.p. and rotaries of considerably higher power. The swinging of a rotary engine is easier owing to the fly-wheel effect due to the weight of the engine.

The main causes of difficulty in starting an engine are: cold weather, which prevents the petrol from gasifying readily, and a weak or dirty magneto, to which may be added dirty plugs, and sticky or congealed oil on the cylinder walls. The first and last of these causes are commonly overcome by "doping" or injecting petrol into the cylinders. The importance of cleanliness of the magnetos and plugs is readily understood when one considers how slowly the propeller is pulled over, and consequently how slowly the magneto rotates. In this respect the advantage of an accumulator type of ignition which produces a good spark, however slow the speed of rotation, is obvious.

As engines increased in size, the earlier method of starting became impossible, and various devices were introduced. The starting magneto was one of the first. It was found that with a suitable pilot jet carburettor, good gas could be sucked in at the lowest speeds. The starting magneto, which is rotated by hand and which produces a continuous series of sparks, was introduced to supplement the engine magnetos. Its lead is connected to the high tension circuit of the magneto at some point between the armature and the distributor. To start the engine the propeller is first rotated by hand until the cylinders are charged with gas. It is then turned to a position such that one of the cylinders is near to its firing point. Both the main and starting switches are then put on and the starting magneto is turned by hand. Owing to the manner in which the lead from the starting magneto is connected to the main magneto, the distributor directs the sparks to the cylinder which is on or near to firing position. Once the engine has commenced to fire its speed is sufficient to ensure that the main magneto carries on. The piston need not be exactly on the firing point owing to the fairly large area of the contacts of the distributor.

The next step, though a somewhat crude one, is eminently satisfactory in service. It consists of a starting dope pump. A special hand petrol pump of small capacity is fitted in the pilot's cockpit. The delivery pipe of this pump is directed to the inlet manifolds at points near the inlet valves. The use of the pump enables a predetermined amount of petrol to be delivered to the cylinders during the sucking-in process. The pump really takes the place of promiscuous doping by hand. The latter is often a complicated job, and, owing to the lavish manner in which it is often performed, may have injurious effects on cylinder lubrication.

The aforegoing methods of starting all demand that the propeller be rotated by hand. In airships or machines such as seaplanes this is often impossible. The size of some of the high-powered engines recently introduced makes it an impossibility from a physical point of view in their case also, especially if the propeller be geared down. In these instances more complicated devices are necessary.

The compressed air starter provides a method of starting an engine by means of highly compressed air which is carried in a gas cylinder. The high pressure air is carried to a special distribution valve usually driven from the half-time shaft. Leads from this valve distribute the high pressure air to the cylinders through small non-return valves when the pistons are near the top of their working strokes. The air expands in the cylinders, thus rotating the engine. As the engine rotates, it sucks in gas from the carburettor and starts up, whereupon the compressed air supply is turned off.

Another form of starter suitable for large engines employs a special vaporiser and hand pump for supplying a suitable mixture to the cylinders. A special mechanism is provided whereby all the valves may be slightly opened. Air is then pumped through the vaporiser by hand. Whilst passing through the vaporiser it becomes highly charged with petrol vapour. It then enters the inlet manifolds and from thence the cylinders. When sufficient gas has been pumped through to ensure that all the air in the cylinders has been expelled, and that they are completely charged with gas, the valves are all dropped on their seats. The engine is then started by means of a hand-operated starting magneto as already described.

When an engine has been started, it is always run up and tested to ensure its proper working before the machine is taken off. This running-up process is exceedingly important. Its primary object is the testing of the engine. Its secondary object, no less important, is to ensure that the water and oil systems are working properly before the machine is taken into the air. Before an engine is opened up for test or put upon full load by being taken off it is absolutely essential that it should be properly warmed up and that oil should be circulating to all parts. Many accidents have resulted from the skimping of this process. A water-cooled engine may only require to be warmed up for a minute or so in the summer, but as much as twenty minutes may be necessary for warming up the same engine in the winter. During the running-up period the engine should be run as slowly as it will run sweetly without misfiring or jarring. The water temperature should rise to about 65° or 70° C. If it gets too high there is danger of its boiling when taking off. The most important point, and one that is sometimes lost sight of, is that the running up must continue until it is certain that the oil is circulating to all the bearings. The oil-distributing system consists of a comparatively long length of pipes and passages of small bore, some of them much longer than others. Cold engine oil is not at any time easily forced through a small pipe. In cold weather it is particularly viscous. As the engine runs the oil passing through it becomes warmed and thinned. The oilways in the engine also become warmed by conduction. When first starting the oil gauge usually shows a pressure considerably above normal. This is entirely due to the viscosity of the oil. The oil first circulates through those leads which are shortest and of largest bore. In cold weather it cannot reach those bearings served by long and complicated leads until the engine is very thoroughly warmed. Until the pilot is satisfied that every bearing on the engine is getting an adequate oil supply he must on no account venture to take off. It must be remembered that the failure of any bearing is almost certain to cause complete failure in the engine.

If the engine is fitted with a dual system of ignition, it should be tested separately on each system during the running-up process in order to ensure that both systems are working satisfactorily.

When the engine has been warmed up, it is tested, the throttle being slowly opened to its full extent and the revolutions noted on the indicator. The note of the engine when opened out also serves as a very good indication of its condition. An engine must never be run all out unnecessarily on the ground. This practice has a very deleterious effect on both the engine and the machine. It also overheats the engine unnecessarily before it is taken into the air. The compression ratio is too high for running at ground level, also the dust raised by the propeller is drawn into the engine. When testing the engine the control lever must always be held fully back in order to keep the tail of the machine on the ground. Triangular wooden chocks are placed against the wheels of the machine in order to prevent it from moving forward.

The general handling of the engine in the air and whilst taking off demands chiefly a certain amount of sympathy on the part of the pilot. He must be quick to note any change in its running and quick to diagnose the cause. If the engine shows signs of serious trouble he should usually land before he is compelled to do so. The engine if running very roughly is probably doing itself considerable harm. Moreover, it may suddenly cut out, forcing him to land at some particularly unpropitious moment. Stationary engines must never be controlled by switching the ignition off and on. Rotaries must be controlled on the petrol adjustment and not in the switch. In the case of rotaries the danger of switching on and off is not mechanical, but is due to their liability to catch fire owing to the ignition of petrol which accumulates during the period when they are switched off.

The throttle control of all engines must be operated slowly since sudden opening chokes the engine and may even stop it altogether. This is readily understood when it is remembered that for every speed of the engine there is a definite throttle position. If when the engine is running at 800 r.p.m., the carburettor is suddenly set to the 1500 r.p.m. position, the engine cannot be expected to adapt itself. This point is of extreme importance when getting off the ground as the results of choking the engine at this juncture may be serious.

The altitude control must be used with care. An excessively weak mixture may do considerable harm to the engine. The reason for this is that when the air supply is excessive the oxygen is not entirely used in the combustion and the exhaust gases contain an appreciable amount of free oxygen. This oxygen passing over the exhaust valves, which are frequently red hot, causes them to oxidise (i.e. burn) very rapidly.

When a machine comes down from a considerable height in cold weather precautions must be taken to ensure that the radiator does not become frozen up. The blinds by which its effective area is controlled must be closed and if necessary the engine run lightly.

A large engine should always be stopped finally by turning off the petrol and not by switching off. If it is switched off certain cylinders will usually continue to fire irregularly owing to heated carbon or plug points. These irregular explosions will cause considerable stresses in the crankshaft and also in the engine bearer bracings of the machine.

CHAPTER XVIII

ENGINE FAULTS

THE power of being able correctly to diagnose the cause of engine trouble is extremely valuable to the pilot. The most practised engine expert is not always able to say from symptoms noted when in the air exactly what any particular trouble is. His experience will, however, enable him so to localise the cause as to render it comparatively easy for him to fix it absolutely by subsequent ground examination. It may here be remarked that real experts are not frequently met with. They appear to possess some instinct absent in the average man. The ordinary pilot must not, however, be deterred on this account from exercising such faculties as he may have. It is the sense of hearing that plays the greatest part in the art of diagnosing engine faults.

To diagnose the cause of faulty running calls for a very intimate knowledge of the engine, its components and accessories, and a thorough understanding of their various functions. A great deal is to be learned from the recorded experience of others both as to the usual causes of faulty running and as to the particular conditions to which they give rise. Whenever trouble is experienced the pilot must attempt to decide its cause, and he should subsequently confirm his diagnosis, ascertaining the true cause of the trouble should he have been wrong. The next time he encounters the same trouble he will then recognise its cause immediately. Every correct diagnosis makes him more capable and gives him self-confidence. The responsibility of the pilot should not end with the discovery of the fault. He should find out how it arose and also take the necessary steps to prevent its recurrence. When an engine is overhauled it is not sufficient simply to replace defective parts. The defects should be traced to their origin and such measures as are practicable taken to prevent their recurrence. It is, however, proposed in this chapter only to discuss the diagnosis of such faults as may be met with during the running of the engine.

The engine instruments very often fix the cause of bad running. The habit of checking their readings periodically should therefore be cultivated. When any fault in the running is suspected the first action of the pilot should always be to examine his instruments, also all the engine control levers, switches, etc. Faulty running is not infrequently the result of the alteration of some control, tap, or switch, due to vibration or some accidental movement on the part of the pilot. Much information is often to be obtained by testing the controls, especially where duplicate systems of ignition, petrol supply, etc., exist. For example, where dual ignition is fitted the failure of one system would probably only cause a certain roughness in the running. Any failure in either system would immediately be made evident by testing them independently on their main switches. Similarly failure in a particular petrol pump is confirmed by satisfactory running on a second pump or on the gravity tank. Whatever the fault the pilot should always apply all the tests at his disposal in order to diagnose it as accurately as possible. In this way he may save his mechanics a considerable amount of unnecessary work.

Very similar irregularity of running may be produced by a variety of causes. The question can be discussed from the point of view of cause or from that of effect. It is proposed here to examine it from the latter standpoint since this is the way in which it usually presents itself to the pilot. The commoner conditions met with are considered together with the various faults which may cause them.

Before setting out to examine the problem in this way, its other side may be briefly touched upon. The causes may be grouped together. Work done on the engine when in the sheds must be undertaken on this system. When some particularly mystifying trouble is encountered it is often helpful to split up the possible causes into groups with a view to arriving at the actual cause by a process of elimination. Headings under which causes may conveniently be grouped are as follows: the engine services—which include the petrol and other systems, the ignition system, the carburettors and induction pipes, the water circulating system, the oil pumps piping and tanks, and finally mechanical breakage.

Fortunately an engine rarely stops suddenly and completely in the air. When this does occur the commonest cause is failure of the petrol supply owing either to all the tanks being exhausted, in which case the pilot is probably anticipating the event, or to the fact that one tank has been run dry and another not turned on. It may also occur owing to the breakage of a pipe, or failure of the supply pump. Engine stoppage due to lack of petrol is almost always marked by popping back in the carburettors followed by complete silence. If the stoppage is absolutely sudden, and not accompanied by any carburettor popping, but perhaps by a few isolated kicks, it is probably due to failure of the ignition system. A not uncommon cause of this latter form of failure is the accidental knocking off of the switch by the pilot. The engine may fail entirely as the result of a seizure or serious mechanical breakdown. In the latter case the cause will most certainly be heard. When the failure is due to seizure the pilot has usually been forewarned by previous erratic behaviour on the part of the engine. Seizure is nearly always the result of either water or oil failure. Any form of engine trouble which, despite nursing on the part of the pilot, continues to increase usually culminates in sudden and complete failure.

An engine frequently develops roughness in its running. This is a particularly difficult form of trouble to account for with certainty. The condition may arise suddenly or gradually. It may remain constant or show a tendency to increase. If it occurs suddenly and does not appear to increase it is probably the result of a cylinder misfiring. This may be confirmed by an unevenness in the note of the exhaust.

Steady misfiring in one cylinder may arise from two main causes—faulty ignition or a minor mechanical breakdown. In the former case either a high tension lead has come off or become defective, or the plug itself has failed. A plug may fail by oiling or sooting up, by burning, by breakdown of its insulation, or by being blown out. The last cause is usually made apparent by the whistling sound made by the escaping gases. The mechanical cause of steady misfiring is usually the failure of either a valve or its operating gear. This may take the form of a broken valve tappet or rocker, a warped or broken valve, or a broken valve spring. These cause the valve to remain permanently either open or closed, cutting the cylinder out of action in either case.

General and uneven roughness, which cannot be assigned to the complete failure of one or more cylinders, may arise from a variety of causes. It may take the form of, or increase to, a violent vibration which may necessitate immediate landing. It may vary periodically or otherwise in intensity. These facts usually give some clue to its origin. One of the commonest causes is a dirty distributor. This causes the sparks at the plugs to be weak. No actual misfiring may result, but the cylinders do not work evenly, and a general roughness and loss of power ensues. In this case the roughness has a slight tendency to increase. This trouble is chiefly met with when the magnetos are fitted with carbon brushes which actually touch the distributor contacts. An engine will sometimes run very roughly for a moment or two and then pick up again. This is usually the result of the sticking of a contact breaker arm. A somewhat similar condition may arise as a result of starving of the petrol supply due either to a constricted pipe or failure of pressure. In this case it may be marked by a certain amount of popping at the carburettors. If the petrol supply is continuous but insufficient the engine may tend to "hunt," i.e. suffer from periodic fluctuations of power or roughness. The insufficiency of the petrol supply can be confirmed by testing the throttle valve. The engine will probably be found to run quite satisfactorily on, say, half throttle.

A general and even roughness may be caused by maladjustment of the valve clearances. Over-oiling may result in the oiling up of plugs and may cause constant or intermittent misfiring. A mixture that is either too rich or too weak will cause the engine to run roughly. Some indication as to causes of this nature may be obtained by observing the exhaust. Black smoke always indicates too rich a mixture. The commonest cause of too rich a mixture is a punctured carburettor float. The amount of blue smoke indicates the quantity of oil that is being burned in the cylinders. Little puffs of blue smoke from one exhaust pipe would, for example, suggest that a cylinder served by that manifold is missing intermittently, the accumulated oil of several strokes being burned by one explosion. Violent roughness occurring suddenly may result from the failure of a portion of the cylinders due to one of the several carburettors or magnetos which may serve the engine becoming defective. The breaking of an inlet valve generally causes violent roughness since the supply of gas to the other cylinders served by the same manifold is seriously interfered with.

Popping back in the carburettors is always indicative of too weak a mixture. This may be due to an insufficient supply, choked jets or filters, or a serious air leak in the induction system. Water in the carburettor has a similar result. Water in the jets can often be cleared by diving with the engine on and the throttle part opened. This induces a considerable suction in the choke.

An engine that is allowed to get too hot usually runs roughly. Overheating may be caused by too weak or too strong a mixture. It is most often due, however, to oiling or water trouble. An engine with high compression designed to fly at a considerable altitude tends to overheat when flown low down. Causes of overheating originating in the water system are: breakdown of the pump, loss of water due to leakage, stoppage of pipes due to accumulation of dirt or sludge, or an insufficient supply of water. A further possible cause is the insufficiency of the radiator area for the conditions in which the machine is flying. If the machine is climbed too hard, and at too slow a speed, the draught through the radiator will not suffice to dissipate the heat. The remedy is to increase the speed and to reduce the rate of climb. If the trouble lies with the oil this should be indicated by the oil gauge.

Overheating usually leads to pre-ignition, which is the ignition of the gas before its proper time by incandescent carbon or heated plug points. Engines when nearing their time for decarbonisation are particularly prone to this form of trouble. Pre-ignition usually confines itself to one or two cylinders. It may cause very serious vibration. Local overheating of a particular cylinder will probably cause pre-ignition in that cylinder. The overheating may also arise from a local air leak or from mechanical friction.

Mechanical noises such as metallic knocking or thumping usually indicate some form of mechanical trouble; they may, however, also be caused by serious pre-ignition. A continuous knock indicates the slackness of a bearing or piston. A loose propeller may cause like sounds. A heavy thumping may be due to looseness of the engine in its bearers or looseness of the bearers themselves. This fault is usually made apparent by the bodily movement of the engine. A damaged propeller, owing to its lack of balance, also causes knocking or vibration. The correct diagnosis of the cause of knocks and metallic noises calls for a good deal of experience.

Any faulty running leads to loss of power. At times, however, engines will be met with which, whilst not showing any active signs of faulty running, do not give the power and revolutions that are to be expected of them. They may also somewhat mysteriously lose power in course of service. There are a variety of possible causes for this. In the case of engines which have more than one carburettor or magneto it is not uncommon to find that their various controls have not been properly adjusted and synchronised. The carburettor serving one bank of cylinders may only open to $\frac{3}{4}$, whilst the other is opening fully. The timing on the magnetos may differ, as may also the relative movement of their controls. In connection with the timing of the magnetos it should be noted that the effect of an excessive gap between the contact breaker points is to retard the spark. An obstruction in the petrol system may restrict the petrol feed to one of the carburettors. Dirty distributors may cause a loss of power unaccompanied by any active misfiring or vibration. An insufficient oil supply also causes a loss of power, though this is usually accompanied by overheating. If the oil is either too hot or too cold this may affect the power considerably. Again, a very marked loss in power results from the use of inferior petrol. If during assembly of the engine the valves of one bank or all the cylinders have been incorrectly timed the effect on the engine will be very great. An engine nearing the time when it should be decarbonised always loses power. Losses developing during the running of an engine must be traceable to some cause which has arisen since the last occasion when it was running satisfactorily. This remark may appear somewhat obvious; much valuable time is, however, often wasted by thoughtlessness and the investigation of remote and unlikely possibilities. In all engine work a little time spent thinking over the problem before starting to pull the engine to pieces often saves a great deal of unnecessary labour.

The only way to ensure against engine trouble is to see that engines are systematically cleaned, examined, and adjusted after every few hours' running. An engine that is running badly will very quickly wear itself out, and any work which prevents this is an economy. The possible expense which may attend the complete failure of an engine requires no comment. It has already been pointed out that, given skilful piloting, nine accidents out of ten are the result of engine trouble. It may now be added that nine engine failures out of ten result from inadequate or insufficiently skilled attention.

MARTINSYDE SCOUT--ROLLS ROYCE ENGINE

AIRCO 1 A (1916) BEARDMORE 120 HORSE-POWER ENGINE

CHAPTER XIX

THE CARE OF ENGINES

THE satisfactory running of an engine depends to a great extent upon the care with which it is tended whilst on the ground. After every few hours' running time it must be gone over and cleaned, and any necessary adjustments must be made. Periodically it must be more thoroughly cleaned and examined. After a certain number of hours (these varying with the type of engine) the cylinders must be removed and decarbonised. This last operation provides occasion for a certain amount of internal examination. If wear is apparent the engine should be completely stripped, the bearings adjusted, and any worn parts replaced. There are three essential factors necessary to ensure good engine work, namely, conscientious workmanship, cleanliness, and method. A special system embodying the jobs to be done and the order of doing them should always be adhered to. This system must be specially adapted to the particular class of engine and must be developed from an intimate knowledge of its peculiar requirements. If work is done in a haphazard manner certain jobs will inevitably be forgotten or perhaps left only half done.

It must always be remembered that the aero-engine is built on the principle of power for weight. It runs the bulk of its time at full load, and during this time each component part of it is loaded up to its safe limit. It is only to be expected that an engine working under these conditions will require considerably more attention than the engine of a car. If the engine has a sufficient margin of power to render it possible for it to work normally at, say, two-thirds of its full output it will be found to require considerably less attention in service and to run for much longer periods between overhauls.

The particular work necessary to keep the engine efficient varies with different types of engines. On one engine the plugs will require special attention owing to their position in the cylinders. On another the design of the valve operating gear may be such that the valve tappet clearances need frequent adjustment. Again another may have the habit of developing induction leaks at certain points. The following remarks must therefore be taken as applying generally, though perhaps they apply more particularly to the stationary class.

The keeping of log books showing all work done on an aero-engine is now obligatory. The log should be entered immediately the job is completed. It is a very sound scheme for the workman doing the job to sign either the log or a rough copy of it ; this brings home to him a sense of his responsibilities, besides making it possible to trace the author of any particular work later if necessary. Petrol and oil and water consumption is also recorded in the log book. The figures in this record often indicate troubles which would not otherwise be very apparent.

The following procedure should govern the work that is done on an engine after every three or four hours' flying. Whilst the engine is still warm the valve tappet clearances should be checked. The propeller should then be slowly and steadily turned, which proceeding may give much information to the experienced mechanic. The force required to turn it indicates the condition of the compression, and if any cylinder is faulty it will now be detected. Whilst the propeller is being turned, any untoward sounds should be carefully noted. If a valve is seriously burned or sticking it may be heard to blow. Dry valve stems or mechanism will squeak. Gearing that is wearing severely may grind. This pulling round of the propeller is in fact the most comprehensive test that the mechanic can apply to the engine. On most engines it is desirable to clean the plugs after every few hours' flying. An excellent arrangement is to keep two sets ; the spare set may then be cleaned when convenient. Spare plugs should be kept in a warm, dry place. When the plugs are out the compression may conveniently be tested further. The compression being released, the propeller can be swung round with comparative ease. One man should swing the propeller whilst another applies his thumb to each plug orifice in turn. The force with which the thumb is blown off the plug hole forms quite an accurate test of the compression of the particular cylinder. The distributor should be removed and if necessary cleaned. Emery cloth should never be used for this purpose. It wears the materials unduly and differently according to their hardness. Metal polish applied with a soft rag should be used. All piping and joints should be superficially examined. If accumulators are used the voltage of these should be tested. The carburettor jets and filters should be removed and cleaned in petrol. If signs of water are found the system should be cleaned more thoroughly. The main oil filter should be examined and if necessary cleaned with paraffin. The engine should be cleaned down generally, and any oil that may have escaped should be wiped off. This cleaning should include the bearers, cowling, etc.

With regard to the filling up with petrol, oil, and water a very sound rule is always to complete this job before the machine is run into the shed. This practice precludes the possibility of the filling being forgotten if the machine is subsequently required in a hurry. It also reduces fire risks due to handling the petrol inside the sheds.

Each job done on an engine must always be finished in every detail before being left or before another piece of work is begun. It is the neglect of this rule that makes it possible for a machine to take off with some of the plugs not screwed properly home, the distributor cover not locked, or with the results of some similar negligence which may have serious consequences.

Periodically the engine should be more thoroughly examined and cleaned. The time which may safely elapse between these more thorough inspections will vary considerably with the type of engine and the service on which it is employed. With a good water-cooled stationary engine they are usually necessary after every 15 to 25 running hours. At these more systematic examinations all the work already detailed should be gone over only somewhat more thoroughly. All the engine control gear should be examined and oiled, and particular attention should be paid to all nuts, split pins, and other locking devices. All the oil and petrol filters should be removed and thoroughly cleaned. The whole of the oil should be drained off and all the oilways flushed with paraffin, a powerful syringe being used. For engines using castor oil methylated spirit is more satisfactory than paraffin. The condition of the oil removed and the sediment found in the filters often furnish indications of the internal condition of the engine. If the engine is badly carbonised the oil will be blackish and will probably contain particles of carbon. The presence of any metallic sediment usually indicates that excessive wear or partial seizure is taking place somewhere, and whenever it is found steps should be taken to locate the trouble. In the case of new engines it is not uncommon to find chips of metal in the oil filters. This is usually due to the incomplete cleaning of the oilways. Before the oil is put in again some should be squirted through the oilways to clear any accumulations of paraffin which may remain. All engine bearer bolts, propeller boss fixing bolts, and any other parts that may work slack should be particularly examined. If a sump and drain is provided at the bottom of the petrol tanks a small amount of petrol should be drawn off, as any dirt or water will settle to this point.

The cleaning of tanks often furnishes rather surprising information as to the amount of dirt carried into the systems by petrol and oil. At all times every possible precaution must be taken to prevent this. Petrol must always be passed through chamois leather to prevent the ingress of dust or water. The leather should be examined periodically for pin holes. Oil should be passed through a gauze of as fine a mesh as is practicable (usually about 25 per inch). Petrol funnels, and particularly oil funnels, when not in use must be kept in some place where they are protected from dust, since all dust which settles on them is necessarily washed into the tanks. The spouts or tops of oil cans must always be cleaned before the oil is poured out.

The time that an engine should run until it requires to be decarbonised varies a good deal with the type. It is usually from 30 to about 100 hours, but may be longer if the engine is generally run at only part throttle. Air-cooled engines and rotaries generally become carbonised more quickly than a water-cooled stationary engine. The process of decarbonisation consists of removing the cylinders and scraping off all the carbonaceous deposit which forms on their heads and on the crowns of the pistons. The valves are at the same time reground. Whilst the cylinders are off it is usually convenient to open up other parts for examination. The engine is always removed from the machine for this work, and it can be much better done in the workshop. Even if it is possible to do it on the machine, there is always a great risk of dust getting into the crank-case and other parts. The deposit is scraped off with any convenient tool, the surfaces being finally cleaned with emery. The valves are ground on to their seats with emery or carborundum powder and oil, care being taken not to grind away more metal than is essential to secure a good seat. Whilst the valves are stripped their springs may be tested, and any that have weakened in service must be renewed. The parts are then thoroughly washed in paraffin and well oiled with engine oil before reassembly. Points requiring particular attention are the insides of the piston crowns and the piston ring grooves. Any piston rings showing wear or blackening should be renewed. A useful tool may be made from an old cylinder and piston, a handle being fitted on to the latter. This is used to grind in any new piston rings. The clearances of rings, pistons, etc., need not be discussed here as information is always given about them in the maker's handbook for any particular engine. During the decarbonisation overhaul just described an odd connecting rod big end which is slack may be taken up and any similar job done. If, however, much work of this nature appears to be necessary the engine should be thoroughly overhauled.

The complete overhaul of an engine involves the stripping of every part of it. The necessity for this or otherwise is usually evident when the cylinders are taken off for decarbonisation. The time between these overhauls varies from 50 to 150 hours. The work should never be undertaken by any but a really skilled workman. All bearings are stripped, examined, and, if necessary, rebedded. All parts showing wear are replaced. On reassembly the engine is subjected to a searching test on the bench; it is run for some time at full load and the output is measured by some form of brake. An old propeller serves as a very satisfactory brake. If the same one is always used for test purposes the reading of the revolution counter is a sufficient measure of the power. An engine after complete overhaul should be as good as, if not even better than, a new one.

In all engine repair or overhaul work cleanliness and system are of the highest importance. The work should be done in a place as free as possible from dust. All parts must be thoroughly cleaned with paraffin as soon as they are stripped, and must again be thoroughly cleaned and oiled before being reassembled. As parts are stripped all nuts, etc., must be replaced on their own screws. All the parts of one engine must be carefully kept together. Each cylinder assembly, including the valves, piston, connecting rod, etc., should be kept in a separate box. A clean and light workshop is conducive to good work. Its equipment should include paraffin baths for soaking and washing parts, swivelling benches for mounting the engine in to work upon, and suitably partitioned boxes in which the various parts may be placed as they are stripped.

Engines, unless properly cared for, are apt to give a good deal of trouble in cold weather. This arises from three main causes: the freezing of the water, the dampness of the atmosphere, and the congealing of the oil owing to the cold. After a machine has landed, unless it is possible to store it in some warm place, the water and oil should immediately be drained off, particular care being taken that every vestige of water is removed. The engine should then be covered with a quilted cover to protect it from all draughts. If possible heat should be applied to it in some manner calculated to keep it continuously warm. This may be done by means of special petrol or electric heaters so designed as to minimise the risk of fire. The heat, being retained by the cover, keeps the whole of the engine warm and dry. If this method is used and the oil tanks come under the influence of the heat, the removal of the oil is not necessary. When the engine is to be started the radiator is filled with boiling water, and the tanks, if they have been emptied, are filled with hot oil. The engine is then started as quickly as possible. The radiator, especially if exposed to the wind, freezes very readily. If any undue delay occurs in starting, more boiling water should be added to the radiator and an equivalent amount should be drained from the lowest point of the system. The engine should be kept ticking over as long as it is standing in the open.

If ignition trouble is experienced when starting, the fibre bush on which the contact breaker arm works may be looked to as the most probable cause. Failing this, the system generally may be damp. The only certain cure for the latter trouble is to remove the magnetos and plugs and dry them thoroughly in a warm place.

The subject of water and oil filling and heating deserves some comment. The same water must be used continuously, that is to say, the water that is drained out of the engine when it comes in must be carefully conserved and used over and over again. Every pint of new water that is passed into an engine conveys in with it a certain amount of mineral hardness which is added to the "fur" accumulated in the radiator and cylinder jackets. Anti-freezing mixtures are not usually to be recommended. When draining the engine particular attention must always be paid to the pump. A few drops of water may easily remain in its casing. These may freeze the rotor to the casing. When this occurs, if the propeller be turned the result is usually a broken pump or pump drive. For this reason it must always be made quite certain that the pump is free before any attempt is made to turn the propeller. Whilst the machine is standing a notice should be hung on the propeller forbidding people to touch it. The main point of importance in heating the oil is to avoid burning it. It should never be heated in a drum over an open fire; its viscosity prevents it from circulating freely, with the result that parts of it become overheated Castor oil, which becomes very viscid in cold weather, may be thinned before use by the addition of a little methylated spirit. An engine usually requires rather smaller jets in winter owing to the increased density of the atmosphere. A thinner grade of oil may also be used. All exposed water or oil pipes should be lagged by wrapping them with asbestos string or other material of low conductivity.

CHAPTER XX

INSTRUMENTS

THE experienced pilot seldom refers to his instruments in normal circumstances. He flies the machine instinctively, and he immediately recognises any change in the running of the engine by its changed note. When, however, circumstances are abnormal, he becomes very dependent upon his instruments. When flying through clouds, for instance, the pilot can see nothing but the thick vapours around him. Placed thus, the machine may behave most erratically, and the pilot has no means other than the use of his instruments whereby he may judge of its position relative to the earth. Engine trouble can often be diagnosed immediately by reference to the various gauges. Again, where a machine is being navigated from place to place, the navigator may be entirely dependent upon certain of his instruments for the fixing of his position. Instruments are necessary to efficiency because they measure performance in units which are at once standard and impersonal. Before it is possible to say that any mechanical device is giving the best possible results, standard figures must be available for purposes of comparison. Scientific improvement demands scientific methods, and the latter demand accurate records of progress capable of comparison.

The instruments in common use on aircraft are :

1. The Air Speed Indicator or "Pitot."
2. The Magnetic Compass.
3. The Engine Revolution Counter.
4. The Altimeter or Aneroid.
5. The Cross Level.
6. The Petrol and Oil Pressure Gauges.
7. The Petrol (Quantity) Gauge.
8. The Voltmeter and Ammeter.

9. The Watch.
10. The Turn Indicator.
11. The Engine Thermometer.
12. Other Special Purpose Instruments.

Of the above list Nos. 1 and 2 are sufficiently important to deserve more detailed mention than can be given them in this chapter. A special chapter has therefore been devoted to them.

Every aeroplane does not of course carry the full list of instruments detailed above, but only such as are essential to its proper control.

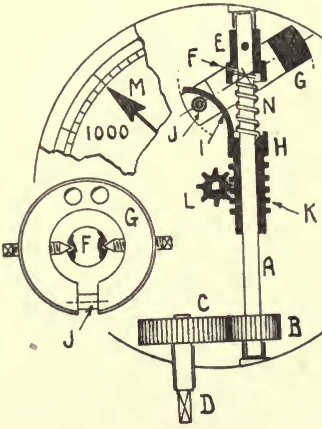


FIG. 105.

The Revolution Counter is used to indicate the speed of rotation of the engine. It is calibrated in revolutions per minute. A common form of construction is that indicated in Fig. 105. A shaft A is driven by gearing BC from the connection D. To D is attached a flexible shaft similar to that used in the case of a motor speedometer. The other end of this shaft is connected to some convenient rotating part of the engine, usually some part of the timing gear. The shaft A has pinned to it a sleeve E on which is pivoted (at F) a heavy ring G. Sliding on the shaft is a second sleeve H, which is fitted with a curved finger I. The latter engages a small roller J on the ring. The body of the sleeve H has on it a series of grooves K which mesh with the teeth of the pinion L on the pivot of the pointer M. Between E and H is a compression spring N which tends to force them apart. As the shaft A rotates, the ring G, owing to centrifugal force, tends to assume a position at right angles to the shaft. This motion is resisted by the action of the spring. The faster the speed rotation, the greater will be the force exerted by the ring and the more the spring will be compressed. The spring is compressed by the movement of the sleeve H. This movement rotates the pointer on the dial of the instrument. The dial may therefore be calibrated to read revolutions per minute of the engine. Instruments of this type require little attention and are comparatively accurate. They may be calibrated by comparison with a standard test instrument. The readings of any one instrument, even if not absolutely correct, are always relatively so, which from the pilot's point of view is the essential. The only attention necessary as far as the instrument is concerned is occasional lubrication. Excessive oiling is, however, to be avoided. After long use the instrument may be cleaned internally. If replacements appear necessary it should be returned to the makers. Trouble is sometimes experienced with the flexible shaft drive. This usually arises from taking it round too sharp bends. It must be kept well lubricated, which is easily done by pouring oil through the casing.

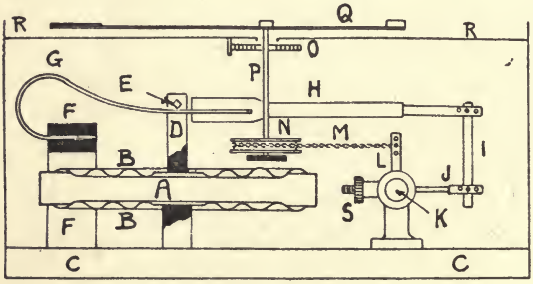


Fig 106

The Altimeter is a simple aneroid, the dial of which is graduated in thousands of feet. The pressure of the atmosphere falls as indicated by the curve in Fig. 139. The altimeter dial reads 10,000′ where the aneroid would indicate a pressure of about 10 lbs. per square inch or 20″ of mercury. Its construction and working may be followed from the diagrammatic view in Fig. 106. A is a flat circular box made of German silver. The top and bottom surfaces of the box BB are circularly corrugated to render them flexible. This box is exhausted of all air and is absolutely airtight. The effect of the external atmospheric pressure is to force together the two flexible walls. One face of the box is rigidly fixed, as shown, to the base C of the instrument. The force due to the external atmospheric pressure, which tends to crush the sides of the box inwards, is resisted by the upward pressure of the strong leaf spring G on the pin E, which passes through a pillar D mounted on the other face of the box. The leaf spring is mounted on a bridge F, which is fixed to the base C. It is evident then that as the machine ascends and the external pressure is reduced the pin E will gradually rise. This movement is suitably magnified and transmitted to the indicating pointer Q which moves over the graduated dial R. The magnification is due to the following mechanism. To G is fixed an arm H. The oscillation of this arm is transmitted to a rocking shaft K, which is mounted on the base of the instrument, by the link I and the adjustable lever J. On this rocking shaft is mounted the lever L to which is attached a very light chain M. This chain passes over a drum N on the pointer shaft P, thus actuating it. The chain is kept tight by the action of the spiral hair-spring O. The ratio between the movements of the pin E and the pointer may be varied by adjusting the screw S or by using the alternative pin holes shown in the various levers. The altimeter may be calibrated by comparing its readings with those of a mercury barometer in a vacuum chamber and using a curve similar to that shown in Fig. 137. The scale of the altimeter is usually arranged to be capable of rotation so that the zero can be set before leaving the ground. This is necessary owing to the fact that the atmospheric pressure varies slightly from day to day. If the barometer were to fall ½″ between two flights the altimeter would be found reading 500′ when the machine was wheeled out for the second flight. When using the instrument it must always be remembered that the zero is set to the height at which the machine starts, and that therefore in the course of a flight it does not indicate the height above the ground, but the height above the starting-point. The ordinary altimeter is not convected for temperature variation. It is calibrated, assuming a uniform temperature of 10° C. The readings are therefore subject to considerable error at high altitudes, the instrument indicating a height greater than the true one. The following figures show the very approximate corrections: 10,000′ – 200′, 15,000′ – 500′, 20,000′ – 1000′. The error depends on the existing temperature conditions.

FIG. 107.

The Cross Bubble is a very simple instrument; it consists of a bubble tube, as shown in Fig. 107, sufficiently curved to show angles of 10° to 15° each way. It is mounted on the instrument board in such a way as to indicate the cross level of the machine. The uses of the instrument are two: first, to indicate whether the machine is flying on an even keel, and, secondly, to check the accuracy of turns. Its action in the first case is obvious. In the second case the accuracy of a turn is indicated by the bubble remaining exactly in its central position throughout the whole turn, whatever the bank. This appears somewhat curious; the reason, however, is as follows. If a turn is correctly banked, the banking effect exactly balances the centrifugal force (see Fig. 17). The same state of affairs exists in the bubble tube. The tendency of the bubble to run to one side owing to gravity is exactly equalised by the centrifugal effect tending to send it in the other direction. A further fact demonstrating this is that if a pilot does even a comparatively steep turn absolutely correctly and his passenger is not looking out of the machine at the time the passenger will be quite unaware that he is turning. Likewise when a pilot is in a cloud he cannot possibly tell without referring to his instruments whether the machine is flying straight or doing a correctly banked turn.

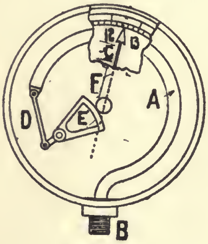


FIG. 108.

The pressure gauges used on aeroplanes for indicating pressure of from about 2 lbs. per square inch upwards are made on exactly the same principle as those used in steam and other types of heavier engineering. They are constructed on the well-known and easily demonstrated principle that if a curved tube is subject to an internal pressure it tends to straighten itself. The usual form of the instrument is indicated in Fig. 108. The piping system in which the pressure is to be measured is coupled by a union B to the curved oval section pipe A. This when subject to internal pressure straightens itself by an amount proportional to that pressure. The resulting slight movement of its free end is suitably magnified and transmitted to the pointer by the link D which actuates the toothed quadrant E. The latter gears with a small pinion F on the pointer shaft. These instruments seldom get out of order, but they are often not very accurate. If, however, for any particular reason, extreme accuracy becomes desirable, they can easily be calibrated by being tested against a more expensive standardised instrument of the same type.

Gauges indicating the quantity of petrol in the tanks are not usually very satisfactory, at any rate on aeroplanes. The pilot generally satisfies himself that the tanks are full before he starts, and then, knowing the rate of consumption, makes sure of landing with a balance of petrol in hand. The simplest type of gauge consists of an ordinary glass gauge tube fitted as indicated on Fig. 109. This is only suitable in cases where the tank is in the immediate view of the pilot. It has the further disadvantage that in the event of a crash, which may not break the tank, the gauge will probably break and cause a very undesirable flood of petrol. Gauges of this nature should always be fitted with taps so that in the event of breakage the petrol may be shut off. Another simple arrangement consists of a float in the tank, which is coupled by means of a cord and suitable gearing to the pointer of the gauge instrument. The cord is very liable to stick into its guides and so give misleading readings. An ingenious arrangement, which is fairly satisfactory in some situations is indicated in Fig. 109. This consists of an indicating pointer E attached to a twisted metal strip B, which passes through a slot in the float C. The float C is prevented from rotating by the fixed guide rods DD.

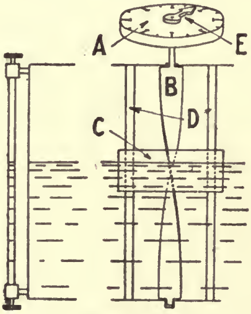


FIG. 109.

Concerning the electrical instruments—usually a voltmeter and sometimes an ammeter—little need be said. Space does not permit of a description of the principles on which they work. They require no attention in upkeep, and if they do go wrong the question of their repair is one for the makers. These instruments are very delicate of construction, and must at all times be very carefully handled. They should also be protected as far as possible from vibration.

The Turn Indicator is an instrument not often used on aeroplanes except when cloud-flying is anticipated. The difficulty of telling whether a machine is keeping on its course when in a cloud has already been touched upon. The dial of the instrument is as indicated in Fig. 110. It simply shows the direction in which the machine is turning. There are two common forms. One works on a simple gyroscopic principle. The second consists of a differential air speed indicator (see Chapter XXI). A head is fitted at each wing tip, the dial reading being influenced by the difference of speeds of the two wings and also, to some extent, by the centrifugal force on the air in the pipes.

FIG. 110.

The Thermometer is a very necessary fitting on all water-cooled engines. Every engine has a water temperature at which it runs best, and some form of thermometer is necessary to enable the pilot to control this. The type of instrument ordinarily used is shown in Fig. 111. It consists of a small metal cylinder A, which is usually situated in the top header of the radiator, i.e. the point at which the hot water from the engine enters. It is connected to a metal tube B of very fine bore and of sufficient length to reach back to the instrument board. The cylinder A is filled with a liquid of very low boiling point, usually ether. The temperature of the water in the radiator causes the ether to boil. As the temperature rises the vapour pressure in the cylinder and pipe due to the boiling ether also rises. The gauge C is an ordinary pressure gauge which, instead of being graduated in lbs. per square inch, is graduated in temperatures necessary to raise the ether in the cylinder to the corresponding pressures. When using the thermometer the effect of the atmospheric pressure on the boiling point of water must always be remembered. The fall of the boiling point is approximately 1° C. per 1000 feet.

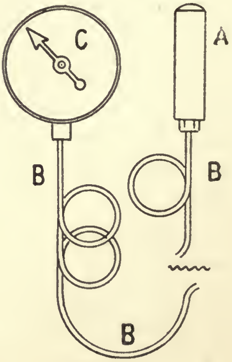


FIG. 111.

CHAPTER XXI

THE COMPASS AND THE AIR SPEED INDICATOR

THE Compass is the only instrument by means of which the aviator can tell the direction in which he is flying. He is very dependent on it when the machine is above clouds or otherwise cut off from the sight of recognisable landmarks. It is therefore essential for him thoroughly to understand its use and to be able to make the adjustments on which the accuracy of its readings depends. In order to understand the compass some elementary knowledge of the laws of magnetism is essential. A magnet is a body possessing the power of creating a magnetic field about it. It has always two "poles" from which the magnetic lines of force radiate. The field created by a bar magnet is as shown in Fig. 112. Each line of force leaves the magnet at one of its poles and re-enters it at the other. The intensity of a magnetic field is measured by the number of these lines per unit area. The strength of the field therefore increases very rapidly as the poles are approached. If any magnet is freely suspended in the field of another magnet it will swing into such a position that the line joining its poles lies along the lines of force of the field, the so-called "North Pole" of the one magnet pointing towards the "South Pole" of the other. The fundamental law is: "Like poles repel, unlike attract one another."

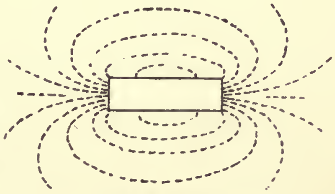


FIG. 112.

The earth is itself a magnet having its poles situated in the neighbourhood of the geographical poles. Any magnet if freely suspended in the earth's field, therefore, takes up a position such that it lies along the lines of the earth's magnetic field, its North-seeking or South pole pointing North. Owing to the fact that the magnetic and geographical poles do not coincide, and owing also to irregularities in the earth's magnetic field, introduced by igneous rocks and other causes, a correction has always to be applied to a bearing as read on the magnetic compass in order to obtain the true or geographical bearing. The amount of this correction is termed "Variation." The variation at any point alters slightly annually. At Greenwich the magnetic compass points about 15° West of North; the variation is 15° W.

Steel and iron may be magnetised by being placed in the magnetic field of some other magnet; the more powerful the magnet and the field which it produces, the more intensely will they become magnetised. Soft iron or steel, whilst readily capable of being magnetised, has little power of retention. Hard steel, however, if strongly magnetised retains a portion of its magnetism for a long period and becomes what is called a permanent magnet.

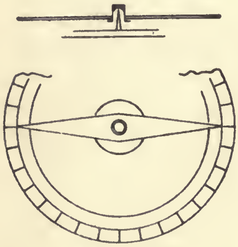


FIG. 113.

The compass in its simplest form consists of a permanently magnetised hard steel needle pivoted as indicated in Fig. 113, and arranged to rotate over a suitable scale. The direction of the magnetic lines of force between the earth's poles is not necessarily parallel to the earth's surface. As a matter of fact, at Greenwich they point downwards at an angle of 67° to the horizontal. Were a magnetic needle horizontally pivoted, it would point downwards at this angle. This is obviated in the case of the compass needle by pivoting it (as shown in Fig. 113) at a point above its centre of gravity and making the south-seeking end the heavier. The vertical component of the magnetic attraction is then balanced by the forces due to gravity. The needle is, however, perfectly free to adapt itself to the horizontal direction of the magnetic lines of force; the navigator only concerns himself with directions in the horizontal plane.

The compass as used on aircraft is more complicated than that shown in Fig. 113. The scale is usually attached to the needle, this "card," as it is termed, being read against a fixed line on the body of the instrument termed the "lubber line." A compass needle suspended in air rotates very freely and oscillates a great deal before coming to rest at its true reading. The aero-compass is "damped" by completely filling the casing of the instrument with liquid. This device also provides a method of balancing the weight of the moving system, which consists of two or more magnets and the card. The weight is balanced by means of a float. The liquid is usually alcohol so as to avoid freezing.

Fig. 114 shows diagrammatically a typical aeroplane compass. A is the spherical casing which is filled with liquid. In order to allow for the expansion and contraction of the liquid with varying temperature an expansion chamber C with a corrugated face is fitted. A glass window O is provided through which the card is observed. D is the vertical pivot on which the moving system rotates. There is a second guard wire N with a small clearance, preventing the moving system from jumping off the pivot. The moving system consists of the float F in which is fitted the agate bearing point G and to which are attached the two magnets (one shown) H and the card E. The card E is cylindrical and is graduated on its inner surface, bearings being read against the lubber line I, which is fixed to the casing. The bowl is carried in the casing J, and is insulated from vibration by the soft felt pads K. The case J is fixed to the instrument board of the machine. To it is also attached the cylinder L containing the rack M in which may be inserted the compensating magnets.

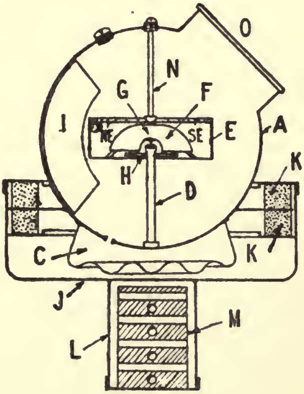


FIG. 114.

It has already been stated that iron and steel become magnetised when placed in a magnetic field. The degree and polarity of magnetisation depend on their direction relative to the lines of force of the field and are a maximum when they lie along those lines. To this fact is due much of the error termed "Deviation" to which the compass is liable in service. A considerable amount of steel is used in the construction of an aeroplane, and this becomes magnetised owing to its being situated in the earth's magnetic field. The softer metal becomes magnetised according to the machine's position at the moment relative to the lines of force of the earth's magnetic field. The harder metal may, however, become more or less permanently magnetised. The soft metal affects the compass differently according to the direction in which the machine is flying. The hard exerts a constant effect irrespective of direction of flight. Any electric circuit near the compass affects it. The magnetos may also have quite a large effect on the compass, and this effect varies according to whether the engine is standing or turning. Vibration affects the compass adversely, and must therefore be avoided as far as possible. In choosing the position for the compass all these points must be taken into consideration. It must be placed as far as possible from steel members. Steel must not be used in the construction of its fixings. The compass should also be as far away as is practicable from the engine, and the mounting should insulate it from vibration.

An obvious way to neutralise the effects of permanently magnetic portions of the machine is to place small permanent magnets near the compass, and to arrange these as far as possible in such a way as to neutralise the magnetic effects in the neighbourhood of the moving system. In this way the readings may to a great extent be corrected. The remaining errors which are mainly due to soft iron and which are not usually corrected, are tabulated on a card which is fixed near the compass, the necessary corrections being made from this.

The method of adjusting the compass is as follows. Lines are pegged out on the ground, showing the four cardinal magnetic points and the four intermediate points. The machine is set up in flying position pointing N. and then S. If the compass is in error a small corrector magnet is placed in one of the slots of the rack M (see Fig. 114) pointing in an E. and W. direction. The higher up in the rack the magnet is placed, the greater is its effect. If necessary more than one magnet is used. It will be noted that a magnet placed in an E. or W. or crosswise direction in the rack will affect the N. and S. readings of the compass, but will have no effect on its E. and W. readings since when the compass points in the latter direction it is lying parallel to the lines of force of the field created by the correcting magnet. The machine is now pointed first E. and then W., the error being corrected by putting one or more magnets in the rack in a fore and aft direction. The machine is now swung round and the errors noted on all points, the compensating magnets if necessary being so adjusted that a minimum average error is obtained. When adjusting a compass in this manner care must be taken that any movable steel is in a normal position. The compass should be tested periodically for frictional error. This is easily done by deflecting the card with a magnet and noting that it returns exactly to the point at which it started. After the compass has been set, the engine should be run, and it should be noted whether this has any appreciable effect on the readings.

In the air the compass must be relied upon only in straight flight. Its readings during a turn are apt to be very misleading. When a machine banks the compass card banks with it. In this banked position the magnets are affected not only by the horizontal component of the earth's magnetic force, but also by the vertical. If a machine flying North, for example, be banked steeply to the right, the card will immediately swing to the East owing to the magnet becoming affected by the downward component of the earth's magnetic force. The card may also be subject to certain inertia effects which render its readings inaccurate during manœuvre.

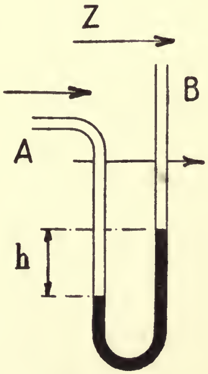


FIG. 115.

The Air Speed Indicator, or "Pitot," as it is commonly called, measures the air speed of the machine, and is therefore, to the navigator, only second in importance to the compass. The name Pitot is that of a French engineer who first applied the principle to measuring the rate of flow of water. The principle of the instrument is an application of the law $P=KA\rho V^2$. If a tube arranged as shown in Fig. 115 be situated in a current of air of velocity V, then a pressure proportional to V^2 will be produced in the tube A, whereas the pressure in the tube B, the orifice of which is at right angles to the direction of flow, will simply be the static (or no velocity) pressure which obtains at the point. If a column of liquid be situated in the lower " U " of the tube, then it will be depressed in A and raised in B, the difference in height *h* being proportional to the square of the velocity of the air. A scale might be fitted to read *h* in miles per hour. The earlier instruments were in fact made in this way. Later types of instruments, however, dispense with liquid, a delicate gauge being used to measure the pressure, and a dial indicator graduated in miles per hour being fitted.

The Pitot " Head," as it is called, is usually made as shown in Fig. 116. A is the pressure tube; B is the tube measuring the static pressure, commonly, but erroneously in this case, called the suction tube. These are mounted on a convenient part of the machine C by the metal frame D. The pipes E are led to the gauge in the pilot's cockpit. The tube A is open. B is closed and streamlined in front and has a number of very small radial holes drilled in it. In fixing the head it is essential that it should be placed clear of the propeller slip stream and of any eddies created by parts of the machine. It must also point exactly in the direction of normal flight. One of the leading interplane struts is the position normally chosen.

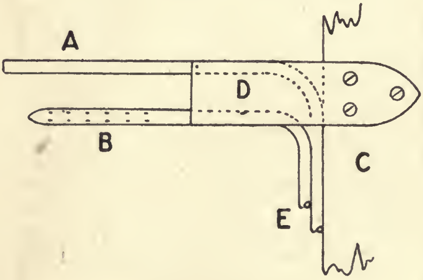


FIG. 116.

Great attention must be paid to the pipe lines between the head and the instrument. This is the seat of most of the troubles to which the air speed indicator is liable. Thin aluminium piping of about $\frac{3}{8}$-inch bore jointed with rubber tubing is commonly used. The chief trouble likely to arise as the result of faulty arrangement of the pipe line is due to water. When flying through clouds or in rain, water is apt to get driven into the tubing. The lie of the piping should not provide any points where this can settle and freeze. Faulty working is often traceable to perished rubber joints. The joints may easily be tested by putting a tube on the head and blowing up with the mouth a pressure equivalent to, say, 100 m.p.h. on the gauge. If the tube is then pinched together and held, the gauge reading should remain constant. The suction tube is not so important as there is normally practically no suction or pressure in it. The simplest method of testing it is to change over the pressure and suction connections at the gauge. The suction tube is then tested in the same manner as the pressure. The aluminium tubing, which is usually fairly thin, must be guarded against the possibility of becoming kinked by cowling or other moveable parts of the machine.

The instrument itself is simply a rather delicate pressure gauge and is constructed somewhat on the principle of the altimeter. Two aneroid boxes A and B are fixed, as indicated in Fig. 117, to the casing of the instrument. Their free expandable surfaces are connected by a short link C, which at its centre carries a longer arm D. The arm D, which greatly magnifies the motion, engages a slot attached to Quadrant F. The latter engages a small pinion fixed on the pointer shaft. The instrument casing is made airtight and the suction pipe from the head is coupled to the casing by the connection S. The pressure pipe is connected to P, which is fitted with two branches *pp* inside the instrument communicating with the interiors of the two aneroid boxes. These boxes are subject internally to the pressure produced in the open tube of the Pitot head and externally to the static pressure of the air in the neighbourhood of the head. It should be noted that owing to fuselage eddies this latter pressure may vary considerably from that existing in the cockpit. The expansion and contraction of the boxes is therefore entirely dependent upon the air speed of the machine. The dial of the instrument is graduated to indicate the air speed in miles per hour. The only trouble commonly met with in the

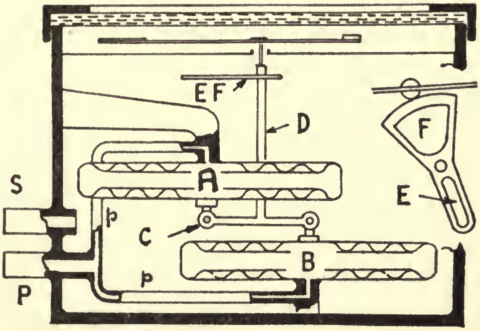


FIG. 117.

instrument itself is air-leakage of the case. This occasionally occurs at the joint of the glass, and is usually caused by want of understanding of the principle of the instrument on the part of some person who has taken it to pieces and not reassembled it with sufficient care or skill, as the case may be.

A point worthy of note is that any fault to which the various parts of the Pitot may become subject in service causes it to give low readings. If the head becomes bent it does not receive the full effect of the machine's air movement. Other faults are all connected with either air-leakage or choking of pipes. These likewise cause the readings to be low. The only really satisfactory test of the Pitot is a flying one. A measured ground distance is flown and the flight is timed by stop watch. In doing this test, allowance must be made for wind. The simplest method is to fly a course directly up and then down wind timing in both directions.

The chief correction which must be applied to the Pitot in service is that due to altitude. This matter is, however, dealt with in a separate chapter on altitude effects.

PLATE XI

AIR SPEED INDICATOR--DIAL AND HEAD

AERO TYPE COMPASS

CHAPTER XXII

RIGGING

THIS chapter, being devoted to rigging, must necessarily touch upon many subjects more particularly discussed in other chapters since any discussion upon rigging itself necessarily involves mention of the general care of all parts of the machine other than the engine. The subject is, however, treated here solely from the point of view of the work done in the sheds.

Rigging is the art of erecting the machine and so adjusting the various surfaces, controls, etc., that it is in a fit condition for flying. The upkeep of the machine is also part of the rigger's work. The various dimensions must be checked and adjusted and any parts showing signs of deterioration replaced. The importance of this work cannot be exaggerated. To ensure real efficiency the mechanic must have a genuine and personal interest in it. He must feel a sense of responsibility and he should be encouraged to realise that upon his efforts depends the consistent good working of the machine.

The capable rigger should have a general knowledge of the loads to which the different parts of the machine are subject. Rule of thumb is useless, and mere experience hardly less so. The invaluable rigger is the man who thinks about his work, connects cause with effect, draws inferences from personal observation, and thus turns the fruits of his accumulated experience to practical account. To such a man nothing is more disappointing or discouraging, however, than to feel his work unrecognised or unappreciated.

The ultimate test of rigging is the air test. Two machines of the same type both rigged as accurately as possible may nevertheless vary greatly in their air performance. The mechanic has to depend entirely on the pilot for the necessary information upon which to base his adjusting of the machine. The pilot, on the other hand, has less time than the mechanic for examining the machine on the ground. Moreover, he is probably less skilled in the art of detecting possible faults. The highest efficiency therefore necessarily involves the closest co-operation between pilot and mechanic. A pilot should have an intimate knowledge of the rigging of his machine. When this is the case good work can be accomplished even with an inferior mechanic, provided the latter is conscientious and trustworthy.

One of the first rules of rigging is that a machine should not be rigged too tightly. This only strains the fittings unnecessarily. It also imposes loads on the machine in flight over and above those due to the air reactions. In the case of the main planes, for example, the landing wires take all the load when the machine is on the ground. The flying wires should then be appreciably slack. If, however, they be too slack, when the machine is in the air and they take the load the landing wires will be so loose that they will vibrate excessively. When adjusting any particular wire the effect of the air forces on the parts concerned must be considered. This point finds illustration in the case of the extension flying wires on a machine where the extension is not braced by a king-post and wires on the top of the plane. When the machine is on the ground the weight of the extension is supported by a bending moment in the spars which consequently sag somewhat. Were the wires rigged tightly the effect would be to increase this sag, the plane being pulled out of shape. The extension lift wires are therefore left very slack.

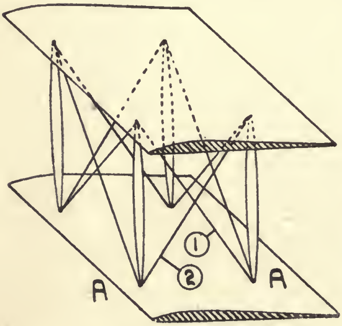


FIG. 118.

A further point of great importance is the effect which the alteration of one wire may have upon others. The adjustment of one wire usually necessitates the adjustment of several others. An example of this is to be found in the alteration of the incidence of the main planes (Fig. 118). To increase the incidence of the plane at A the rear spar is dropped slightly relative to the front one. This is done by adjusting the incidence wiring. The wire 1 must be lengthened and the wire 2 correspondingly shortened. This, however, affects the landing and flying wires. Since it is the rear spar that is to be dropped the rear landing wire must be lengthened and the flying wire correspondingly shortened. In order therefore that the incidence wiring may be adjusted the rear landing wire must first be slacked off.

Unnecessary loads are often inflicted on members of the structure of machines by the way in which they are handled when under repair. When a machine is supported in any way on trestles these must be so arranged that the points of support are at joints in the structure and never at a point part way along a strut, as, for example, in the middle of one of the fuselage bays. Also care must be taken that the trestle does not bruise the woodwork or do other damage. If necessary, padding of some kind must be interposed. A machine is designed to stand upon its undercarriage. If this has to be repaired or replaced the problem of supporting the whole weight of the machine arises. To support it from joints of the fuselage other than those where the undercarriage is attached is usually unsafe since these are not designed to be sufficiently strong. In this case a common method is to take the weight by lifting the engine, either packing it up from a trestle, or using a tripod for the purpose. This method, however, cannot always be adopted. When it is impossible other methods must be sought. The largest weights are usually the engine and the tanks if these be full. The supports must be so applied that parts of the machine not designed to take these concentrated weights should not be called upon to do so.

The tools required by the rigger consist of a selection of spanners, pliers, wirecutters, etc., also certain measuring tools which are used to check the accuracy of the machine. These last include straight-edges of various sizes, trammels, a steel tape, a spirit-level, and sometimes a clinometer level. In order to check the truth of any part of the machine the latter is always first set up in "flying position" (i.e. the position of normal flight) by raising the tail off the ground the correct amount by means of an adjustable trestle. The various lengths are then checked by measurement, and the angles of the lifting surfaces by applying a level to them.

The straight-edge consists simply of a strip of wood, the two edges of which are planed parallel and perfectly straight. Several of varying length are usually kept. The chief use of the straight-edge is to check the relative level of different parts, for example, the two top longerons. The straight-edge is laid across the two points to be checked and the spirit-level laid on the top edge of the straight-edge. The vertical truth of parts is checked by means of plumb lines. A modified form of straight-edge which is exceedingly useful for checking the truth of angles differing slightly from the horizontals, such as the angles of incidence of the lifting surfaces, is shown in Fig. 119. The straight-edge is here provided with two fingers AA adjustable by means of screws. The figure indicates the way in which it is applied to the checking of the incidence of the main planes. The fingers are so set that when they are held in contact with the lower surfaces of the main spars the straight-edge itself is level. The correctness of the incidence angle is then shown by the spirit level at B. This form of straight-edge is really a simple form of clinometer.

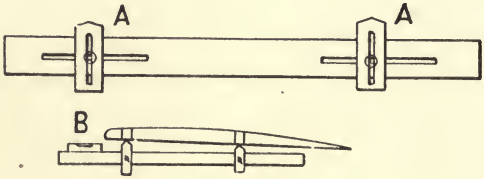


Fig. 119.

A clinometer suitable for rigging work is shown in Fig. 120. The instrument consists of a short straight-edge C which carries a spirit-level A. The level is mounted in such a manner that it can be rotated. The position of the level is read on a scale marked on B. The scale is so graduated that it shows the angle at which the straight-edge is inclined when the bubble is level. In use the clinometer is usually applied to a longer straight-edge.

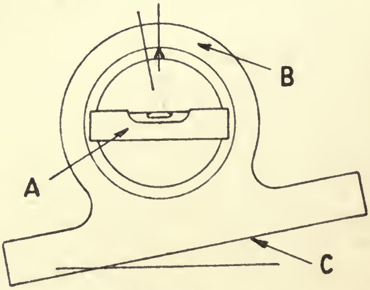


Fig. 120.

Trammels consist simply of two pointers or scribing points attached to a light rod adjustable in length. They are used for the accurate comparison of lengths, as, for example, the two diagonals of a symmetrical bay of the fuselage bracing. The steel tape is used for checking the accuracy of the larger dimensions of the machine; the symmetry of the whole machine may, for example, be checked by measuring on each side the distance from, say, the outer interplane strut sockets to the rudder-post.

The next chapter is devoted to a fairly detailed description of the complete assembling of a typical aeroplane. It is proposed here only to describe a few very elementary rigging jobs, partly as being illustrative of the principles involved and of the uses of certain tools, and partly as an introduction to the next chapter.

To true up a symmetrical side bay of the fuselage, centre lines such as AB and CD are first marked on the struts and longerons at the joints, as shown in Fig. 121. The two diagonal bracing wires would then be tightened up approximately, the truth of the bay being judged visually. The trammels are set to the distance WX; the distance YZ is then checked with them, the lengths of the bracing wires being adjusted till these two are exactly equal. The tension in the two wires is then adjusted to approximately the same amount by feeling the tautness. The dimensions WX and YZ are finally checked. Lastly the turnbuckles are locked with wire, as indicated in Fig. 58.

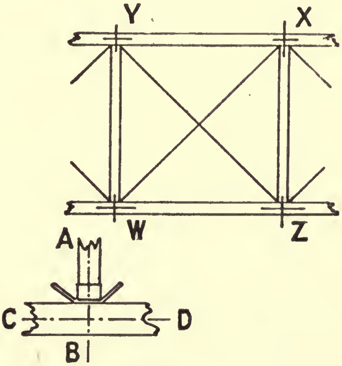


FIG. 121.

Suppose that a machine is found to be flying nose heavy—i.e. it tends to drop its nose and to adopt an excessive speed when the control pillar is in its neutral position. The probability is that the tail plane is rigged with too much incidence. In most machines the line of action of the propeller pull is horizontal when the machine is in its position of normal flight. The level of the engine bearers is therefore commonly taken as the basis from which the rigging is checked and adjusted. The tail is raised on a trestle to such a position that the engine bearers are exactly level in fore and aft and crosswise directions. This is checked by trying them by means of a spirit-level placed either directly upon them or on a straight-edge placed across them. In some instances it happens that the bearers themselves are not very convenient of access, in which case some part rigidly attached to them and known to be correct, as, for example, the front portion of the top longerons, may be used as a basis instead. The machine being in flying position, the incidence of the tail plane is tested. Before altering it, it is usual to check it with the standard dimensions for the type of machine. The incidence of the tail plane may be given in degrees or by the "rise" or difference in level between the two tail plane spars. In the former case the measurement is most simply made by means of a clinometer as shown in Fig. 120. In the latter a straight-edge, as shown in Fig. 119, would be used. Some form of adjustment of the tail plane incidence is always provided. This usually takes the form of an adjustable fuselage fixing for either the main or the rear spar. If it is decided to alter this, the first thing done is to unlock and slacken off all the tail plane bracing wires ABCD, shown in Fig. 122. The incidence is then decreased by such an amount as experience has shown to be necessary to effect the required decrease in the speed of the machine. If a doubt exists as to the amount of a correction it is usually wise to err on the side of under rather than over correction. The incidence having been corrected by the required amount, the tail must be trued up. A level is placed along the main spar, the wires AA being adjusted till the spar is perfectly level. The length of the wires are also equalised (by

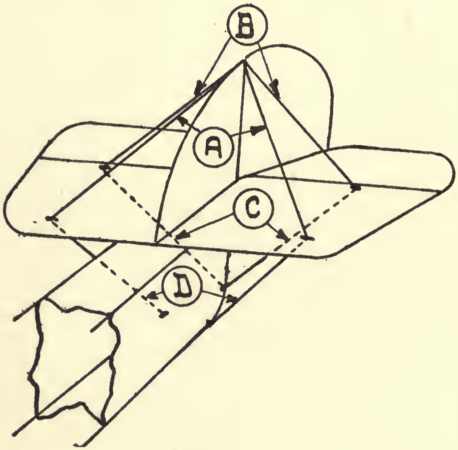


FIG. 122.

trammelling) in order to ensure that the rudder-post is not pulled out of the vertical. The wires DD are then tightened till they are just tight, but not excessively so. The same process is gone through with the rear spar, the wires BB and CC being adjusted. As a check the incidence and the tail at different points may be checked with a straight-edge and level, as shown in Fig. 119. Finally all wires should be locked.

In view of the extreme importance of even the smallest detail of the rigger's work, slovenliness of any kind can never be permitted. Untidiness leads to slipshod methods and bad workmanship, which in their turn must inevitably lead sooner or later to disaster. At times, as, for example, in the absence of some required spare part, it is necessary to modify the original construction of the machine in some minor detail. Such alterations must, however, always be considered and authorised by some person thoroughly competent to judge of their effects. Another essential rule in rigging work is that one job must be finished before another is begun. There are always so many small lock nuts, hinge pins, split pins, etc., each one of which is vital to the safety of the machine, that, unless one section of the work is finished before another is begun, oversights are almost inevitable.

All jobs should be independently checked before being passed for service. A perfectly definite system of doing, checking, and recording all work must be adopted and adhered to. The question of recording the work is an important one. It is now necessary by law that every aeroplane should carry its log book in which all repairs, alterations, etc., shall be recorded. Apart from this, however, the keeping of really comprehensive records of all work done and the having each entry signed by the person who has done the work is perhaps the soundest way of ensuring method and systematic efficiency. The act of signing brings home to the rigger or checker his responsibility for the work, besides which, having the worker's name thus recorded, makes tracing a man who has done unsatisfactory work a simple matter.

Shed work includes the routine cleaning of the machine. Machines must periodically be cleaned down thoroughly both inside and out. After every few hours' flying the parts which have become dirty or oily must be cleaned. Rust must never be permitted to exist anywhere. The object of cleaning a machine is twofold. First, it prevents unnecessary deterioration. Secondly, the periodical cleaning and consequent inspection of the various parts by the rigger familiarises him with their condition and immediately brings to his notice any defects. No good pilot will allow his machine to be kept dirty, for this reason if for no other.

PLATE XII

CLERGET 110 HORSE-POWER ROTARY ENGINE

CHAPTER XXIII

THE ERECTION OF A MACHINE

THE complete erection or rebuilding of a machine usually involves simply the assembling and adjusting of the various components, the planes, fuselage, engine, etc. The erection of these several components concerns the manufacturer only. It is proposed in the following pages to describe in some detail the work either of erecting a new machine or of reassembling one that has been stripped. The work involved in rebuilding a machine that has been seriously crashed is essentially the same; in this case, however, it is further necessary very carefully to inspect each part before it is used, replacing any parts that are not perfectly sound. For the purpose of illustration a single-engined tractor biplane with staggered planes has been chosen. This is at the present time the form of machine most commonly used. Furthermore in the course of its erection it provides examples of most of the more usual rigging problems.

The fuselage is the datum from which the machine is built and adjusted. As all the other parts are attached to it, it is naturally most simple first to get it absolutely true and then to adjust each of the other parts relative to it as they are built on. In order that the fuselage may be trued up it is set up on trestles in the position of normal flight. This may be obtained by reference to drawings of the machine. Most machines are in normal flying position when their engine centre line is horizontal. Fig. 123 shows a fuselage set up in this manner. The trestles are placed exactly under the joints, as indicated, in order to avoid straining the bottom longerons or throwing the structure out of truth. The first operation is to check the truth of the engine bearers. This is done by trammelling the bays and trying the level of the bearers themselves crosswise with a straight-edge and spirit-level. They are, if necessary, corrected by adjusting the lengths of the bracing wires. The engine bearers when true serve as a datum from which the rest of the fuselage is adjusted. By packing or other more convenient form of adjustment the trestles are set up until a level placed on the engine bearers shows them to be truly level in both the fore and aft and the crosswise directions.

The next step is to true up all the internal or cross bays of the structure. Their truth is checked entirely by trammelling. These bays must necessarily be trued up first as the subsequent adjustment of the side and top and bottom bays is thereby facilitated, that is to say, the trueing of one side bay will true up the corresponding bay on the other side.

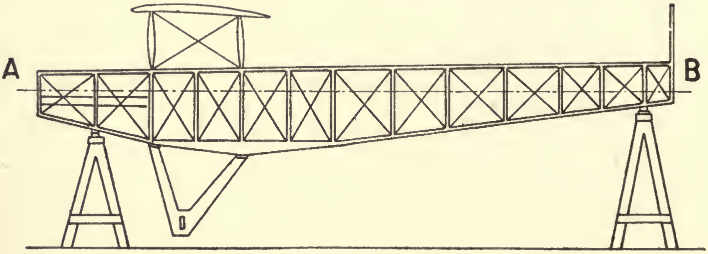


FIG. 123.

A tight string line is now put through on the side of the fuselage, as indicated by AB in the figure. For the position of this line reference must be made to drawings or rigging diagrams. In many machines the top longeron in the side elevation is straight, and in flying position it is either horizontal or has a steady rise or fall aft. The amount of this rise from, say, the first strut aft of the engine bearers to the rudder-post must be obtained. Suppose that there is a rise of 4″, a mark, preferably of a permanent nature for future reference, is made, say, 7″ below the level of the top surface of the top longeron on the rudder-post, and another mark is made 3″ below the same surface on the strut. These marks fix the datum line from which the side of the fuselage is adjusted. If the fuselage is true the string line will be horizontal when stretched from the one to the other. This may be checked by holding a long straight-edge along it and testing its level with a spirit-level. In order to true up the side bays each vertical strut must be marked with the position where the string line should cut it. These points may be obtained from the drawings. If they are not given they must be either calculated or obtained graphically. For example, if there is a drop of 4″ and there is a distance of 16′ between the points, the centre line will drop ¼″ for each foot run. It is very usual for the makers to mark these points on the struts in course of manufacture. Having all the marks on the struts, the rigger adjusts the bracing wires of each bay, working back from the one most forward, so as to bring the points on the side struts coincident with the string line. In the trueing up of the side of the fuselage in this manner it is probable that the fore and aft level of the engine bearers will have been thrown slightly out. If so, the tail end of the fuselage must be slightly raised or lowered, as the case may be, to correct this level. The bays on the other side of the fuselage, which should have been slacked off during this adjustment, must now be trued up. This is most simply done by placing a straight-edge on which is laid a spirit-level across the longerons, the bays being adjusted until this is level.

The top and bottom bays are now trued up. As the fuselage in plan view is always symmetrical this is a comparatively simple operation. From the centre point of, say, the cross strut nearest to the engine bearers a string line is run through to the centre line of the rudder-post. The centre points are marked on all the intermediate cross struts and the wiring of the various bays is so adjusted that the centre points all lie on the string line. Whilst the wires of the top bays are being adjusted those of the lower should be slacked off. The fuselage should now be absolutely true in every direction. The rudder-post provides an excellent check. This in most machines should be truly vertical.

The locking of all wires is commonly left until the whole of the work has been completed and checked, since, if the checking discloses any error, the extra work of slacking is thus obviated. Finally, the whole of the bracing is gone over and its tightness checked by twanging the wires. The latter should be of even tightness throughout. The effect of rigging wires too tightly has already been pointed out.

The undercarriage is usually fixed next. This is a simple operation. With the ordinary " V " type the only measurement that does not automatically fix itself is the diagonal one. This is checked by trammelling the cross-bracing wires.

The centre section of the top plane is now fitted. It is extremely important that this should be done accurately as the truth of the main planes relative to the fuselage depends entirely on it. The centre section is usually carried by four centre section struts. The whole is loosely assembled in position, and then trued up as follows. A centre point is marked on the leading edge and a plumb line is hung from it. By adjustment of the front crosswise bracing wires this point is brought directly over the centre line which has already been marked on the cross struts of the fuselage. The rear bay crosswise bracing wires are similarly adjusted. In side view the centre section struts are commonly vertical. This being the case, the fore and aft cross bracing wires are adjusted to bring the struts into the correct position as sighted by a plumb line. The truth of the finished work should be thoroughly checked. To do this the level of the spars is tried with a spirit-level. The absolute parallelism of the sides of the plane with the centre line of the fuselage is checked by means of plumb lines.

The main planes are next attached. The way in which this is done varies with the form of inter-plane bracing. If only one pair of struts is used the planes must be fitted on separately. The top plane is first attached, being temporarily supported by props or slings. The lower plane is then fixed. As soon as the latter is in position the weight of the top plane can be taken by the landing wires and inter-plane struts. In cases where there are more than one pair of inter-plane struts the planes are usually assembled on the floor prior to attachment. The planes are stood up on their leading edges and the inter-plane struts and wires are fitted. The two planes are then lifted as a complete structure and attached to the fuselage and centre section.

To true up the planes the first dimension to be adjusted is the dihedral. This is set on the front spar by tightening or slackening the front bay landing wires. The angle, which is commonly about 3°, is set by using a special straight-edge similar to that shown in Fig. 119 and a spirit-level on the top surface of the spar. Alternatively a string line may be tightly stretched from wing tip to wing tip on the top plane, and the distance of this line above the centre section spar may be measured. Once the dihedral is set the front landing wires are not altered. The front flying wires may now also be tightened. A check on the symmetry of the planes may be made by trammelling on each side the distance from the centre point on the leading edge of the centre section to similar points at each side on the lower fittings of the front inner inter-plane struts.

The stagger is now adjusted. Suppose that this is 12″, i.e. in flying position the leading edge of the top plane is 12″ forward of the leading edge of the lower plane. This is measured by hanging plumb lines from the top leading edge and measuring the distance to the lower leading edge with a rule. The stagger is adjusted by means of the incidence or stagger wires (see Fig. 38).

The incidence of the planes is now checked, using a straight-edge and level, as shown in Fig. 119, either on the spars or from the leading to the trailing edge. In the latter case it should be applied directly under a rib. The incidence is usually made the same throughout, but will probably require some slight adjustment after an air test has been made. In connection with the incidence of planes the terms "wash in" and "wash out" are sometimes used. A plane is said to be rigged with "wash in" if it has greater incidence at the tip than at the root. The converse arrangement constitutes "wash out."

The incidence near the fuselage is fixed absolutely by the position of the spar fixings. Farther out it may be adjusted by altering the rear bay landing wires. The incidence should be very nearly correct, being affected by the incidence and stagger wires. Any alteration will affect the stagger dimension to some extent. If serious discrepancies are found the centre section must usually be looked to for the trouble. All wires are finally suitably tightened and locked. Any drift wires are attached. These should not be tight and should take no strain except in flight. The general symmetry of the planes may be checked by measuring with a steel tape the distance from, say, the lower rear outer inter-plane strut socket to the rudder-post on each side of the machine.

The tail unit is now fitted. This offers little difficulty. The tail plane is first attached. Its cross level is checked by means of a level laid on the front spar and adjusted by the bracing wires. Measurements should also be made from a convenient point on the centre line of the fuselage to the tips of its main spar to ensure that it is square with the fuselage. The incidence is checked in the same manner as that of the main planes and is adjusted by setting the rear spar, which has usually an adjustable attachment to the fuselage. If the plane is fitted with an incidence control this is set in its mid-position. The fin or fins are next attached. They are usually braced from the tail spar, and are set vertical and parallel to the centre line of the machine. The rudder and elevator are hinged on. All the wires and hinges are then gone over and properly locked.

It is now only necessary to fit the various control wires. Sufficient has been said concerning these to render any further description of their adjustment unnecessary.

Finally the engine, tanks, etc., are fitted in and all piping and engine controls are coupled up. When the fuselage covering has been laced up and other minor details attended to, the machine is ready for its air test. Before this takes place it is usually advisable that some entirely independent inspector should examine the work systematically to ensure that no lock nuts or other details have been overlooked.

CHAPTER XXIV

FLYING INSTRUCTION

LEARNING to fly is not difficult, and in these days flying need involve no greater strain upon the nervous system than driving a motor-car. It is true that the first flight affords a somewhat novel sensation, especially if any "aerobatics" are indulged in, but so does the first ride in a high-powered car. The sensation of ordinary flying as opposed to aerobatics is perhaps disappointing. In fact, to all intents and purposes there is none. The feeling of height is lost. The earth is seen from a distance certainly, but there is no foreground by means of which to gauge that distance. For the same reason no sensation of speed is experienced except when flying near the ground. At first there is a certain sensation of novelty, but this passes with time. What never passes is the sense of mastery, the feeling of exhilaration, and the appreciation of the endless beauties of nature seen in a new form, particularly when the flight leads amongst broken clouds. At the present stage of development of the aeroplane flying in bad weather may be very trying, but only the really experienced pilot is as a rule called upon to do this sort of work. It is here proposed only to discuss teaching the average person to fly a simple type of machine in normal weather conditions. Anything beyond this is merely a matter of practice and experience. During the war many thousands of very average men not only learnt to fly, but became expert pilots, and almost any one can be taught enough to attain to this standard. As for the super-pilot, of him it can only be said, as of the poet—*Nascitur non fit.*

In flying, age imposes certain limitations, probably because most people tend with increasing years gradually to lose their power of adaptability and to some extent their nervous vigour.

Only the exceptional man will take to aviation with any degree of enthusiasm when over thirty-five. It is difficult to lay down any hard-and-fast rule as to the qualities which should be possessed by the would-be pilot. Good general health is essential, particularly during the period of instruction, and only the most experienced pilots should fly when not physically up to standard. Eyesight too is a matter of great importance. Both eyes must have good sight on account of the necessity for judging distance accurately when landing. It is now possible to buy goggles fitted with special lenses which will not splinter, and these should if necessary be used.

The most essential mental qualities for the aviator are quickness of thought, decision, and self-reliance. These need not be highly developed, but must always be present in some degree. They are difficult to assess quantitatively, but they inevitably show themselves in general character and bearing. A few minutes' conversation is usually enough to reveal their presence or their absence. General temperament is of considerable importance. The man who is good at all forms of outdoor sport, the keen cricketer, horseman, or boxer, seldom fails to make a good pilot, chiefly because sport nearly always develops the mental alertness, as well as the bodily vigour so essential to the successful aviator, particularly during the early stages of his training.

It is not necessary for the pilot to be an engineer though he should be possessed to some extent of that feeling which rebels against the neglect or abuse of things mechanical. The man who can drive a car uphill on the top gear with the engine knocking the whole time will treat an aero-engine on similar lines, but probably with more serious results. Although the pilot need not be an engineer, he cannot afford to be entirely ignorant of mechanics. Flying is like riding a bicycle. A knowledge of how to mend a puncture will not prevent the rider from falling into the ditch, but it will frequently enable him to reach his destination in spite of accidents, which is, after all, the main object for which he rides his bicycle.

The ultimate success of the pilot depends greatly on the methods adopted in the course of his instruction. An immense amount of experience on this subject has been obtained during the war. As the result of this it has been possible to fix upon what is probably the only really satisfactory system of teaching. This method originally developed by Col. Smith-Barry has now been almost universally adopted. The effect of this officer's work on the progress of flying generally has been tremendous. It has brought what used to be the aerobatics of the super-pilot safely within reach of practically all. The foundation of this system is progressive dual instruction controlled by telephone, the main principle being that the pupil is made to do everything himself and is taught to realise that he alone is doing it.

The progress of a prospective pilot taught on these lines is somewhat as follows. First of all, he is given a certain amount of instruction on the ground. This includes lectures on the use and effect of the various controls, the controlling of the engine, and so forth. He is also probably taken up once or twice as a passenger, so that when his actual flying instruction begins the sensation of being in the air will not be entirely new to him. Further, he may with advantage watch the other pupils in the air, the evolutions they are performing being explained and criticised for his benefit by an experienced pilot.

He is next taken up for his first dual instruction. The machine used is fitted with complete controls in both the pilot's and the observer's seats, and telephones are fitted to the caps of both pupil and instructor. The pupil occupies the pilot's seat throughout the whole of his instruction. For the first few flights the instructor takes the machine off and climbs it to a safe height. He then passes entire control over to the pupil. The first exercise is to fly the machine straight and level, the pupil's efforts being criticised by the instructor. To learn this step should only be a matter of a few minutes. The next step is to move the various controls and gain practical knowledge of their several effects on the machine. An instinctive use of the controls is thus gradually acquired, as is also the "feel" of the machine in the air.

Instruction on turns now begins; the instructor criticises and corrects the movements of his pupil by telephone, never touching the controls himself except in cases of emergency or to demonstrate a complete turn. The pupil first does slow slightly banked turns, being taught how to apply the correct amount of rudder for the bank and how to hold the nose up in its normal position by holding back the stick. The reason that a machine drops its nose on a turn, and other similar matters, will have been amongst the subjects discussed in the preliminary ground instruction. (The use of the controls in various manœuvres is explained in the next chapter.) The steepness of the bank is now gradually increased. This will probably bring the first lesson to its close. It is important not to teach too many things at a time.

Between this and the next lesson the pupil should be encouraged to think well over the "dos" and "don'ts" of his trip. Cerebration conscious and unconscious has a great effect on progress. For this reason the personal influence of the instructor is of great moment, and should be such as to inspire the prospective pilot with self-confidence.

The dual instruction is continued in such a way as to form a gradually developing course, the amount taught in each flight depending on the assimilating power of the individual pupil. The first part of each lesson is devoted to giving him an opportunity of practising what he has already learnt. Prolonged flights are to be avoided, half an hour in the air at a time usually being ample. When the pupil is well practised in turning he is shown how to glide the machine at a correct angle and taught the difference between turning on the glide and turning when in normal flight. Finally he is taught how to land normally into the wind, how to take off, and how to taxy. All this usually takes about six hours' tuition, and during practically the whole of this time the pupil has had entire control of the machine. At the end of it he should be able to do turns and glides with precision, and judge a landing with very fair accuracy. Most important of all, he should have gained entire confidence in himself. When all this has been accomplished he is ready to go solo, a proceeding which should present no fears.

He is allowed to fly solo for a few hours, during which time he practises the manœuvres he has been taught. Beyond these he must not venture. The instructor's eye should frequently be upon him to ensure that he is not acquiring bad habits. After this, dual and solo flying are undertaken alternately, a dual lesson being given after every two or three hours' solo, so as to check the pupil's progress, prevent the development of slovenly ways, and to teach him new forms of manœuvre. This checking is extremely necessary. A pilot must always fly precisely, and in early stages he is apt to form habits, such as a taste for turns in one direction, a tendency to turn with too little bank, to land too fast, and so forth. If, however, he is forced during the whole of his period of instruction to adopt and to adhere to the habit of precise and accurate manœuvre, he is unlikely to lose it subsequently.

His further instruction now proceeds somewhat as follows. He is taken up and taught to fly in bad weather; he learns to turn the machine vertically, to side-slip, to stall, to dive, and so on. He also learns the effect of bad turns and how to correct their results. He is taught to make forced landings in confined spaces, and landing across the wind is practised. Finally, when the instructor is satisfied that his pupil has completely grasped the theory and practice of what may be termed ordinary flying, he begins to teach him aerobatics. He teaches him to spin, loop, and roll correctly and confidently. By means of this gradually developing system the pupil becomes accustomed to the machine in all positions. Gradual progress is the essential point. Accidents in the air usually occur as the result of pilots attempting manœuvres which they do not understand, and to which they have not been brought up by degrees from simpler things. There is another point of view from which aerobatics should be regarded, namely, that of the stresses to which they subject the machine. If they are performed inaccurately stresses sufficient to break the machine may easily be caused. Gradual and progressive development of the manœuvre, which involves a gradually acquired knowledge of the "feel" of the machine in its different positions, obviates any likelihood of breakage.

Henceforth the pupil flies entirely solo and may be trusted to do whatever he likes. The whole course of instruction extends over some thirty or forty hours in the air, of which about one-third are dual. The finished pilot should be sound and entirely trustworthy. The sole thing required for the completion of his education is experience, and this can only be gained with time. A good deal of valuable knowledge may be acquired from other people. A pilot should always keep his eyes and ears open and be ready to profit by the experiments, the successes, and the failures of other pilots. This borrowed knowledge extends to a variety of things, technical matters, cross-country routes, the quality and nature of various aerodromes, and so forth. It is a good plan to keep a notebook in which to record scraps of information picked up in this way and which are likely to prove of use in the future.

The system of instruction outlined above will find many ready critics, mainly owing to its long duration and the expense it necessarily involves. The critic will doubtless quote the many pilots who learnt to fly in an hour or two without any adequate dual instruction. The system has, however, amply proved its worth. It is the truest form of economy in that it involves practically no "crashes" and turns out thoroughly efficient pilots. Less thorough methods cost more in the long run both in machines as well as in the lives of pupils. From a commercial point of view sound training is a valuable asset since the mistakes of pilots are apt to result in considerable financial loss, to say nothing of the fact that they bring aviation into disrepute with the general public.

SOPWITH DRAGON—DRAGONFLY ENGINE

CHAPTER XXV

AERIAL MANŒUVRES

IT is proposed in the following pages to describe the various standardised forms of manœuvre of which the machine is capable in the air. In the case of those which constitute ordinary flying as opposed to aerobatics, i.e. the movements necessary to flight, the operation of the controls by the pilot is described. The question of the loads to which the various manœuvres subject the machine is also very briefly touched upon. The illustrations are largely relied upon to describe the more complicated evolutions of the machine. In order to make these simpler to understand a monoplane having the underside of planes black is shown.

Diving in its simplest form means adopting a downward direction of flight, the machine maintaining its normal position on its flight path. Gliding is a special form of dive controlled by the engine, the power being cut off or reduced and the machine following an inclined flight path at its normal speed. A machine may, however, be controlled to dive vertically. This is done by pushing forward the control lever and thus giving the elevators a considerable positive incidence, a large upward air reaction being produced at the tail. The result of this is that the point at which the total air reaction on the machine acts moves aft of the centre of gravity and, in order to restore equilibrium, the machine has to dive. The manœuvre may be regarded in another manner. The upward air reaction on the tail may be considered as lifting it and thus reducing the angle of incidence of the main planes. The speed must, therefore, increase. As the power is unaltered, this must be achieved by gravity, and the machine loses height or dives.

The loads to which the actual dive subjects the machine depend simply upon the speed of the dive. During the dive the incidence is so reduced as to alter the lift forces but little. The drift forces are, however, very considerably increased. Some small machines are so designed that they will support the maximum drift forces that can be brought into play. In this case if the machine is put into a vertical dive it increases its forward speed until the drag forces induced become just equal to the weight of the machine. It then continues to dive vertically at this speed. It is, of course, practically impossible to design a large machine of sufficient strength to withstand treatment of this kind. The larger the machine, the less the speed at which it can safely be dived. An aeroplane is not often broken by diving. It is the subsequent pulling out of the dive that is the danger point. To come out of a dive the control lever must be eased back gently. The effect of this is gradually to increase the incidence of the main planes, thus causing the lift to increase and the flight path to become more horizontal. The effect of attempting to pull out quickly is as follows. Suppose that a machine, which normally flies level at 80 m.p.h., be dived at 160 m.p.h. If the control lever be suddenly pulled back during the dive the incidence of the main planes will be increased to more than its value for normal flight. The lift forces on the planes vary as the square of the machine's air speed. The forces brought into play may therefore be many times greater than those to which it is subject in normal flight. Any machine can be broken in the air by suddenly being pulled out of a steep nose dive.

Stalling consists of pulling back the control lever and increasing the incidence of the main planes beyond the point of maximum lift, as shown by the K_l curve in Fig. 24. If a machine is flying level and the control lever is gradually pulled back, the speed is reduced until the minimum speed of flight is reached. At this point the feel of the machine becomes very "sloppy," movements of the control being very ineffective and the control lever offering very slight resistance to movement. The feel of the control always warns the pilot when he is approaching the stalling point. If the pilot attempts to reduce the speed below this minimum by continuing to hold the control back, the machine stalls, and all control is momentarily lost. The machine first commences to drop bodily, or "pancake" as it is termed. This motion brings into play an entirely new kind of air reaction. The centre of pressure travels rapidly aft, the result being that the machine suddenly drops its nose and commences to dive. Until the machine has dived a sufficient distance to recover its flying speed, the pilot is unable to control it. The manœuvre involves no danger when done at a height sufficient to allow the machine to regain flying speed. If a stall is allowed to occur near the ground, the consequences are usually disastrous. Tail-sliding, which on most machines is a very dangerous form of aerobatic, may be brought about by pulling the machine up almost vertically to stall it; it may then tail-slide backwards for some little distance before it drops into its dive When the machine is stalled at all suddenly, the change of the conditions of air flow which accompany the manœuvre is particularly apparent. The machine drops its nose into a vertical dive very suddenly.

Zooming consists of utilising the speed and kinetic energy which a machine has in excess of its minimum flying speed for the purpose of climbing. The control lever is quickly pulled back, and the machine climbs and loses speed in consequence. The control lever is then pushed forward again before the stalling point is reached. This manœuvre may subject the machine to severe loads in exactly the same manner as pulling out of a dive does, and it must therefore be practised with a considerable amount of care.

The art of landing is very intimately connected with the question of stalling. To land a machine it is glided down at a slow speed, allowing a reasonable margin of safety over the stalling speed. As it approaches the ground it is flattened out, the control lever being so manipulated as to cause it to continue its glide with its wheels about two feet off the ground. As the engine is off, the machine loses speed continuously, and in order to keep the machine off the ground the control lever has to be pulled farther and farther back, the machine being forced to adopt a greater and greater angle of incidence in order to maintain its weight. At some point B (Fig. 124) it reaches its angle of maximum lift or its stalling point, and pancakes gently on to the ground. Birds may be watched performing exactly the same manœuvre.

Fig. 124.

The causes of bad landings may be considered. One cause consists of not flattening out soon enough; the machine consequently strikes the ground at too high a speed and bounces into the air again. Again the machine may be allowed to settle on to the ground before its actual minimum flying speed is reached. This may do little harm. On rough ground, however, the jarring due to the running on its wheels at an excessive speed may strain it. Another form of bad landing consists of flattening out too high up. This means that the final pancake, instead of being from one or two feet, may be from several, a serious shock being the result. In an exceptionally bad landing of this type the machine may even have time to commence to drop its nose as in a stall, in which case it will probably turn over. It is important that the machine should be level laterally when it strikes the ground, otherwise the landing shock is all concentrated on one side of the undercarriage. Another not infrequent cause of bad landings is drift. If the machine is not landed exactly into the wind, it will have a certain amount of drift, i.e. it will be travelling in a slightly crab-wise manner relative to the ground. If it is landed whilst so travelling, a serious side-shock to the undercarriage will result.

Occasionally it is necessary to land more or less across the wind. These cross-wind landings are made as follows. The machine is canted in such a manner that the up-wind planes are lower. This causes it to side-slip into wind, the extent of the side-slip being controlled by the amount of the bank. This side-slip is so adjusted that it just neutralises the drift effect. It is, of course, necessary that the machine should land on one wheel first. To land a machine successfully in this manner demands a considerable degree of skill.

The turning of the aeroplane may now be considered. Suppose the pilot wishes to turn to the right.

The first thing he does is to push the control lever towards the right, causing the machine to commence to take a right bank. It is very important that the bank should be commenced first. Were the rudder harshly applied first, an outward side-slip would be encouraged, and this might very easily cause the machine to spin. As the machine begins to take its bank the right rudder is gently applied. This will cause the machine to begin turning to the right. It has also the effect of making the machine drop its nose. In order to counteract this, the control lever must be pulled back somewhat.

The dropping of the machine's nose as the rudder is applied is due to the following cause, illustrated in Fig. 125 (which shows a machine, as seen from behind, turning to the right). The air reaction on the rudder is shown by P_R. This may be resolved into P_{RH}, which acts horizontally and causes the turn, and P_{RV}, which acts vertically and has no effect on the turn, but simply causes the machine to drop its nose. If a machine is turning very rapidly, and is banked vertically, the rudder ceases to act at all as such, the elevators acting solely as a rudder and the rudder itself simply serving to control the horizontal attitude of the fuselage. The gradual sharing of functions between elevator and rudder during a turn might appear to be somewhat confusing to the pilot. As a matter of fact, during his earlier flights only is this the case. The combined use of elevator and rudder in a turn becomes entirely instinctive with practice.

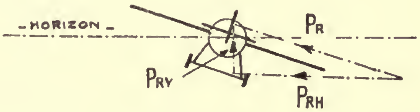


FIG. 125.

To return to the machine, which has been left commencing its turn—the bank is now adjusted by lateral movement of the control, according to the rapidity with which it is desired to turn. The rudder is applied sufficiently to prevent either inward or outward side-slip, the absence of which may be checked by observing that the cross-bubble is central. The control lever is pulled back in its lateral position sufficiently to keep the nose of the machine level and to counteract the diving tendency introduced by the rudder. When the machine has turned sufficiently, the process is exactly reversed. The rudder is first centralised or even reversed. The bank is then taken off, the lateral position of the control lever being reversed in order that this may be done. The control lever is pushed forward again at the same time. The analysis of the control of a turn is somewhat cumbersome. The actual evolution is effected simply by swinging the control lever in a more or less circular manner, the rudder at the same time being operated by the feet. The extra loads on the structure induced by a turn are not usually very great. Apart from the controlling forces transmitted from the tail through the fuselage structure they consist simply of the centrifugal force induced by the turn, which is supported by the outward component of the lift force on the main planes.

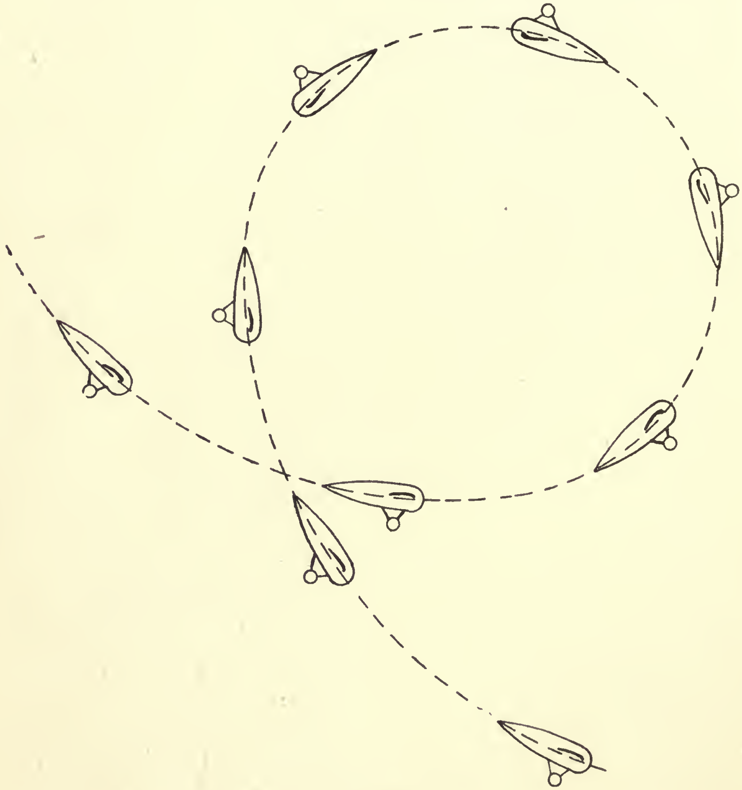


FIG. 126.

To side-slip a machine the control lever is simply pushed over to one side and held there as long as it is desired that the side-slip, resulting from the laterally inclined position of the machine, should continue. The rudder has also to be operated in order to prevent the machine from dropping its nose. The centre of side pressure being aft of the centre of gravity of the

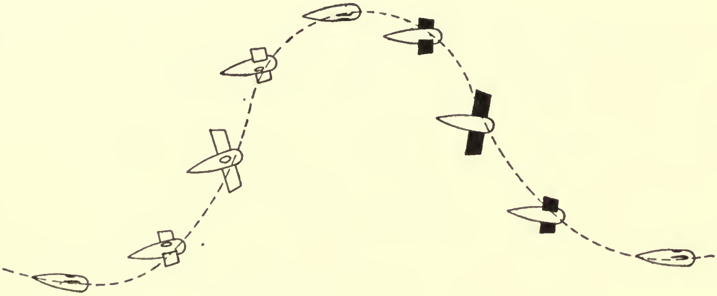


FIG. 127.

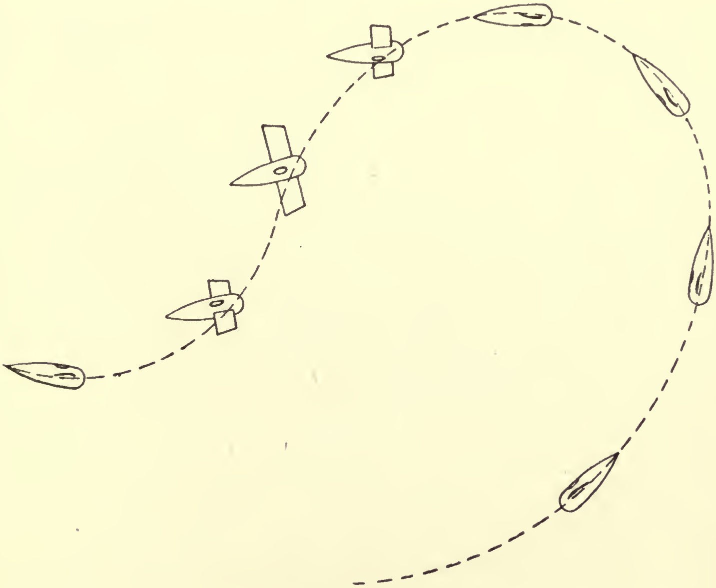


FIG. 128.

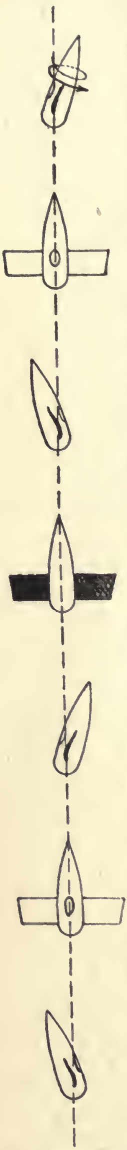


FIG. 129.

machine, it is the air reaction on the lateral surfaces which causes the machine to drop its nose. The rudder is used to counteract this tendency in exactly the same manner as it is used to counteract a similar tendency in a vertically banked turn. The forward speed of a machine when side-slipping is maintained at its normal value, so that when the bank is removed the machine does not have to stall and dive prior to resuming normal flight.

Looping is a comparatively simple aerobatic. It is illustrated in Fig. 126. The machine is flown or dived if necessary at a sufficient speed to ensure its going over without stalling in the upside-down position. The control lever is then pulled gently backwards, and the machine follows the path indicated in the figure. If the evolution is properly performed the centrifugal force is sufficient to maintain the pilot in his seat even in the upside-down position. One of the most curious sensations of looping is afforded by sitting in the machine and observing the earth above instead of below. In order to help the loop the engine is kept full on till just past the top of the loop, it being then throttled back so as not to exert a downward pull during the dive. The point of danger in a loop is when the machine is just entering. Its speed is then high, and any sudden pulling back of the control lever may induce very serious loads on the wing structure.

Rolling is shown in Fig. 127. The machine follows a corkscrew path, continuing to fly forwards in the same direction.

The Immelman Turn, which was developed before the roll proper, is shown in Fig. 128. The manœuvre commences with the first half of a roll. When the machine is on its back, instead of completing the roll, it does the second half of a loop and comes out of the manœuvre flying in the opposite direction. It is the quickest method of reversing the direction of flight, and was first developed by the German airman Immelman as a means of eluding attack from the rear.

The spin consists of descending vertically, the machine spinning round during the descent. The vertical downward velocity of the machine is not very great, and excessive loads are consequently not induced. The spin is illustrated in Fig. 129. The machine adopts a position such that the inclination of the main planes is greater than the stalling angle, and a considerable air reaction is thus induced. The manœuvre is perfectly controllable and is much used by fighting pilots to escape from an awkward situation.

The loads on the structure of the machine induced by spinning, looping, and rolling, if these are properly performed, are about three times the normal.

CHAPTER XXVI

PRACTICAL FLYING

IT is proposed to devote this chapter to what might be called "advice to the young pilot." It is simply a collection of rules and facts which are the outcome of experience. It is hoped that the pupil pilot will find much that is useful to him, and that those less directly connected with the actual flying of a machine may perhaps be led to see certain of the pilot's difficulties from the pilot's point of view. The experienced pilot will find little or nothing here that is new. He, however, is often not so staid and balanced as the somewhat dogmatic "dos" and "don'ts" of this chapter would ask him to be. Whilst knowing the danger of what he does, his occasional exuberance of spirit will lead him out of bounds. He will nevertheless always be the first to agree that the soundest pilot is the one who most conscientiously avoids taking unnecessary risks.

The rules of the air, expressed very briefly, are, keep to the right, give way to a machine approaching on the right-hand front quarter, and avoid a machine that is being overtaken. The rule of the ground is that a taxying machine gives way to a machine that is taking off or landing. There is only one really safe rule, and that is always to avoid another machine and never to rely on it performing its share of the contract. Accidents due to collision in the air are fortunately rare. Their results are generally fatal. They are only likely to occur at places where there is congestion, such as over a busy aerodrome. The commonest cause is two pilots coming in to land at the same time, each of them so intent on the aerodrome alone that the other machine escapes his notice. The obvious rule is to cultivate the habit of glancing round periodically for other machines, and, if another machine is in the neighbourhood, to assume that its pilot has not taken the same precaution. Never cut in front of another machine in order to land.

Before a flight the pilot should always make a point of having a few words with the mechanics who have been working on the machine. This is partly for his own satisfaction, it being essential that he should know all there is to know about its condition. His remarks should, however, be designed for their satisfaction as much as for his own. If they are keen on their work they themselves have a very personal interest in the machine. This spirit must be fostered and developed. Nothing tends to do this so much as a feeling of co-operation, and this the pilot alone can engender.

The pilot's first action on getting into the machine should be to test the controls to ensure that they work freely and are not jammed in any way. After running up the engine (which subject is discussed in another part of the book) he is ready to taxy out into a suitable position for taking off. The machine should always be taxied to the place which allows it the longest take-off possible, even if it is of a type which takes off very quickly. Every foot of height gained before leaving the aerodrome is of advantage in the event of the engine giving trouble, and it is just when taking off that it is most prone to do this.

There are several points of importance as regards taxying. Many tractor machines when on the ground are very blind in front. The nose then being very high, the pilot's view is very much obscured by the engine. It is for this reason comparatively easy to taxy into an obstacle that is straight ahead. It is wise also to keep an eye down-wind, since it is from this direction that other machines will land. Another most important rule is always to glance behind before taking off in order to ensure that no other machine is landing in the line.

The modern machine may be fairly complicated owing to the number of different controls with which it is fitted. These all have a correct position for taking off or landing. The fact that one of them is set wrongly may make considerable difference to the machine at these most important times. The pilot must form the habit of checking them. A simple device for aiding the memory while checking is to form a word of the initial letters of the controls to be attended to, always using this and checking the controls in the same order. For example, the word TAPS, meaning Tail control, Altitude control, Petrol taps, Spark (ignition) control. When a machine has an adjustable tail plane control this should usually be set in mid-position for taking off, and full back, giving the slowest glide, for landing. It is essential that the petrol taps should be set in such a position as to give the maximum supply without relying upon wind-driven pumps. The ignition must be fully advanced and the altitude control fully closed in order to ensure the engine's opening up sweetly and giving its full power. One of the commonest faults observed in taking off is that the throttle valve is too rapidly opened and the engine consequently choked.

A not uncommon source of accident is due to engine failure immediately after having taken off. When the machine has left the ground it is climbed, usually fairly steeply, in the upwind direction. When the engine fails the pilot is tempted to turn down-wind and get back into the aerodrome. The reason that the manœuvre so frequently leads to disaster is that he watches the ground as he turns, forgetting that as he is turning down-wind he must (in order to maintain the same air speed) increase his ground speed by twice the speed of the wind, and consequently he stalls on the turn. As he has probably insufficient height to recover from the stall, the machine dives into the ground.

The question of turning up and down wind is one much discussed amongst pilots, turning down-wind near the ground often being regarded as dangerous. As a matter of fact, there is no difference whatever, provided that the pilot flies by the nose of the machine and not by watching the ground. "Flying by the nose of the machine" means always judging the attitude of the machine by the position which its nose occupies on the horizon. Whether the machine is flying in still or in moving air does not matter in the least. It is simply carried along in the air and (relative to the ground) has the air speed added to its own. An appropriate illustration is that of a fly flying about in a moving railway carriage. The danger of flying down-wind, as remarked in the previous paragraph, arises entirely from watching the ground. If one is flying near the ground, it is certainly wise to fly up-wind as much as possible, since, if for some reason a landing has to be effected, the machine is in a position to make it. What height it has may be utilised in choosing the best spot and need not be wasted in the turn into wind which would otherwise be necessary. It is usually found to be more bumpy flying down-wind. The bumps are due to air currents caused by inequalities of the ground. The ground speed being greater down-wind, more of these bumps are encountered.

It is now proposed to discuss a few rules, the strict observance of which should go far to prevent such accidents as occur at the present time.

When flying from place to place always fly at a reasonable height. The main reason for this is that if engine trouble does necessitate a landing, the higher the machine is, the greater the choice of landing ground. Moreover, the engine failure may be due to a petrol tap having become closed or to some similar trivial cause, and the higher the machine is, the more the time available to discover and to remedy matters of this kind. It is probable also that the machine has an adjustable tail and flies normally at a speed much greater than its gliding speed. In this case time is necessary for the pilot to re-trim the tail by means of the wheel and also to accustom himself to the changed conditions of speed. A much wider range of vision is obtained as the height is increased, which makes it easier to find the way. The direction of the wind has a certain influence. The speed of the wind usually increases with height. It is therefore not economical to fly at too great a height if the course is against the wind.

Never, unless it be absolutely unavoidable, fly over obstacles at a height insufficient to allow the machine to glide clear of them in case of necessity. By obstacles are meant woods, towns, etc. Local rainstorms should not be flown through if they can be avoided. Rain is very bad for the machine and propeller ; moreover, it is never quite certain how severe the conditions may turn out to be inside the storm. Snow is an element to be treated with very great caution since extremely dangerous air conditions frequently accompany a snowstorm ; it is also practically impossible to see in it. Snow is particularly dangerous to airships. This is due to the fact that it settles on the upper surface of their hulls and so adds to their weight that they can no longer maintain themselves in the air.

Never fly a machine too near its limit of fuel. A pilot is often tempted to try just to get home with too little petrol. It is much better to land the machine and await supplies than to run any risk of a crash.

Never fly a machine the mechanical and control details of which are not familiar. This seems a very obvious thing to avoid. It is, however, very frequently done, and often with serious results. It is not sufficient to know that when a certain tap is turned a particular thing happens. The reason why it happens should also be understood. The quick diagnosis of a fault in the air often enables the pilot to correct it, but unless the mechanism of the machine is thoroughly understood this diagnosis is practically impossible.

Low "stunting," as it is called, is the most dangerous practice in which the pilot can indulge. Many really expert pilots have suffered injury owing to giving way to this vice. In fact, it can safely be said that any pilot who habitually amuses himself in this manner will ultimately come to grief. It is only proximity to the ground that can give a true sense of the speed of the machine, and few sensations are more exhilarating than rushing smoothly along at the rate of a hundred or more miles an hour, jumping over houses, banking between trees and the like. It is small wonder that the practice attracts. None the less, the pilot who is to make flying his business must eschew it since the slightest mistake may cost a machine and possibly also a life.

The subject of forced landings is one deserving of a certain amount of discussion. The reliability of the modern engine has made them of very infrequent occurrence. They must, however, occur occasionally with certain types of machines, and the pilot must therefore be prepared to deal with them. When he is learning to fly he is taught to judge every landing he makes. The subsequent possession of an apparently perfectly reliable engine may tempt him into the habit of always relying on it when landing. Habitually flying in at a height of fifty feet or so, and then shutting off the engine to land, soon causes him to lose that judgment which is essential to landing from a height without the engine.

Suppose that at a height of some five thousand feet the engine suddenly seizes up. The pilot's first problem is to select a suitable field within his gliding range in which to land. In choosing the field he must have regard to the wind direction. To ascertain this may not be easy. It can be done by observing the lateral drift on the machine and the direction of no drift, which proceeding, however, wastes valuable time. The pilot must cultivate the habit of remembering the compass bearing of the wind, and he should also check it from time to time when passing over smoking chimneys. His field should provide a long run up-wind. It should also be level so far as he can judge. Slopes, if gentle, are practically invisible from the air. They must be inferred rather than seen. The colour of the ground, the nature of the surface, the position of water, and any other available clues must be utilised. Small ridges or ditches will show up well from above. Surface conditions must also be considered. Grass is usually safest, although in the autumn stubble provides excellent landing. At times it is necessary to land in long grass, crops, or even water. In these cases the machine must always be somewhat severely pancaked, the landing having to be made as slowly as possible since otherwise the drag on the axle would immediately turn the machine on to its nose. In fact, in the case of forced landings the actual landing should always be made very slowly as the ground may always be expected to be rough. In the case of a landing on unknown ground in circumstances such that the engine is available, the machine should always be flown at a height of a few feet across the patch of ground on which it is proposed to land. This preliminary examination will often reveal some hidden pitfall. Even when landing at an unknown aerodrome the wise pilot will always fly round once or twice before alighting.

Having selected a landing ground, the next problem is to get into it. This is entirely a matter of skill and judgment. To spiral down is not usually wise, as half the time that the machine is in the spiral the chosen ground is out of sight. The most satisfactory device is to do a series of " figure 8's " on the down-wind side of the field. In this way it is kept continuously in sight, and the pilot is not likely suddenly to find himself with insufficient height to glide in. The final glide in calls for the most accurate judgment, specially if the space available to land in is very limited. It is the wind which makes the judgment of the glide difficult. It will readily be understood that the stronger the wind, the steeper the angle relative to the ground. The accurate judgment of the glide is greatly facilitated by side-slipping. The glide itself is so judged that the machine will overshoot, the amount of the overshoot being lost by side-slipping just before the boundary of the field is crossed.

After landing, the pilot's first care must be for his machine. If it seems unlikely that he will be able to get off the same day, all possible provision must be made for its protection. If the shelter of trees is available the machine should be wheeled into it. The machine should also be fastened down, particularly if there is a strong wind or one appears likely to rise. Lashings to firmly driven stakes under the wing tips and tail usually suffice. Covers of some kind should be obtained for engines and cockpits. The re-starting of the engines will probably be facilitated if some attention is paid to the magnetos. These should be packed round with rags to protect them from moisture. Steps should be taken to keep sight-seers from the machine. In cold weather, if the engine be water-cooled, a point of the highest importance is to run out every drop of water immediately the engine stops.

The question of maps is an important one. Special air charts are not yet printed. As the demand grows doubtless they will be. They will be designed to show the ground as it appears from the air, accentuating those landmarks which are most distinctive and relegating others to their proper position in the scale. Most ordinary maps show the roads in particular relief. In England (not, however, to the same extent abroad) roads are the worst possible aerial landmark. From the air, main and by-roads appear very similar and the whole road system appears as a most complicated network. The landmarks used by the pilot, given here in the order of their distinctiveness, are: lakes, seacoasts, canals, towns, large woods, railways, rivers, villages, roads. Maps for aerial use should have all water shown very plainly. Woods also should be shown distinctively, their shape being carefully marked. The railways should be marked, showing the number of tracks. Maps should be marked with latitude and longitude for navigational purposes, and they should also show the magnetic variation. When a series of maps is used it is a great advantage if the various sheets have a small marginal overlap. The most useful scale for ordinary cross-country work is 4 miles to the inch. Large maps are often awkward things to handle in a confined and draughty cockpit. Fig. 130 shows an exceedingly convenient way of folding maps. It will be noted that any point can be referred to without completely unfolding the map.

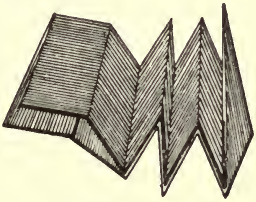


FIG. 130.

CHAPTER XXVII

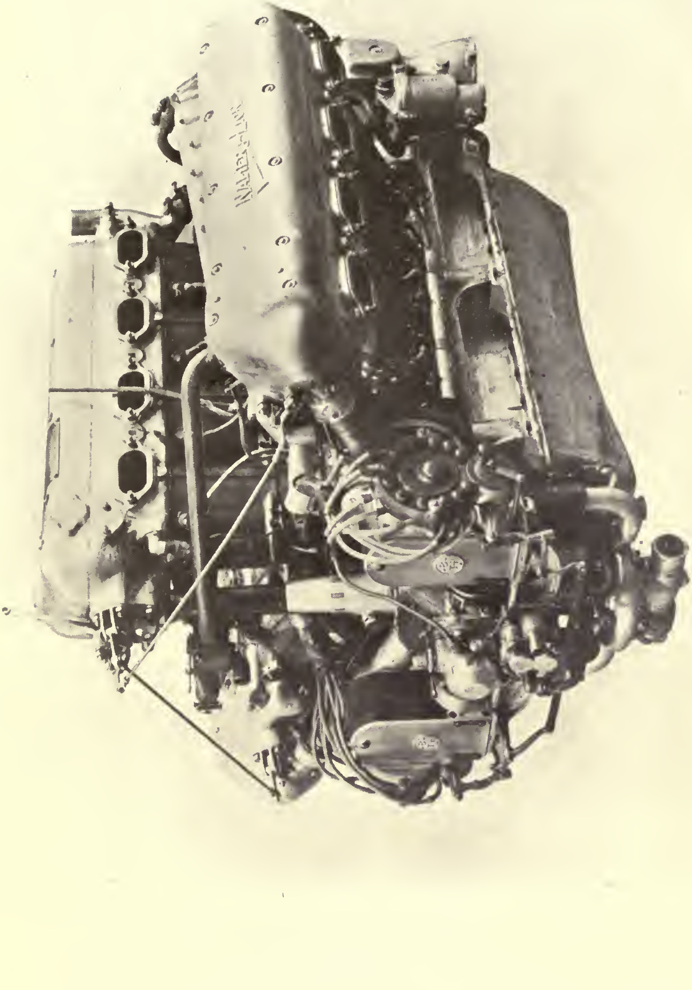
AERIAL NAVIGATION

THE science of steering an aeroplane from place to place is termed navigation or pilotage. Pilotage consists of following a series of landmarks on the ground, either from memory or by the use of a map. When reference to landmarks is impossible, as in crossing the sea, flying above clouds, or flying by night, other methods of calculating and steering a course must be adopted. These comprise the science of navigation. The conditions are practically the same as those obtaining in the case of a ship at sea when out of sight of land. It is proposed here to discuss the methods adopted in flying a machine from one point to another without reference to intermediate landmarks.

In the case of a ship at sea, latitude and longitude can be checked accurately by sextant observations on the sun or stars. This can also be done, although less accurately on the larger types of aircraft. Except on very long journeys, however, it is unnecessary, and this method of fixing position will therefore not be described here.

The instrument on which the navigator chiefly relies is the magnetic compass. As the needle always lies along the lines of the earth's magnetic field it supplies a datum for direction. Owing to the magnetic pole not being coincident with the geographical pole, the correction, termed variation, necessary in order to obtain the true bearing from the magnetic varies from place to place on the earth's surface. In the case of a long flight the variation may change by several degrees. For example, in the course of a flight from the extreme West to the extreme East of the British Isles the variation alters by about 6°. All good charts and maps are marked with the variation for the particular

PLATE XIV



NAPIER LION ENGINE—450 HORSE-POWER

area. Maps showing the lines of equal variation over the surface of the globe are also obtainable.

Some compasses are fitted with an adjustable lubber line against which the card may be read. This may conveniently be kept set at the variation at the point where the machine is. In Fig. 131 B is the adjustable lubber line and is shown set for 15° Westerly variation. The line B then always shows the true geographical course on which the machine is flying. Where a type of compass not so fitted is being used it is usually easiest to work out and fly all courses as magnetic. The variation at Greenwich is about 15° West. It may be noted that 15° must then be subtracted from the bearing shown by the compass in order to obtain the geographical bearing on which the machine is flying. Easterly variation must always be added to the magnetic bearing to obtain the geographical, conversely Westerly variation must be subtracted. Deviation must also be allowed for. This is done by adding or subtracting the necessary number of degrees, as shown by the compass correction card (see Chapter XXI). This correction is usually small.

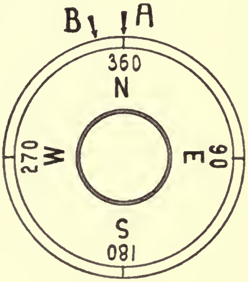


FIG. 131.

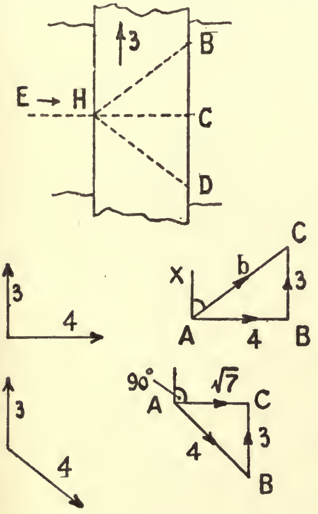


FIG. 132.

If a ship sailed in a currentless ocean or an aeroplane flew in a windless sky, the problem of navigation, given an accurate compass and air speed indicator, would be a simple one. The point to point distance and the geographical direction would be measured off on a map; the vessel or machine would then go on this bearing for a time equal to the distance divided by its own speed. The effect of currents or winds has, however, to be allowed for, and in this lies the main difficulty of navigation.

A machine is said to fly at 80 miles an hour when it moves through the air at that speed. If the air through which it is travelling is itself moving, its velocity is added to that of the machine. The problem is exactly the same as that of a man walking across a moving pathway (Fig. 132). If he walks at 4 m.p.h. across a pathway 4 yards wide, moving at 3 m.p.h., and walks facing in the same direction (EH) as that in which he approached the pathway, then, during the time it takes him to cross the pathway, he will have been conveyed 3 yards and will step off at the point B. Should he wish to navigate himself to the point C, then on coming on to the pathway he would have to change his direction to HD, D being a point 3 yards on his right-hand side of C. It will also be noted that the distance HD, which is moved on the pathway, is longer than HC. The pathway therefore takes longer to cross than would be the case were it not moving. In other words, the velocity of the man in the direction HC is reduced, although his actual velocity relative to what he is walking on is unchanged. It is evident that the problem is exactly the same as that of a machine flying from one point to another in a cross wind.

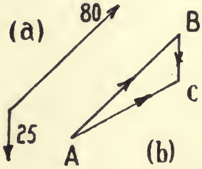


FIG. 133.

It has already been stated that vector diagrams are applicable to velocities in exactly the same manner as they are to forces. In the case of a velocity the length of the vector expresses its magnitude (say—m.p.h.), the angle its direction relative to some datum, and the arrow-head its sense. If a body be subject to a number of velocities, then, if the vectors representing these velocities be set out in order, the second vector being drawn from the end of the first and so on, the closing side of the polygon will be equal and opposite to the resultant velocity of the body. Let this be applied to the case of the man crossing the moving pathway. In the first case he (using bearings) is subject to his own velocity of 4 m.p.h. in direction 90°, and to a velocity of 3 m.p.h. in direction 0°. His resultant velocity (Fig. 132) is AC in direction XAC. In the second case he is subject to velocities 4 m.p.h. in direction 90°+CHD and 3 m.p.h. in direction 0°, and his resultant velocity is AC in direction 90°.

Suppose that a machine is flying on a N.E. course at 80 m.p.h. in a Northerly wind of velocity 25 m.p.h. The triangle of velocities is shown in Fig. 133 (*b*). The actual course relative to the earth, or "track," as it is called, is in the direction AC, and the ground speed, as the speed relative to the earth is called, is AC.

The problem with which the navigator is faced, however, is not—"If I fly a certain course in a certain wind, in what direction will the machine be flying over the ground?"—but —"If I want to fly a certain ground course (track) in a certain wind, on what course must the machine be flown, and what will be the speed relative to the ground?" This question is solved graphically by the triangle of velocities as follows. From any point A draw a line AB representing in magnitude and direction the wind speed (25 m.p.h.). From A draw a line AX in the direction of the ground course on which the machine is to fly. With centre B and radius BC equal to the speed of the machine, draw an arc cutting AX in C. BC then shows the course on which the machine must fly and AC shows its ground speed. ABC is the triangle of the velocities acting on the machine. Similarly if the machine is to do the return journey, its ground speed will be AC′ and it will have to steer a compass course BC′.

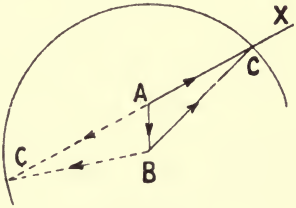


FIG. 134.

To illustrate this main problem of navigation further an actual case may be worked out. The wind speed at 6000 feet is 32 m.p.h., and its direction, i.e. the point from which it is blowing, is 230°. A machine is to fly from Brighton to Bristol and Bristol to Hull. Its air speed is 95 m.p.h. What bearings will it have to fly on and how long will it take on each stage?

Brighton to Bristol—bearing, 292°; distance, 118 miles.

Bristol to Hull—bearing, 31°; distance, 193 miles. Draw AB (Fig. 135) equal (to some convenient scale) in magnitude and direction to the wind velocity. From A draw A B*r* and A H*u* parallel to the ground courses from Brighton to Bristol and from Bristol to Hull respectively. With centre B and radius BC equal to the machine's air speed draw an arc cutting A B*r* at C_1 and A H*u* at C_2. BC_1 and BC_2 then give the bearings on which the aeroplane must fly from Brighton to Bristol and from Bristol to Hull respectively. AC_1 and AC_2 will give the ground speeds of the machine on each course. The journey from Brighton to Bristol is made in 1 hour 34 mins., the true bearing of the machine being 275°. The Bristol-Hull journey occupies 1 hour 33 mins., and the machine is flown on a bearing 25°. The average magnetic variations on the two journeys are 16° W. and 17° W. respectively. Neglecting errors due to deviation, the compass bearings will therefore be 291° and 42°.

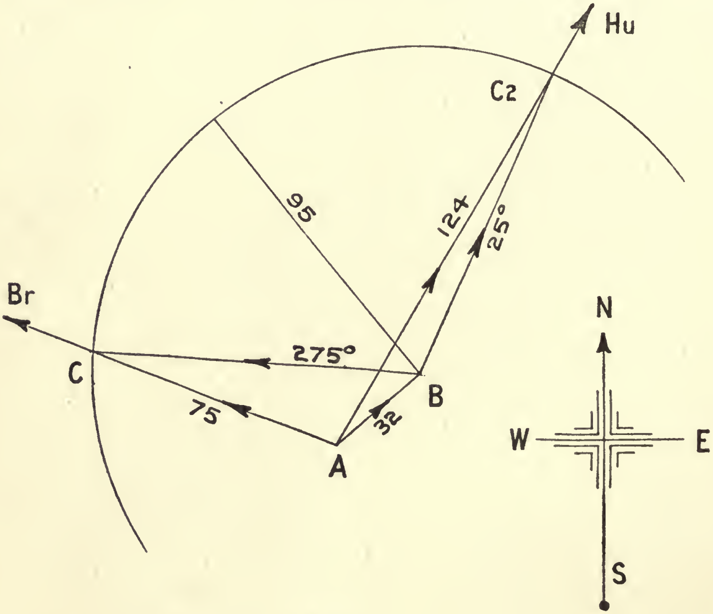


FIG. 135.

The main difficulty encountered in the application of the aforegoing is the correct determination of the wind speed. The wind speed varies continuously at any one place and also varies quite considerably from place to place. The phenomena affecting wind variation are briefly discussed in the chapter on weather, and it must here suffice simply to state the conditions usually met with. The speed and the direction of the wind are much more variable near the ground; local conditions being responsible for this. At higher altitudes the conditions tend to become more uniform from place to place and also less variable at any particular place. The wind normally increases in velocity with height. Its direction also changes slightly, its point of origin usually moving in a clockwise direction as the altitude increases. It is evident then that if point to point navigation is to be reasonably accurate the machine must fly fairly high. Even in these conditions errors will occur due to the inevitable wind variations. The variations to be expected will depend on the variability of the weather conditions in the neighbourhood.

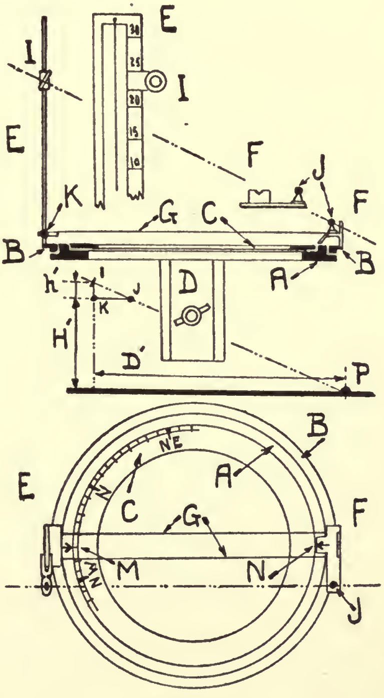


FIG. 136.

An instrument which enables the navigator to correct for wind, and also to observe wind variations, is the "Drift Sight" shown in Fig. 136. It consists of a fixed ring A, which is carried in a conveniently placed bracket, usually at the side of the machine, by means of the lug D. The carrier is so set that the indicating arrow M is parallel to the centre line of the machine. On A may be rotated independently the ring B carrying the fore sight F and the vertical wire back sight E, and also the graduated ring C. Between the two sights are arranged two horizontal and parallel sight wires G. The drift angle is the angle which the centre line of the machine makes with the ground track, i.e. the angle between course and track. To measure this the ring C is turned until M points to 180°. The ring B is then turned until on looking downwards through the sight objects on the ground appear to travel parallel to the wires GG, or objects a short distance ahead have no apparent lateral movement relative to the line of sight.

The drift is then read as so many degrees to port or starboard, as the case may be. If the ground speed is determined by measuring the time taken to cover a distance measured on the map, the wind speed can be determined from the triangle of velocities. Fig. 137 illustrates the use of the sight. Suppose a machine starts to fly from A to B with air speed V in a wind W. The triangle I shows the starting conditions. The drift is ϕ, and the ground speed GS. If the sight is set at the angle ϕ and a point C on the track observed, it will have no lateral movement relative to the sight. Suppose that, as the machine proceeds, the wind increases to W′. If the course is unaltered, the track will follow the line CK. On looking through the drift sight under the altered conditions, the point C′ observed will have developed lateral movement. The sight must be re-set to some new angle θ such that no drift is apparent. If the same track is to be followed, the course must be adjusted to allow for the changed wind. The triangle II shows the conditions before the course is altered. It will be noted that the observation of drift and air speed alone on a constant course does not enable the navigator to determine either the wind or the ground speed; it will, however, enable him to maintain a steady track. If he can obtain his ground speed accurately, he can calculate the wind. By flying on two courses and noting the drift on each, it is possible to obtain the wind, and from it the ground speed can be calculated. The last problem is most simply solved by adjusting the first course so that no drift is apparent; this gives the direction of the wind. The machine is then flown on a course at right angles to the first one; the observed

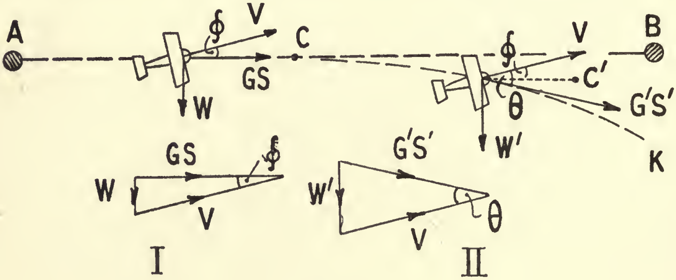


Fig. 137.

drift on the second course provides a ready means of calculating the wind speed. The navigator does not have to set to work in the air to solve the various problems outlined above by drawing or complicated calculation. Several forms of calculating instruments are available which obviate this. Space does not, however, permit of their being described here.

The drift sight is commonly fitted with a device designed for the measurement of ground speed. This consists of an aperture sight I (Fig. 136), arranged to slide up and down a scale on the back sight, and two fore sights J and K arranged as shown in the figure. The diagram exhibits the principle of this device. If a point P on the ground is observed on the line of sight IJ, and the exact time noted until P is on the vertical sight line IK, this time will give a measure of the ground speed of the machine—it is the time taken to travel a distance D′. The vertical scale on which I moves is so graduated that if the sight be set at the graduation corresponding to the height of the machine, the distance D intercepted on the ground between the sight lines IJ and IK is constant. D is usually standardised as half or one mile. It will be noted that the scale is such that $\frac{h'}{H'}=\frac{JK}{D'}$. The accurate determination of ground speed in this manner demands an equally accurate knowledge of the height of the machine above the point on the ground observed. The navigator is dependent on an aneroid for his knowledge of the height; it will therefore be understood that only in exceptional circumstances is the method really accurate. The sights can, however, be conveniently used for the observation of the exact time of passing different objects on the ground, the distances between which are measurable on the map, which method gives absolutely accurate results.

The drift sight may be used to determine the bearings of objects. Such bearings are often extremely useful for fixing the position of the machine. The method of measuring a bearing is as follows. The scale C is first turned to such a position that an indicating mark on A (below N in the figure, and exactly opposite to M) shows the course on which the machine is flying. It will be noted that the scale is then, if magnetic bearings are being used, in exactly the same position as the card of the compass when corrected for deviation. The ring B is then rotated until the observed object is on the line of sight. The bearing of the object is read against the indicator N. Two such bearings, preferably subtending an angle of about 90°, observed practically simultaneously, fix the position of the machine.

For determination of directions, the navigator is dependent on the compass. This instrument, if carefully adjusted and calibrated as described in Chapter XXI, is capable in the most favourable circumstances of giving results correct to about 1°. The air speed of the machine is measured by the air speed indicator. This instrument, as has been already pointed out, is only correct at or near the ground. If the temperature and pressure are measured at the height at which the machine is flying an accurate correction offers no difficulty (see Chapter XXI). Failing these measurements, however, a reasonably accurate correction is made by adding 1·6 per cent per 1000 feet of height to its reading. It must be known, of course, that the instrument is correct under some standard conditions. This may most satisfactorily be tested from time to time by flying a measured course near the ground at some speed near that normally employed. These essential instruments which are liable to error should be duplicated for accurate work. If one fails during flight the fact is then immediately apparent.

All pilots are from time to time called upon to navigate to some extent. If the pilot is flying by following the map he is almost sure occasionally to lose his bearings owing to passing over clouds or other causes. However, if before leaving he has approximated the wind speed and direction, and if he cultivates the habit of constantly observing his compass, he should never be at a loss to pick up his course again. He can at any time visualise a rough triangle of velocities and thus approximate his ground speed and direction. Knowing that he was at some point, say, fifteen minutes previously, he can roughly fix his position on the map. Having done this, he can fly in any direction with a view to picking up some landmark, as, for example, a railway. Thus he again establishes accurate connection with his map.

The problem of aerial navigation will be very much simplified in future by the general use of wireless telegraphy and telephony on aerial routes. These have already been used experimentally with great success. Machines can now be fitted with apparatus which will detect the direction from which wireless waves are being transmitted. It is also possible, using more than one ground wireless station, to fix the position of a machine sending out a wireless message. If working on this system, the machine would send out a message inquiring its locality and the ground stations would signal back the required information. Accurate navigation along a route marked by a series of wireless stations would be practicable in weather such that no visual observation of any kind is possible.

CHAPTER XXVIII

AERODROME AND BUILDINGS

THE choice of a site for an aerodrome is somewhat of a problem, since a really well-chosen aerodrome must satisfy a number of more or less essential conditions. The commercial aspect enters largely into the question. Where the proposed site has disadvantages it is wise to consider whether it would be more profitable financially to remedy these (always supposing them to be capable of remedy), or to fix upon some other site. If the drawbacks are such as will not occasion any serious financial loss, it may be more expedient simply to put up with them. The main point at issue is the extent to which they will adversely affect the machines. This is not merely a matter of actual breakage, but also involves the question of the effects of straining due to taxying over an unsuitable surface, the wear and tear caused to engines which have to drag heavy machines through soft ground, and the cost of labour of cleaning machines that have constantly to taxy through puddles. From a business point of view money spent on procuring the best possible site for the aerodrome is money soundly invested. An ill-chosen aerodrome may occasion an annual expenditure of many thousands of pounds on repairs to machines. It may even at times be wholly unfit for landing. The first essential condition necessary to a good landing ground is that it provides a sufficient length of good surface to make it possible to land up-wind, whatever the direction of the wind may be. The aerodrome of the future will function as an aerial station for some particular district, the aerial transport service both fitting in and competing with other transport services already established. The aerodrome should therefore be well served by road and also if possible by railway.

The size of the aerodrome must obviously depend on the amount of traffic to be handled and the types of machine in use. Shape is largely governed by size. Most existing aerodromes are either square or oblong, the sheds being usually situated at one side. This shape allows of the landing of a considerable number of machines provided their movements are regulated. Where, however, this precaution is neglected, and machines are permitted to taxy about promiscuously, accidents are very liable to occur. A more economical shape for the ground, and one which none the less provides a good long run in all directions, is the "L" shape. Here the two longest runs are at right angles, and machines can land or take off satisfactorily in any wind. What is known as the "all round" type is suitable for a very large aerodrome. In this type the buildings are situated centrally, the landing ground forming a continuous circuit round them. In choosing a site for an aerodrome due allowance must be made for possible future development and extensions. The lay-out should be so arranged that additional sheds can be erected subsequently without this in any way interfering with the general facilities for landing.

The land immediately surrounding the aerodrome must be considered with due regard to the requirements of night as well as day flying machines. The approaches should be as free as possible from obstructions, and it is a great advantage when the ground in the immediate neighbourhood is also such as to permit of emergency landings. To night fliers any high obstruction is a danger. In the case of the day pilot it is usually the casual obstruction that leads to disaster. He can generally see the wood or the church tower. It is the isolated tree or wireless aerial mast that is his most likely source of danger. Surrounding obstacles, be they wood, village, valley, or rough ground, must be considered also in their relation to possible engine failure and forced landings. Engine failure is most likely to occur just after a machine has got into the air. If it occurs when the machine is over one of these obstacles, and before it has had time to obtain sufficient height to enable it to turn back into the aerodrome, a crash is inevitable. Obstacles of the type mentioned are often unavoidable, and in estimating their probable danger it is wise to take into consideration the prevailing winds and consequently the direction in which machines will most often be compelled to take off and to land. Another type of obstruction which often leads to disaster is aerial wiring, such as telegraph wires, etc. Wires are difficult to see from the air, and should, whenever possible, be placed underground. Where this is not possible, as, for example, in the case of wireless aerials, the wires should be flagged.

The ideal aerodrome is level. This condition often being unobtainable, it is necessary to consider the amount of general slope or incidental undulation that may reasonably be tolerated. Pilots to whom the aerodrome is familiar often find slopes an advantage, since they can frequently utilise them to shorten their landings, but to the visitor, as to the careless pilot, they must ever remain a source of danger. Except when the sun is very low, gentle slopes and slight undulations are invisible from the air, even at comparatively low altitudes, so that, generally speaking, the aerodrome in which these occur appears to the pilot level. A general slope in one direction is no great disadvantage unless it be so steep as to make downhill landings difficult. A general slight upward slope from all sides towards the centre is also not unsatisfactory. It helps drainage and makes an uphill landing possible in all directions. It should not, however, become too steep at any point or machines overrunning their landing in that particular direction may get out of control. Downward slopes towards the sheds are to be avoided as pilots taxying downhill are liable to underestimate the distance required for pulling up. The effects of minor undulations are important. These include ridges, hollows, and mounds. To each a simple test may be applied. If the slope at any point is such that any machine moving across it is liable to be thrown on to a wing tip, the slope must be adjusted. An incidental slope that may safely be struck end-on may be much more dangerous if taken laterally. Again, no hollow, however gentle the side slopes, should be so deep as to hide one machine from another at a distance, say, of sixty or seventy yards. A machine hidden in a hollow may be the cause of a serious accident to another machine which may be landing. The slopes on an aerodrome should be considered in connection with prevailing wind, less favourable conditions being permissible in those directions in which landings will seldom be necessary.

Surface conditions require very careful examination. Smoothness and strength are the primary necessities. Undue roughness causes excessive wear and tear by straining the machines. There must be no indentations or lumps that may damage them whether they be travelling fast or slowly. In studying this, the size of the wheels must be taken into consideration. The question of the strength or durability of the surface is more complex. Here a point to consider is the wear to which the different parts of the aerodrome may be subject. The ground adjoining the sheds has to stand considerable wear, and usually requires special treatment. To treat it with tar macadam is most satisfactory, but somewhat costly if done on a large scale. The ground may alternatively be hardened by rolling in cinders or gravel. Trouble due to dust is, however, apt to result if this latter method is adopted. All engines are run up and tested in the neighbourhood of the sheds, and dust is sure to prove a nuisance, especially during hot weather. No special treatment is ordinarily necessary on other parts of the surface, except in such places as require filling or levelling. These should be seeded. Until they have a sufficient covering of grass to prevent wheels from sinking in, they should be marked as being dangerous by means of small red flags.

Surface conditions are always worst during the winter and after heavy rain. Hence the question of drainage over the whole area is of the utmost importance. This makes a subsoil of sand or gravel very desirable. Clay is to be avoided. A good grass surface is the most suitable. Stubble even with thick clover is rarely satisfactory for at least a year. A good test to apply is to imagine the ground thoroughly sodden and then decide whether it would be safe to drive a motor-car over it. If not, it is not good enough for an aeroplane. Where it is necessary in the making of an aerodrome to remove hedges and ditches, it should be considered how far the latter are necessary for drainage, and if advisable a drain should be made before filling them up. The level of water in neighbouring ditches or ponds is often a good guide to the nature of the drainage of the site. A road across the aerodrome may be necessary for access to the sheds. This should be made flush with the surface and cambered as little as possible. The excessive growth of the grass is often a source of trouble in the summer, particularly to the smaller machines. This can be remedied by cutting, an operation which must be regulated so as to interfere as little as possible with the flying. Where night landings are not anticipated, arrangements can often be made for sheep to graze on the aerodrome by night, which scheme answers admirably.

Local weather conditions have to be ascertained before the site for an aerodrome is chosen, this chiefly with a view to avoiding ground mists. If the site is near the sea, the possibility of their arising suddenly must be taken into consideration.

The present generally accepted method of marking an aerodrome is by means of a white circle. This should be about forty yards in diameter, the line being three or four feet wide. It may be marked out in white stones or chalk. The name of the aerodrome may be marked inside the circle. The letters should be some five or six feet square. Dangerous patches are usually marked by means of red flags by day and red lights by night. These should be visible from the air as well as on the ground. Regulations have recently been issued concerning the marking of aerodromes. These relate to both night and day flying. These regulations will have to be complied with at all aerodromes in the future.

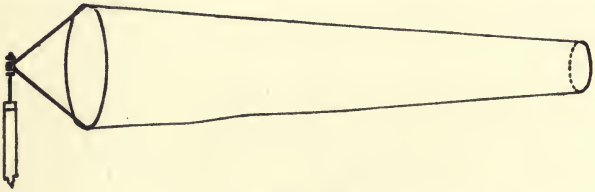


FIG. 138.

A wind gauge must always be placed at some point where it can easily be seen, in order to indicate the direction of the wind. By far the most satisfactory wind gauge is a smoke fire. Failing this, a flag formed as indicated in Fig. 138 is commonly used. This flag should be made of white fabric of light weight. The front end should be stiffened by an iron ring carrying the pivot. The pivot is carried forward in order to prevent the flag wrapping itself round the standard when the wind is insufficient to keep it extended. A stock of rockets and lights should be kept with a view to indicating the position of the aerodrome at night or in thick weather. Night landings require a special equipment. Considerations of space prevent a complete description of this.

The reader is here again referred to the official regulations published on the subject. If it be necessary to indicate a particular landing-point to a machine by day, a white T is commonly used, the downward arm of the T pointing with the wind. The machine should land first touching its wheels at the T. An elevated look-out post fitted with a telephone is often of considerable use. Other special equipment of a labour-saving nature is usually desirable. This, however, depends very much on the type and number of machines handled.

The buildings required at an aerodrome will usually include aeroplane sheds, workshops, offices, and stores. The sheds will necessarily constitute the bulk of the area. Sheds of a permanent or temporary nature may be erected. The former are usually constructed of steel frames covered with corrugated iron or cement, or of brickwork. The roofs are supported by trusses of either steel or timber, and may be covered with corrugated iron or other light water-tight material. Temporary or portable sheds consist of wood sectional framework covered with canvas. The smaller types designed for the accommodation of only one machine may consist simply of a specially shaped tent supported by collapsible poles. Small sheds are usually uneconomical on account of the difficulty of packing in a number of machines of varying sizes. The modern machine of large size is always made with folding wings in order to economise floor space. In spite of this, however, the space occupied by machines is very large.

The situation of the sheds should be so chosen as to provide them with as much natural shelter as possible. This is particularly important in the case of those of a temporary nature. The question of road service to the sheds must be considered as this is essential. A further point of considerable importance is the gap spacing between the sheds. This should be sufficient to render it possible, in case of fire, to isolate any particular shed. If a shed once gets thoroughly alight there is usually practically no chance of saving it or its contents. All effort must immediately be concentrated upon preventing the fire from spreading. The fire-fighting installation is a matter of the greatest importance. Within the sheds large and readily portable chemical extinguishers are satisfactory. Outside a complete water system should be installed if possible. The outer surfaces of the sheds should be covered with material of a non-inflammable nature.

The doors of the sheds must be very carefully designed. They must provide a large area for the passage of machines, and must be opened and shut without the expenditure of an unnecessary amount of labour. The most satisfactory type are usually those which run on rails on the floor and are divided into a number of sections of a suitable size for stowing in a recess provided at the ends. The doors should not open directly on to the aerodrome, otherwise the sheds will during the summer months always be filled with dust raised by the running of the machines for test purposes. A satisfactory arrangement is for the doors to be at each end of a long-shaped shed. The long dimension of the shed is arranged facing the centre of the aerodrome. Wide spaces provided between the sheds serve the double purpose of providing passage way for the machines, and also isolating the sheds from fire risk.

The problem of handling machines in the sheds, particularly when they are of a large size, is an important one. Where all hands available are necessary to move a machine, the interference with routine work is considerable. An arrangement which has been adopted, and which materially reduces this work, consists of laying trolley tracks along the shed floor. These are sunk below the floor level, and the trucks have platforms which lie flush with the floor. The economical use of these trolleys, however, demands that a sufficiently wide space shall be kept clear along the centre of the shed for the passage of the machines.

On account of the importance of the work done on the machines whilst in the sheds the problem of lighting must be carefully considered. By day it is satisfactorily solved by the provision of a considerable area of window and skylight. At night electric lighting is the only safe form on account of fire risks. To light a shed efficiently in such a manner as to make the work on all parts of an aeroplane possible as by daylight would call for the expenditure of a considerable amount of electrical energy. The most satisfactory working arrangement is for the general lighting to be fairly weak, any machine

THE SUPERMARINE BABY FLYING BOAT

which is being worked on being specially illuminated by local portable lamps, coupled to wall plugs and supported on suitable standards.

The question of heating deserves attention. In the first place, if good work is to be done, the comfort of the men doing it must be considered. In the second, the effect of temperature and damp on the condition of the machines is of great importance. These effects have already been touched on. It must here suffice to say that the lasting qualities of a machine are probably increased two or three times if it be kept in a suitable atmosphere. Owing to the size of the building, the door area, and the light form of construction usually adopted, the problem is not altogether an easy one. It is, however, satisfactorily solved in large engineering erecting shops, and there is no reason why the same heating arrangements should not be adopted in the sheds.

The number of other buildings required must vary very much with the size of the aerodrome and the nature of the work anticipated. Offices, workshops, and stores will be necessary. At a small aerodrome, these can probably be built as parts of the shed. In larger aerodromes they will be separate buildings. The largest aerodromes of the future may well become the centre of small villages housing the employees and providing temporary accommodation for aerial travellers. The workshops should be capable of undertaking all such running repair work as the machines may require. Their equipment should be very similar to that of a high-class motor repair works. Electrical driving of machine tools has the advantage that one form of power generated at the aerodrome or supplied by a neighbouring power station will serve for all the requirements of the aerodrome. The only material stored that requires special treatment is petrol. Considerable stocks of this must naturally be held. Underground storage offers several advantages, particularly from the point of view of the prevention of fire. Systems are in common use where the bulk storage is in buried tanks, the service supplied being pumped to a more elevated tank, and led thence to suitable machine-filling points by pipe lines.

CHAPTER XXIX

THE EFFECTS OF ALTITUDE

THE condition of the atmosphere alters very considerably with altitude. The changes of pressure, temperature, and density, under average conditions, are shown in Fig. 139. It will be noted that these changes are very considerable between the limits of height at which aeroplanes commonly fly. It is the business of this chapter to discuss the various effects of these changes. It is proposed to do this in three sections: first, the effect on the machine; second, the effect on the engine; and, thirdly, the effect on the pilot.

There is a definite relation between the pressure, temperature, and density of a gas. The pressure and temperature are measured by the barometer or aneroid and the thermometer respectively. The density or mass per unit volume, which is of most importance, can be calculated, the values of the pressure and density being known, by the application of the following laws. Boyle's Law states that the density of a gas varies directly as its pressure, and if p and ρ are the pressure and density at sea-level and p' and ρ' at some height H, then:

$$\frac{p}{p'}=\frac{\rho}{\rho'} \text{ or } \rho'=\frac{p'\rho}{p}$$

Charles' Law connecting temperature and density states that the density of a gas varies inversely as its "absolute" temperature. The absolute temperature is the temperature in degrees centigrade $+273$, i.e. the zero on the absolute temperature scale is -273° C. If t is the temperature at sea-level in degrees centigrade and t' that at an altitude H, then:

$$\frac{\rho'}{\rho}=\frac{t+273}{t'+273} \text{ or } \rho'=\rho\frac{t+273}{t'+273}$$

The conditions at sea-level vary considerably from day to day and from place to place. In order that machine tests, experimental data, and the like may be exactly comparable, their results must always be corrected to some standard condition of air density. The accepted standard density of air is ·00237. This is the mass of one cubic foot of air at 15° C. and 760 mm. (mercury) barometric pressure. 760 mm. is equal to 30″, or a pressure of 14·7 lbs. per square inch. Accepting the figure ·00237 as standard, then at any altitude where the temperature is t° C. and the pressure p lbs. per square inch, the density of the air is:

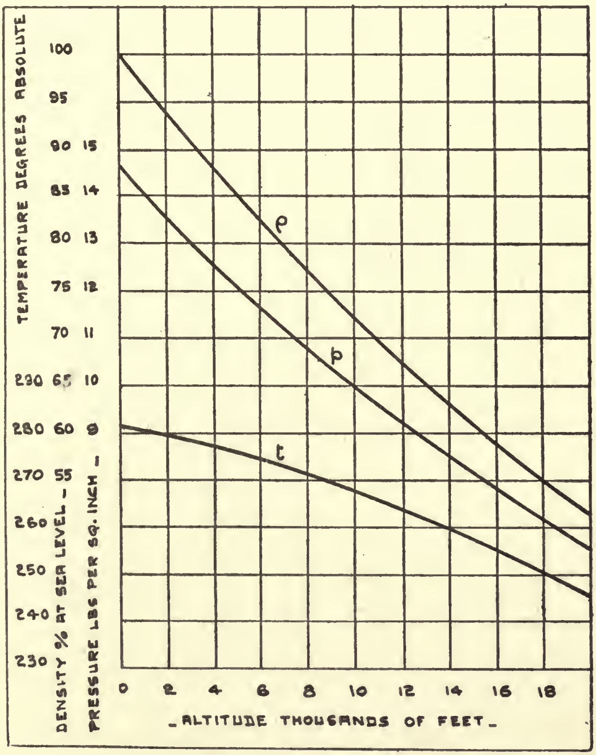


FIG. 139.

$$\rho' = {\cdot}00237 \times \frac{p}{14{\cdot}7} \times \frac{273+15}{273+t}$$

The curves in Fig. 140 are average conditions as shown by experiment. It will be noted that the effect of the decreased pressure is to decrease the density, whereas the lowered temperature increases it. The former effect, however, predominates, with the result that the density falls off considerably with height. At 20,000 feet the density is only about half that at sea-level.

The equation $P = KA\rho V^2$ is fundamental in considering the aerodynamic effects on a machine. Considering the lift forces on the machine only, it may be written $W = K_L A\rho V^2$. It is evident from this that as ρ decreases either the angle of incidence or the velocity must be increased in order to maintain the weight of the machine. Let a quantitative example be considered. Suppose that a machine flies level at 60 miles per hour (88 feet per second) at sea-level. With the same incidence, at what speed must it fly at 8000? Reference to Fig. 139 shows that the density at 8000 is ·77 normal. W, A, K_L remain the same:

$$\text{At sea-level} \quad \frac{W}{K_L A} = V^2\rho = 88^2 \times {\cdot}00237 = 18{\cdot}4$$

$$\text{At } 8000' \qquad V^2 = \frac{W}{K_L A} \times \frac{1}{\rho} = \frac{18{\cdot}4}{{\cdot}77 \times {\cdot}00237} = 101' \text{ per sec.}$$

$$= 69 \text{ m.p.h.}$$

It will be noted that if the machine be climbed with constant incidence, then the speed must be progressively increased and the power must necessarily be increased proportionately. In this manner the limit of the engine power is soon reached. Further upward progress can then only be effected by increasing the angle of incidence. The angle of incidence is then gradually increased until it reaches the value which makes K_L maximum. The machine has then reached the greatest height to which it can attain. This height is termed its "ceiling."

There is another very interesting point to be noted in this connection, namely, the effect of altitude on the readings of the air speed indicator. The instrument has already been described. It measures the air speed by indicating the pressure induced in a tube by the forward progression of the machine. At any speed V there is a pressure of P in the instrument. The point on the dial which corresponds to P is marked V miles per hour. $P = KA\rho V^2$ or $V^2 = \frac{P}{K\rho A}$, that is to say, the readings of the instrument are affected by density. The instrument is constructed to be correct at normal density; consequently it becomes incorrect as the machine climbs. As ρ decreases, the readings become low. The correction to be applied to them is $\frac{\rho}{\rho'}$, where ρ' is the density of the air in which the machine is flying. It has already been noted that in the case of the machine also (when flying at constant incidence) V varies as $\frac{1}{\rho}$. Thus, if the machine climbs at a constant incidence, although V actually varies, the air speed indicator will register the same speed. The instrument does, however, to some scale, show the angle of incidence regardless of height. It is the angle of incidence on which the efficiency and stability of the machine depend. The same angle will be the optimum angle or the stalling angle at any height, although at that particular angle the air speed increases with height. If the machine stalls at (say) 40 m.p.h. near the ground, it will stall at exactly the same speed as measured by the air speed indicator at any altitude. It may be noted that to correct the air speed indicator readings approximately 1·6 per cent must be added for every thousand feet that the machine is above sea-level.

Decreasing density has a great effect upon the power output of the engine. The engine produces work as a result of the combustion of certain hydrocarbons with oxygen. The carburettor is adjusted to add sufficient petrol to the oxygen in the air sucked in to ensure complete combustion. The power per working stroke is therefore dependent upon the amount of oxygen sucked in. As the density is reduced the charge sucked in becomes correspondingly less. Hence the power of an engine falls off roughly in proportion to the density of the atmosphere in which it is working. In calculating the ceiling of an aeroplane this is a controlling factor.

Little has as yet been done to overcome this disability. Aero-engines are normally designed with a high compression ratio. This helps to some extent, but the principle can only be applied to a limited degree as an exceedingly high compression would render them unsuitable for flying at low altitudes. Whatever height they are designed to fly at, they must nevertheless be capable of developing power during their climb and at such times as they may be compelled to fly low. Engines with very high compression are apt to give a lot of trouble from overheating and rough running near the ground. Forced induction seems to offer the most practical solution of this problem. The principle consists of pumping the air supply to the carburettor at such pressure as to make good the decrease owing to the altitude at which the machine is flying. The engine therefore works continuously in a normal pressure.

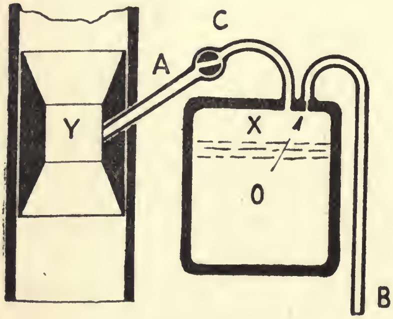


FIG. 140.

A system which has been tried with satisfactory results consists of a centrifugal air pump driven by a gas-turbine which utilises the pressure of the exhaust gases. The air delivered by the pump is supplied to the carburettors.

The decreasing density of the air also affects the action of the carburettors. The mixture becomes progressively richer as the machine climbs, which results in misfiring, uneven running, and further loss of power. It is then necessary to provide some means of reducing the ratio of petrol to air. This may be done either by admitting more air at a point beyond the choke or by limiting the amount of petrol supplied. The latter system is the more satisfactory. The amount of petrol delivered through the jet depends, first, on the size of the jet and, secondly, on the difference of pressure between the interior of the float chamber and the choke. The former is normally that of the atmosphere. The petrol supply is controlled by reducing the pressure in the float chamber. This is effected as follows. The air which normally maintains the petrol in the float chamber at atmospheric pressure is admitted by the pipe B and through the small orifice O (Fig. 140). The regulator consists of a pipe A fitted with an adjustable valve C coupling the float chamber and the choke. It is evident that if the pipe B were closed entirely and A were open, the pressure at X would be the same as at Y, and no petrol would flow. The effect of slowly opening the valve C is, however, to permit an increasing amount of air to flow through the system BOCA. The air which flows through BO into X must necessarily be due to a pressure lower than atmospheric in X, the difference of pressure being necessary to force the air through the pipe B and the orifice O. The greater the quantity of air flowing through, then the lower is the pressure in X, and consequently the less the amount of petrol forced out of the jet. The carburettor shown in Fig. 85 is fitted with this type of control. The lever controlling this device is always coupled to the throttle lever in such a manner that as the latter is shut so also is the altitude controlled. The reason for this is that the altitude control must be shut off before the machine comes down, otherwise the resulting over-weak mixture when the engine is again opened up at a lower altitude would lead to violent popping back and danger of fire. As the throttle must necessarily be closed to come down, the inter-connection of the levers ensures the desired result.

Owing to the low temperature obtaining at great altitudes, the normal radiator area necessary near the ground becomes excessive. The radiator is therefore usually fitted with an adjustable blind consisting of a number of narrow shutters by means of which its effective area may be controlled. This is a very essential fitment for another reason. In order that the machine can come down the engine must be practically shut off. Consequently little heat is supplied to the cooling water circulating through the radiator. At the low temperatures met with, were the bulk of its area not screened, it would certainly become frozen up.

A man is affected by altitude in much the same way as an engine. The human body depends for its energy on the consumption of oxygen. As the density decreases, so does the amount of oxygen drawn in per breath. As the altitude increases the rate of respiration increases. This, however, cannot go on indefinitely. At a height of 16,000 feet the normal body has become a very poor machine. It is capable of sitting still and controlling the aeroplane, but any action calling for the display of muscular activity proves very exhausting. The brain also is affected and becomes exceedingly sluggish in action. The obvious method of sustaining the pilot at great height is to furnish him with an auxiliary supply of oxygen. This is supplied to him from a cylinder of compressed gas through a regulating valve and a mask which he wears. The valve is so adjusted that it automatically supplies an amount of oxygen which increases as the surrounding pressure decreases. The height at which oxygen should be used varies with the individual; 16,000 or 17,000 feet is about normal.

The only other discomfort experienced is due to the cold. In the winter, even at very moderate heights, frostbite is not uncommon. It is usually the face which is attacked owing to exposure. In cold weather the face should not be exposed more than can possibly be helped. If prolonged flights at considerable height are indulged in, a complete face-mask should be worn. The skin can also be protected to a great extent by rubbing it thickly with lanoline or other grease. General coldness can only be guarded against by the use of suitable clothing. Electrically-heated clothing has been manufactured for use at very high altitudes, but this is seldom necessary. Aerial clothing generally must be designed to be both heat-retaining and wind-proof. As combining these two qualities leather is the most suitable material. The ideal is a close-fitting one-piece garment. It should have no loose parts to blow about and should allow the maximum freedom of movement. The outer layer should be durable and wind-proof and the inner layer or layers should consist of thick material designed solely to retain the heat of the body. The position of the pockets is a matter of some importance. The pilot's seat, although comfortable, allows little room for movement. Therefore the pockets must be so arranged as to be readily accessible without moving from the normal sitting posture.

Cold is usually felt most in the hands and in the feet. Experience has shown that the wearing of silk next to the skin is most conducive to the retention of heat in these parts. Wool should be worn over the silk, and then the gauntlet or boot. Gauntlets having no separate fingers are most satisfactory. If separate fingers are necessary for any reason, a type of gauntlet with a mitt which may be drawn over the fingers at will is most desirable. Boots should be lined with sheep-skin throughout and should extend up to the knee.

CHAPTER XXX

INSPECTION

THE inspection of an aeroplane begins with the inspection of the raw materials from which it is constructed. These are always supplied to a specification which usually lays down the ultimate stress which the material must be capable of withstanding and the percentage extension that a test piece of certain dimensions must show before rupture. The nature of the tests specified varies with the material. Wood, for example, is commonly tested by cross bending, i.e. loading centrally a test piece of standard dimensions supported at its two ends as a beam until it breaks. Metals are usually tested in hydraulic tension testing machines. These are made in sizes capable of breaking a 1-inch diameter specimen of the strongest steels. Samples are taken from every batch of material used, thus ensuring, as far as possible, that no defective material finds its way into the finished machine.

The various parts must be further inspected during the process of manufacture. Timber, when being worked, may show flaws in odd pieces which might pass the examination of the most skilled inspector when in the rough. Metal parts likewise, although made from sound material, may have their strength seriously impaired in the course of the manufacturing processes through which they pass, owing, for example, to improper working or heat treatment. For this reason all parts are usually inspected at each stage of their manufacture. The works inspection of most importance is the final one to which every finished part is subjected before being assembled in a machine. A final examination of the machine is made before its air test to ensure that none of the erecting work has been in any way skimped.

During the process of manufacture the man in the best position to inspect each part is usually the man who makes it. The manufacturer can best guard his own reputation and the interests of his customers by offering every inducement to his employees to report any material or parts which they think to be defective. The workman should always recognise the extreme importance of even the smallest detail, and appreciate his personal responsibility for the safety of the finished machine.

In manufacture the question of interchangeability is an important one, particularly as affecting engines. It must be possible to supply spare parts for a machine or engine without the necessity of their being fitted on the actual job. This is ensured by the use of gauges. Every part is made to match a certain gauge or standard. It is then certain that it will be interchangeable with any similar part made to the same standard. In engine work, so-called "limit gauges" are much used. It is decided that the limits of error on a certain part, say, the diameter of a gudgeon pin, are $\frac{1}{2000}$ over size or $\frac{1}{1000}$ under size. A standard gauge with two pairs of jaws is then made, the width between one pair of jaws being 1·2505 and between the other pair 1·2490. The part is ground to such a size that one side of the gauge will pass over it and the other will not. All gudgeon pins made to the same gauges will then, within the limits of the gauge, be interchangeable with others made by the same firm.

The form of inspection which most affects the airman is the inspection of new or used machines on purchase or on taking over, and the continual inspection necessary to ensure the safety of a machine whilst in service. The essential factor for the satisfactory carrying out of this work is system. Inspections must be made at definite intervals, and when made must follow some definite system. Perhaps the simplest method of describing the work that should be done is to start from the simplest form of inspection, i.e. that to which the machine is subject after each flight, and to work up to the more complicated examination necessary when an unknown machine is being examined.

The various parts of the machine should always be gone over in the same order. This ensures that parts do not get overlooked. The engine may be examined first. As to the order in which the parts of the machine are examined, a beginning may conveniently be made from the nose, working aft, the machine being divided into sections, as, for example, engine bearers, undercarriage, main planes, cockpits, fuselage, tail unit, and finally all controls. The parts particularly requiring examination will vary according to the type of machine and the nature of its work. Only experience of the particular type of machine can teach them. The following remarks must be taken as generally applicable.

After each flight of appreciable duration, and apart from any particular defects which the pilot may have observed in the course of the flight, the machine must be subjected to a general inspection. This may conveniently be combined with the routine work of cleaning and greasing. So far as the engine is concerned, it will usually suffice to turn the propeller, and to examine the filters, magnetos, etc., in the manner described in the chapter on the care of engines. The rigging should normally require little adjustment, but should always be gone over nevertheless. The engine cowling should be removed and the bearer bracing wires examined for slackness. The undercarriage should be carefully examined to ensure that it has not been strained. The examination of this part should include an inspection of the fittings by which it is attached to the fuselage and of the shock-absorbing devices. The wheels, tyres, and particularly the wheel fixings, should be examined with particular care. The main planes come next. The faults most likely to be found are small tears in the fabric, or the slackening off of locking nuts on the bracing wires. In the cockpits the different control levers should be operated to ensure that they are not either sticking for want of lubrication, or liable to slack back owing to having worked loose on their pivots. It must also be ascertained that no loose tools or other articles, which may subsequently work into and jam the controls, have been left lying about. The fuselage, as a rule, gives little trouble, and need only be superficially examined to ensure that no parts have been seriously strained. If it be of the wire-braced type, the wires can usually be felt through the fabric. The wires in the neighbourhood of the undercarriage, or where the landing shocks are received, are those which most likely give trouble. The tail unit should always be rather carefully inspected on account of its importance as affecting the control of the machine. The tail should be lifted off the ground so as to relieve the rudder of the controlling effect of the tail skid, whilst its freeness is being tested. If the tail plane is adjustable this should be tested throughout its whole range of movement. The shock absorber and fixings of the tail skid should be inspected. Finally, the whole of the control system must be gone over with particular care. All cables must be felt to ensure that their tension is correct; their turnbuckles and terminal fixings should be looked at, and any points where they are liable to rub or chafe should be particularly carefully examined. All guide pulleys or fairleads must be inspected to ensure that they are thoroughly greased, and that their fixings are not working loose. The hinges of all the control surfaces must be carefully examined to see that they are properly lubricated and that the hinge pins are properly locked in position. In going over the machine the mechanic should take into consideration any circumstances which may have affected the machine since it last left the shed. For example, if the engine has been reported as vibrating, the bearer bracings should receive special attention. If the weather is frosty and the ground rough, the tail skid and its fixings are points liable to be affected.

At regular intervals ot twenty hours' flying, the machine should be subject to a more searching inspection. This should, if possible, be undertaken by some person other than the mechanics who ordinarily work on it, although the latter may with advantage be present and assist in the work. This should include all the items of the daily inspection, but all should be gone over in a rather more detailed and searching manner. Little additional work is necessary as regards the engine. This acts to some degree as its own inspector, its running immediately making apparent any maladjustment or undue wear. All pipes, wiring, and connections should, however, be carefully examined for leaks, perishing, or chafing. All parts should be perfectly clean before this examination. The bearers should be carefully scrutinised for slack bolts or fittings, or the undue softening of ply wood or other parts, due to the effects of oil. If the necessary facilities exist, the internal bracings of the planes should be examined. The general truth of the main planes may be checked with a steel tape, and if there be any reason to doubt its correctness, the incidences should be checked with a spirit-level. The planes should be carefully felt over for broken ribs. All patches should be examined to ensure that they are adhering properly. When inspecting the wheels the fabric discs should be removed in order that any broken spokes may be seen. When examining the cockpits, attention should be given to the instruments. The rubber connections on the air speed indicator tubes should be tested. The engine revolution counter-drive should be oiled. The various tap and pipe unions should be gone over, and if necessary adjusted. The seat fixings, safety belts, and other details should be examined. The fuselage must be uncovered as far as possible. All the wires must be tested for tension, and carefully examined to ensure that they are properly locked. A string line should be stretched along the fuselage to test its general truth, and any necessary adjustments should be made. The tail unit must be raised into flying position for inspection and its truth tested in all directions, a spirit-level and straight-edges being used. Broken ribs or framework in the various components should be sought. The whole of the control gear should be gone over, old grease being cleaned off, and new substituted. The fingers should be run along the cables wherever fraying or broken strands are likely to occur. For these inspections the machine should be laid up for a day. The occasion may also be utilised for the changing of engine oil, and for other similar periodical engine work, such as is described in the section devoted to that subject.

When a new machine is taken over, a flying test should always be witnessed. This ensures that it is at least in a reasonably airworthy condition. When a machine, whether new or otherwise, has been delivered, it should be subject to a thorough inspection as described above. If it be new, it can then be flown with confidence. The chief trouble likely to be experienced with a machine when new is the clogging of oil and petrol filters with dirt from the tanks. These should be cleaned with particular care. A new engine should be eased as much as possible during the first few hours of its life so as to enable the bearings to settle to their work. If the machine is not new and little is known of the way in which it has previously been cared for, it is usually wise to take very little for granted. The tanks should all be cleaned out and internally examined for dirt. All rubber connections should be carefully scrutinised and some removed for internal examination. The machine should be set up in flying position, and all its dimensions carefully checked. In the course of the inspection various indications will be found as to the manner in which it has been looked after, and these will serve as a guide to those points which should receive most attention. The fact that a machine flies well does not in any way prove that it is in a safe condition to fly.

The pilot who flies a machine should always constitute himself its chief inspector. By keeping himself thoroughly acquainted with its condition, and by noting results of any ill-treatment to which he subjects it, he learns to associate cause and effect, and this gives him increased confidence as well as understanding in flying it. His constant inspection and interest in its condition will also ensure the best work on the part of the men working on it. At first he must usually be content to learn a good deal from the mechanics. In due course, however, owing to his superior advantages in the way of dealing with different types, his judgment and opinion concerning matters of workmanship should come to be of great value.

CHAPTER XXXI

OTHER AIRCRAFT

AIRSHIPS are lighter than aircraft, being a development of the free balloon.. The free balloon consists simply of a spherical gas bag filled with hydrogen or some other gas lighter than air, with a basket attached to it, the difference in weight between the volume of gas in the balloon and the air which it displaces being sufficient to support the weight of the envelope, rigging, and load. The free balloon is capable of rising into the air, but is then dependent entirely on the air currents which it encounters for its motion relative to the earth. As its buoyancy depends entirely on the difference between its overall weight and the weight of the volume of air which it displaces, it continues to rise until it reaches such a height that the density of the air has decreased to what may be termed the overall density of the balloon. The only form of control which it is possible to provide the free balloon with is a means of varying its weight. This is done by loading the basket with a certain amount of ballast and providing a gas valve for the release of gas from the envelope. When the balloonist desires to rise he discards ballast, while to descend he releases gas. One other fitting is provided, namely, a ripping panel. When a balloon has landed, there being necessarily no party to receive it, it is, owing to its lightness and large size, subject to every gust of wind. The only way to protect it is to deflate it as quickly as possible. The ripping panel is a specially sewn section of the fabric, a cord lead to which enables the balloonist to rip it at will. This he does at the moment of landing.

The possible uses of the free balloon are obviously very limited. Many inventors endeavoured to fit it with some form of propelling device which would render it independent of the wind as a means of progression. The problem was not a simple one. The volume of gas necessary to provide the buoyancy necessitated a large envelope, the propulsion of which, even against only a slight wind, called for a considerable amount of power. It was not until the advent of the petrol motor with its low weight per horse-power that a practical solution of the problem was possible. The first airships constructed differed little from the present non-rigid type. They were somewhat crude as regards detail, and, owing to the high weight per horse-power of the then available motors their range of flight was very limited, as was their power to fly against any but the lightest of winds. Subsequent development has been due chiefly to the improvement of the aero type motor and to the improved detail construction which has been the result of continuous experiment.

The envelope of a free balloon is always spherical, this shape containing more gas for the same expenditure of material than any other. On account of head resistance this shape was obviously impracticable for a self-propelled airship. The first airship envelopes were shaped rather like an elongated egg. As experiment added to the designer s knowledge of streamlining, the envelope was gradually elongated until it assumed the proportions adopted to-day. In the case of the non-rigid type, the shape approximates to that adopted for the section of the streamline struts of an aeroplane, the shape being of a very perfect streamline form, its perfection of streamline shape only being limited by the fact that it must be made of as large a gas capacity as possible. In the case of the rigid type constructional considerations lead to the adoption of a form more parallel near the centre.

Suppose that an envelope of the non-rigid type were completely filled with gas at ground level. As it ascends the pressure of the atmosphere surrounding it gets lower and lower ; gas has therefore to be allowed to escape or the envelope would burst. As the airship descends again the envelope will become flabby. In order to avoid this waste of gas whilst ascending and to maintain the shape of the envelope whilst descending, ballonets are fitted internally, as shown in Fig. 141. A centrifugal air pump in the car is connected to these, and they are kept pumped up to a sufficient pressure to maintain the shape of the envelope. Latterly the pump has commonly been dispensed with, an air scoop taking its place, the forward speed of the ship maintaining a sufficient pressure in the scoop. Portable centrifugal blowers are used to inflate the ballonets when the ship is on the ground. When the airship is on the ground these are practically full of air. As it ascends air is discharged from them, thus conserving the airship's supply of hydrogen ; when it descends air is again pumped in. The loss of hydrogen is thus reduced to that which leaks through the fabric of the envelope. In this connection the effect of changes of temperature alone should also be noted. Diurnal variation is very considerable ; there are also more rapid variations which are chiefly due to direct heating by the sun. Sudden changes of the latter type may render the ship very difficult to handle when near the ground,—for example, when landing.

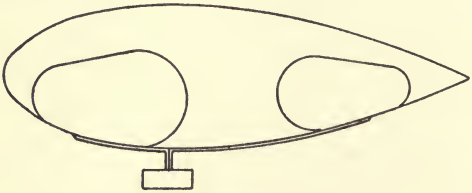


FIG. 141.

It will be noted in Fig. 141 that there are two of these ballonets, one situated at each end of the envelope. The object of this is as follows. By transferring air from one ballonet to the other, the centre lift of the hydrogen contained in the envelope can be moved forward or aft, thus altering the trim of the airship. Valves are arranged at the air pump to allow of this transfer. This provides a ready means of fore and aft control. The rigid airship carries a certain amount of water ballast in distributed tanks by the transference of which it effects the same results.

There are three means of control on an airship. Firstly, it can alter its weight by the dropping of ballast or the release of gas. This alters its speed of climb or descent. Secondly, by the transference of air between the ballonets or by the movement of ballast, it can alter its trim. If the ship is in motion, this change of trim will cause it to climb or dive owing to the air reactions which will be introduced on the lower and upper surfaces of the envelope. Thirdly, it is fitted with a controllable tail similar to that fitted on an aeroplane. The operation of this depends entirely on the motion of the airship relative to the air. A further means of control is sometimes added by swivelling the propellers. These are driven through bevel gearing so designed that the propellers can be swung round in such a way that their thrust may be directed forward or aft or upwards or downwards at will.

The non-rigid airship consists of an envelope of streamline form, from which is suspended, by means of steel wire rigging, a car, which houses the engines, passengers, and all control gear. The envelope is made of rubbered cotton fabric. This fabric is made of varying thickness according to the tension to which it is subject. The strength is varied by altering the number of layers of fabric of which it is composed. The joints are made by seaming, the seam being overlaid by a strip of fabric cemented on with rubber solution. At points where rigging is attached, it is specially strengthened by the addition of patches. The envelope is usually treated with special dopes to render it more weather-proof, and to prevent the absorption of moisture. The tension in the fabric, assuming the gas pressure uniform, varies as the diameter. The tension of the envelope renders it sufficiently rigid to support the weight of the framework carrying the fins, rudders, and elevators. These are braced directly on to it. At the nose, owing to the small radius of curvature, the fabric tension is not very great. The pressure of the air in flight is, however, greatest at this point; a special stiffening consisting of a light wooden framework is therefore usually fitted. The rigging, which supports the weight of the car and transmits to the envelope the tractive force of the engines, is commonly carried to a specially strengthened belt on the under side of the envelope.

The car is usually divided into two sections, one housing the navigator, passengers, and all the control gear, the other the engines. The propellers, of which there are usually more than one, are either carried on brackets at the sides, being driven by shafts and bevel gears, or sometimes at the end of the car, as in aeroplane practice. The general shape of the car is made as nearly streamline as constructional considerations will allow. Little need be said of the engines. They are usually of similar type to those used in aeroplanes. On all but the smallest airships there are more than one. The normal-sized non-rigid airship has commonly two and the larger ships of the rigid type five or more. The navigator has much the same instruments as are used on an aeroplane, to which must be added gauges showing the gas pressure in the envelope and ballonets. These pressures he adjusts by means of valves, the controls of which are situated in his compartment. The rudders and elevators are controlled by hand wheels. In the case of the larger rigid airships, where the engines are situated in different cars, their control is centralised by means of telephones coupled to the central control car. One of the chief things against which the designer has to guard in the construction of the cars, and particularly the engine-rooms, is the possibility of fire. Fire on an airship is even more dangerous than on an aeroplane. In addition to the possibility of the petrol supply catching, the hydrogen leaks from the envelope may become ignited, leading to the immediate destruction of the airship.

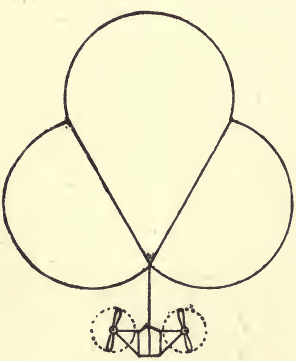


FIG. 142.

The rigging of a non-rigid airship is necessarily somewhat complicated. It involves a very great length of exposed cable, which adds considerably to the head resistance of the ship in flight. This has been overcome to a great extent in the Astra type. Here the envelope is in the form of three lobes, a section of which is given in Fig. 142. This arrangement admits of the bulk of the rigging being situated inside the envelope.

The rigid type of airship consists of a rigid framework built of struts and wires covered externally with fabric. The structure is usually built of duralumin, or in some cases wood. The cross-bracing is composed of steel wires. The outer envelope serves simply to provide a smooth surface, and to protect the framework and gas bags from the weather. The gas is contained in a series of internal gas bags of cylindrical shape. The general construction is illustrated in Fig. 143, which shows a section of the nose of the airship, and also one of the transverse frames of the structure. These transverse frames, usually about twelve in number, consist of struts—usually seventeen—of built-up lattice construction, braced by a series of radial wires as indicated. These main transverse frames are connected by a series of longitudinal girders running the length of the ship. These in their turn are braced by a series of intermediate transverse frames, which have no radial wiring. The structure is diagonally braced with wire throughout. Fig. 144 shows a small section of the outer framework. BB are the main transverse frames and longitudinal girders, and CC are the intermediate transverse frames. There is one gas bag arranged between each pair of main transverse frames (see Fig. 143). The pressure of the bag is transmitted to the framework by means of netting fixed in the inside of the girders. The structure is further strengthened by the addition of a keel either external or internal; this is shown in Fig. 143. This keel also provides a passage-way connecting the different cars and providing a ready means of examining the different parts of the ship. The petrol tanks, ballast tanks, pipe lines, and control cables are also arranged in the keel, where they are readily accessible for repair, even during flight, if necessary. From the keel a vertical passage-way is provided, leading to the top of the airship. A walking way is usually run from end to end along the top of the structure

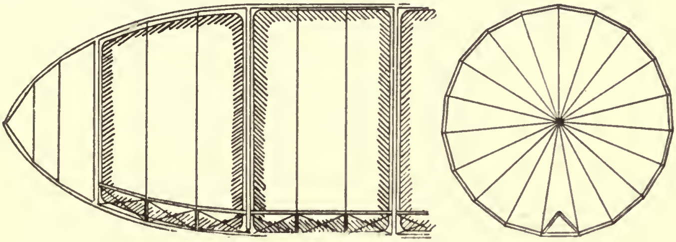


Fig. 143.

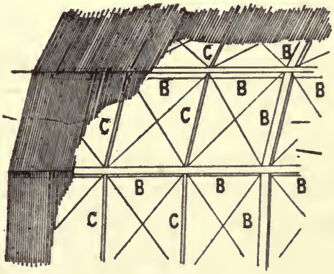


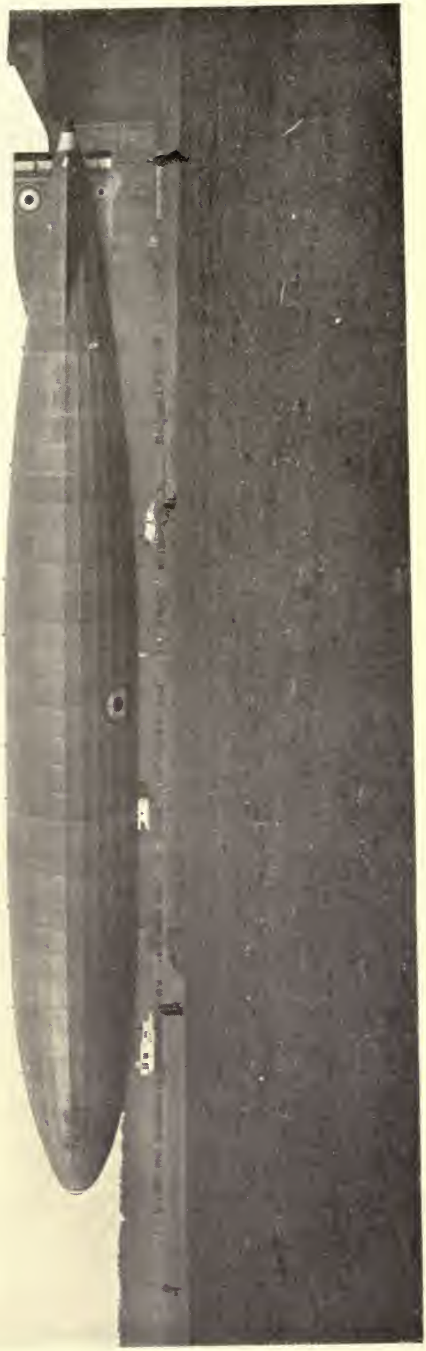
Fig. 144.

enabling the envelope to be readily inspected. The general particulars of a recent British airship of the rigid type are as follows : length, 743 feet ; diameter, 78·7 feet ; total lift, 73 tons ; B.H.P. of engines, 1800 ; ceiling (maximum), 23,000 feet ; speed, 72 miles per hour. The magnitude of the problem of both design and erection of a structure of these dimensions, and at the same time of so light a weight, is very evident.

The rigid form of construction offers many advantages for a large-sized airship. Owing to the substitution of a number of smaller gas bags for the one large envelope, an injury to the covering will normally affect only one of these, and the ship will have a sufficient margin of lift to continue to fly, but at a lower altitude. Ballonets and fans are unnecessary. The cars may be built directly on to the framework, and the air resistance of rigging avoided. The various parts of the ship are accessible during flight. The cars may be placed in such positions that they load the structure evenly, and the separate propellers can work under efficient conditions. The subdivision of the power plant into a number of entirely separate units makes it very reliable and economical. For cruising, one or more engines may be stopped down. This also admits of minor repairs being done on long flights.

The great advantage of airships as a class is that they are not dependent on their engines to maintain them in the air. They can make use of any favourable air current, if need be, without the expenditure of any engine power at all, and can reserve their full power to make headway against adverse currents. Fog and low clouds present no difficulties. Owing to the more stable temperature conditions they are more easily handled at night than by day. Their main disadvantages are their cost in the first instance, and also the cost of the large sheds which are necessary to house them. A further great disadvantage is the difficulty of handling them in a wind. The problem of getting them safely in and out of their sheds is considerable. In this connection the Germans have gone so far as to construct rotary sheds which can always be turned into wind. When the size of the shed necessary is considered it can well be imagined that an undertaking of this nature must be extremely costly. An aeroplane

PLATE XVI



RIGID AIRSHIP—SIR W. G. ARMSTRONG, WHITWORTH & CO.

can spend a few days in any convenient field, if need be, without suffering much damage. An airship must be housed in a shed, unless the weather is favourable. The general provision of these sheds must necessarily greatly limit the development of the airship. Mooring masts to which the ship is tethered, and which are of sufficient height to keep it clear of the ground, have been used with some success.

It is not proposed to deal at any length with the subject of seaplanes. The idea of landing on water occurred early in the history of flight, and the seaplane has grown up alongside the land machine. The advantages of a machine which will alight on water are obvious, and in the earlier days, when forced landings were frequently to be anticipated, they were particularly evident. The seaplane can fly from place to place over a continuous aerodrome. Amphibious machines have also been constructed, and there is doubtless a considerable future for them. Where waterways exist, the advantages of the seaplane are self-evident. The possibilities of the seaplane as a means of opening up the great waterways, both civilised and unexplored, of the world are immense. The seaplane offers the same aerodynamic problems as the aeroplane for land use. Its general construction from this point of view is similar. The main difference lies in the alighting gear. The earlier types utilised floats in place of wheels, and many of the lighter machines of to-day are fitted with these. The idea of using the fuselage as a boat, however, soon occurred to designers, and the flying boat has been the result. This has been built in all sizes from single-seaters up to sea-going machines of very large dimensions, capable of weathering comparatively rough seas.

In detail design the seaplane varies from the land machine in many points. The engine, in order to keep it and the propeller clear of the water, has to be situated very high. This necessitates special consideration in designing the tail in order to procure longitudinal stability. The lowering of the centre of side pressure owing to the presence of floats or a boat fuselage also has a considerable influence on the lateral stability. Entirely self-contained engine-starting gear is also a necessity. The bottom planes must be designed to resist the effects of moisture, and in sea-going machines the shocks due to waves. The various fittings must be as rustproof as possible. Materials which corrode easily must be avoided in their construction.

A parachute may perhaps be classed as a form of aircraft Its only man-carrying use is as a means of descending in an emergency. It has been used successfully for dropping mails or other loads from aeroplanes at places where a landing is either impossible or inexpedient. The parachute is shaped like the covering of an umbrella and is made from light, strong fabric, the load being carried by means of a number of cords attached to equally spaced points on its periphery. At the centre of the fabric is a large hole. This serves to stabilise the parachute in descent owing to the effect of the jet of air which is forced through it. In the absence of this device the load may commence to swing, and the oscillations may develop to such an extent that the parachute may entirely overturn. The parachute is folded in such a manner that as it falls the air gets into it and it opens automatically. The load, be it man or goods, must fall freely a certain distance before this opening takes place. Satisfactory descents have been made from aeroplanes. In the case of serious fire, for example, a parachute provides the only means of escape for the occupants. When designed for use in this manner the parachute is usually packed in a case strapped to the pilot's back, the cords being fixed to a suitable harness designed to distribute the sudden load which accompanies the opening of the envelope evenly over the body. In an emergency the pilot or passengers would spring clear from the craft, at the same time releasing their parachutes.

CHAPTER XXXII

THE WEATHER

A VERY large part of man's energies is consciously or unconsciously directed towards making himself as far as possible independent of weather conditions. The aviator has to face the same problem from a somewhat different point of view from that of other men. To ensure success in commercial aviation the general working must be unaffected by any but the most abnormal conditions. The modern aeroplane can be flown in any weather which permits of two essentials: firstly, that the pilot should be able to see the ground sufficiently to enable him to land; secondly, that the weather is not so boisterous as to make it unsafe to move the machine on the ground. The first condition precludes falling snow, fog, and heavy ground mist; the second, any wind of exceptional strength. The problem of cross-country flying is further complicated in bad weather by the wind effect on the speed of the machine and consequently on its possible radius of action. Generally speaking, however, if the weather conditions admit of the machine's being safely taken off the ground, and landed again, only very exceptional circumstances will prevent a cross-country flight being made. The modern machine, particularly if it be of a multiple engine type, can be practically guaranteed against the necessity of having to make a forced landing, and the length of its journey is therefore only limited by its petrol capacity and the strength and direction of the existing wind.

Flying in bad weather calls for a considerable amount of skill and determination on the part of the pilot. It is not pleasant, and at the present stage of development of aeroplane design, it imposes a certain nervous strain which a pilot cannot fairly be expected to undergo as a matter of regular routine. The effect on the aeroplane, as at present constructed, of flying in bad weather has also to be considered. Rain or hail are very injurious to the leading edges of the planes and to the propeller. Developments in the design of machines for this special work can, however, be relied upon to provide against these disadvantages in the future. Experience has proved a snowstorm to be the most dangerous condition for flying. The pilot's visibility is entirely obscured and the air conditions are extremely severe.

The problem of running an aeroplane service to a time-table with the same regularity as is achieved by a railway service is of interest. Owing to variable winds, the journey between two points must necessarily occupy a different time on different days. The operational difficulties of the problem are as follows : getting into the air, navigating between the termini, and getting on to the ground again. The first calls for a machine of sufficient structural strength and with a sufficient margin of engine power to withstand bumps due to the turbid condition of the air near the ground. Safety whilst moving along the ground can probably be secured by providing a very wide undercarriage. Once in the air, multiple engines having a sufficient margin of power may be relied upon to ensure entire dependability. The machine might be navigated with absolute accuracy by means of wireless without the pilot's at any time seeing the ground over which it was flying. The crux is the landing at the journey's end. The problem of safe landing in a thick fog has yet to be solved. It remains to be seen whether a solution will be found in some special type of illumination capable of piercing the fog, or in some more mechanical device. Alternatively a fog-shrouded aerodrome might be temporarily avoided, machines being diverted by wireless messages to some more favourable landing-place. The main essentials to a successful aeroplane service are ample and absolutely reliable power and the installation of a definite system of wireless communication.

The study of the weather and of such conditions as affect it is of great importance to the pilot. As flying becomes more general, meteorological reports and forecasts adapted to his special needs will doubtless become more generally available. Confidence in these forecasts, however, is greatly increased by a knowledge of the principles upon which they are worked out; moreover, the pilot is bound at times to have to depend on his own knowledge and experience.

The chief feature of the weather, particularly in Western Europe, is its variability. It not only varies considerably from hour to hour, but also from place to place. The weather at two places—say, a hundred miles apart—may change its character completely in the course of a few hours, improving in the one place and becoming worse in the other. The wind likewise may change in direction and velocity at the two places. It is not sufficient to obtain a telegraphic report from the place to be flown to, although this may be helpful, especially if it be possible in any way to anticipate the tendency of the weather. Weather changes occur in accordance with certain laws which are perfectly well understood and from which they can be prophesied with a considerable degree of accuracy. Fortunately the weather conditions most dangerous for aviation are those most easily prognosticated.

The main causes of weather changes are varying winds. Wind results chiefly from variations in the pressure of the atmosphere —i.e. the barometric pressure. It is further affected by the rotation of the earth. As, however, the velocity of the earth is the same at any particular latitude the variation in atmospheric pressure must be looked to for the causes of changes in the wind at any particular place. Let the effect of the barometric pressure in producing wind be considered. The air, like any other fluid, tends to flow from a region of high pressure to one of low pressure. If the pressure at A is less than at B, there will be a tendency for air to flow from B to A, thus creating a wind. Further, the rate at which it flows will depend on the amount of the difference in pressure (i.e. " pressure gradient ") between the two points. It is thus evident that in order to study these effects the meteorologist must be furnished with simultaneous barometer readings from a large number of places. From such data a map such as is shown in Fig. 145 is prepared. Here lines such as X, Y, and Z are drawn, joining all points at which the pressure is the same. The meteorologist takes for his unit of atmospheric pressure the Bar, which is a convenient standard measurable in centimetre-gramme-second units, and which approximates to the normal barometric pressure.

The Bar is subdivided into 1000 Millibars. The pressure distribution map usually shows lines for from every two to ten millibars pressure according to the scale of the map and the completeness of the data from which it is compiled. These lines are analogous to the contours on a land map and are called Isobars. The map commonly exhibits areas of low and of high pressure. These are termed "Cyclonic" and "Anticyclonic" areas respectively, and are indicated at A and B in Fig. 145. The wind due to the pressure gradient would tend to flow from B to A. However, the effect of the earth's rotation considerably modifies this, causing the wind almost to follow the isobars, crossing them at a slight angle towards the low pressure area. The winds in the Northern Hemisphere circulate in an anticlockwise direction and inwards about a cyclonic area, and clockwise and outwards from an anticyclonic area. In the maps of this type the wind is indicated by arrows drawn flying with it. The velocity of the wind is indicated by the number of barbs according to the Beaufort Scale. The Beaufort Scale is very useful for the purpose of approximating the ground wind speed. It is tabulated in the Appendix. It will be noted that the wind

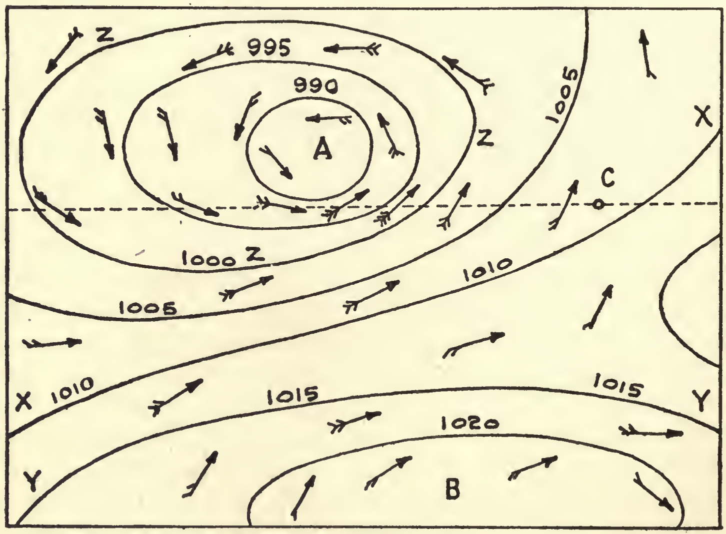


Fig. 145.

velocity is greatest on the sides of the depression where the pressure gradient is a maximum and light and somewhat indeterminate in direction at the centres of either high or low pressure. Cyclones and anticyclones move about over the surface of the globe. The former usually move fairly rapidly. The latter are usually of larger area and slower of movement. In this part of the world cyclones nearly always travel in a North-Easterly, Easterly, or South-Easterly direction.

The winds near the ground are largely affected by local conditions, such as hills. At higher altitudes they tend to follow the isobars more accurately. As the height is increased, the wind is generally found to grow stronger, and its point of origin usually swings slightly in a clockwise direction. This is due to ground friction, local temperature conditions, and the effect of the rotation of the earth. During variable weather the conditions are much more constant at high altitudes than near the ground. On stormy days high clouds may sometimes be observed to be moving in a very different direction to those near the ground.

Cyclones and anticyclones are accompanied by certain characteristic forms of weather. As they move about over the surface of the earth the weather conditions associated with them are carried with them. The cyclone is accompanied by Northerly wind and improving weather on its Western side, light, indeterminate winds and probably heavy rain at the centre, and overcast weather with rain accompanied by Southerly winds on its Eastern side. The strength of the winds and the general severity of the conditions vary according to the depth of the depression. The anticyclone is characterised by fine weather and light winds, and it generally provides excellent flying conditions, although the visibility may often be poor.

The isolated observer can gauge approximately the position of these cyclonic and anticyclonic areas by observing the wind. If he face the wind, the low pressure area is on his right hand and the high on his left. This is Buys Ballot's Law. Suppose that a cyclone is moving past him on the North side and in an Easterly direction. That is to say, he is at the point C in Fig. 145. The point of origin of the wind will move first in a Westerly direction, the wind getting stronger and the weather becoming rainy. As the cyclone passes him the wind will increase again, its origin now moving in a Northerly direction, and the weather will improve. The barometer during this cycle will first have fallen and subsequently have risen again. This cycle of changes commonly takes about twenty-four hours in this country, but may take considerably less. A series of cyclonic depressions are frequently observed to follow one another across the British Isles during the winter months.

The influence of cyclonic and anticyclonic depressions, as far as the airman is concerned, does not end at the question of local weather conditions. Where long cross-country flights are to be made, the study of the pressure distribution in the neighbourhood of the route may enable the pilot to avail himself of more or less favourable winds and weather on both the outward and the return journeys. For example, if the flight is from London to Rome and back, and an anticyclone exists over the centre of France on the outward journey, an Easterly course might be adopted, and on the return a more Westerly course might be taken across the South of France. Local weather conditions apart from wind directions would, of course, also have to be considered, especially if high mountains are to be crossed.

When the average conditions are considered over the surface of the globe, it is found that in certain areas high pressure conditions, and in others low pressure conditions, generally prevail. The locality and intensity of these conditions vary to some extent with the seasons and are also liable to be disturbed in different localities to a varying degree by purely local weather conditions. The fact remains, though, that in most places a certain type of wind prevails. The world air routes of the future will as far as possible be chosen so as to take advantage of these. The great air routes will have to be standardised in some manner, and the prevailing pressure distribution will be one of the chief factors in determining them. The trade winds which blow with great constancy in the Equatorial Belt and are made use of by sailing ships are examples of the most constant winds of which the airman will likewise avail himself.

Clouds and mist must always be an obstacle to the aviator. Some remarks on their nature and formation may therefore be of interest. The atmosphere always contains a certain amount of water vapour. This is carried in solution in exactly the same manner as salt may be dissolved in water. Hot water will dissolve more salt than will cold. If a hot saturated solution of salt be cooled, crystals of salt will be deposited. In the case of a solution of water in air exactly the same phenomena are met with. Water is more readily soluble in warm air. By successively cooling air containing water vapour the saturation point, called the Dew Point, is reached. If the air then be further cooled small drops are deposited in the form of mist. Clouds consist of masses of mist so formed. The quantity of water which air will dissolve varies very greatly with the temperature, a variation of 30° F. in temperature will multiply three times the amount of water which the air will dissolve. It is thus seen that no very great changes of temperature are required in order that clouds shall be formed. Rain occurs when further cooling takes place. Large particles of water are formed which are too heavy to be held in suspension.

The highest fleecy white clouds known as Cirrus, which are above the level of normal flight, owing to the low temperature at the level of their formation, consist of ice crystals. The lower clouds with which the aviator usually meets may be grouped as either sheet clouds or heap clouds. Sheet clouds are the result of the stratified nature of the atmosphere. Layers of warm air coming in contact with cooler layers become cooled below their saturation temperature, cloud being formed at the surface of contact. The cloud layer may be continuous or may consist only of isolated clouds. Heap clouds owe their formation to rising currents of air. which become successively cooled as they rise.

APPENDIX

TABLE I

MISCELLANEOUS DATA

A Statute Mile = 5280 Feet = 1·609 Kilometres.

60 Miles per Hour = 88 Feet per Second = 26·82 Metres per Second.

A Nautical Mile = 6080 Feet = One Minute of Latitude = 1·15 Statute Miles.

A Knot = One Nautical Mile per Hour.

1 Horse Power = 33,000 Foot-Pounds per Minute.

$\pi = 3·1416$.

g = Acceleration due to Gravity = 32·2 Feet per Sec. per Sec.

Weight of 1 Cubic Foot of Water = 62·3 lbs.

Weight of 1 Cubic Foot of Petrol = 44 lbs (mean).

Weight of 1 Cubic Foot of Oil = 58 lbs (mean).

A Gallon of Water Weighs 10 lbs.

Mass of 1 Cubic Foot of Air = 0·00237 Pounds.

Temperature in degrees Centigrade = $\frac{5}{9}$ (Temp. ° Fahrenheit − 32) = Temp. ° Absolute − 273.

Normal Barometer = 30 inches = 760 millimetres = 1016 millibars.

Correction of Air Speed Indicator for Height = + 1·6 per cent per 1000 Feet.

Boiling Point of Water falls 1° Centigrade per 1000 Feet.

TABLE II

MECHANICAL PROPERTIES OF MATERIALS

Material.	Weight lbs. per cub. ft.	Ultimate Tensile. Tons per sq. in.	Extension per cent on 2 in.	Modulus of Elasticity. Tons per sq. in.	Remarks.
Steel Mild . . .	480	25–35	45–35	13500	... ...
Forged	...	35–45	28–22	...	Medium Carbon.
Annealed Carbon.	...	45–50	20–15	...	Spring Steel.
Tempered Carbon	...	60–70	...	...	
Piano Wire (Soft)	...	60–70	...	...	Depending on the diameter of the wire.
,, ,, (Hard)	...	100–120	...	...	
Low Nickel . .	...	35–40	30–20	...	Annealed or Oil Hardened.
High Nickel . .	...	60–80	20–15	...	Heat Treated.
Nickel (for Valves)	...	45	50	...	... ...
Nickel Chrome .	...	50	20	...	Annealed.
,, ,, .	...	80–100	10–5	...	Heat Treated.
Aluminium-Rolled .	165	10	6	5000	... ...
Cast Alloys . .	170–190	10–12	12–7	...	... ...
Duralumin-Sheet .	175	26	15	4700	Heat Treated.
Forgings	...	23	18	...	
Copper-Annealed .	550	12–14	50–40	5500	Yield Stress 4.
Gun Metal . . .	540	12–18	25–10	5000	... ...
Phosphor-Bronze .	535	15–20	8–2	6000	... ...
Lead	710	...	...	...	... ...
Ash (with grain). .	40–45	0·55–0·65	...	550	Ult. Compressive 0·30–0·35.
Spruce (with grain).	25–25	0·30–0·40	...	550	Ult. Compressive 0·25–0·30.
Walnut	35–40	0·45–0·50	...	600–650	Ult. Compressive 0·30–0·35.
Mahogany . . .	35–40	0·8–0·9	...	700	Ult. Compressive 0·40.
Linen Fabric . . .	Weight 4–5 oz. per sq. yd. Tensile 85–100 lbs. per in. width.				
,, ,, doped.	,, 6–7 ,, ,, ,, ,, ,, 100–125 ,, ,, ,, ,, (Warp direction stronger than weft.)				

TABLE III

STRENGTH OF HIGH TENSILE STEEL WIRE (SOLID)

Standard Wire Gauge	10	12	14	16
Breaking Load (lbs.)	2500	1900	1200	800
Stress in Tons per Square Inch . . .	90	100	105	110

TABLE IV

STRENGTH OF FLEXIBLE STEEL CABLE

Diameter (inches)	0·075	0·115	0·137	0·150	0·168
Breaking Load (cwt.)	5	10	15	20	25

TABLE V

MOMENTS OF INERTIA OF COMMON SECTIONS

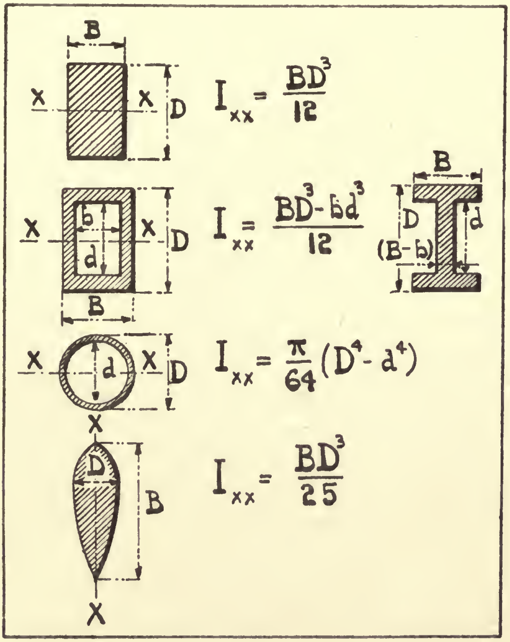


TABLE VI
PARTICULARS OF TYPICAL AEROPLANES

Type.	Engines.	Span.	Length.	Speed Max. M.p.h.	Ceiling. Feet.	Duration full Power.	Total Weight. Lbs.	Useful Weight. Lbs.	Loading per Sq. Ft.	Loading per H-P.	Remarks.
Vickers Vimy .	2 Rolls 700 H-P.	67′ 2″	46′ 2″	100	10,500	8·5	12,500	2870 and Pilot	9·5	17·9	Twin Engine Commercial.
Airco 18 . .	Napier Lion 450 H-P.	...	...	115	15,700	3·25	6042	1600 and Pilot	9·45	12·1	Passenger (8) or Freight.
Airco 9B . .	Siddeley-Deasy 240 H-P.	...	...	113	19,000	4·5	3669	600 and Pilot	8·45	15·3	Passenger (2) or Freight.
Supermarine Boat	Beardmore 160 H-P.	50′ 5¼″	30′ 0″	85	...	4·0	...	460 and Pilot	...	...	Passenger (3) or Freight.
Martinsyde F3 .	Rolls 190 H-P.	32′ 10″	25′ 6″	145	30,000	2·5	2300	590	7·0	7·5	Single Seater Tractor.
Supermarine Sea Lion Boat	Napier Lion 450 H-P.	35′ 0″	26′ 10″	145	...	2·25	...	100 and Pilot	...	...	Single Seater Pusher.
Sopwith Camel .	Bentley Rotary 150 H-P.	28′ 0″	18′ 9″	120	18,000	2·25	1508	100 and Pilot	6·5	10·0	Single Seater Tractor.
Avro Baby . .	Green 35 H-P.	25′ 0″	19′ 3″	80	...	4·0	870	80 and Pilot	4·9	21·7	Single Seater Tractor.

TABLE VII

THE BEAUFORT SCALE OF WIND FORCE

Beaufort Number.	General Description.	General Observations.	Limits of Mean Velocity. Miles per hour at surface.
0	Calm	Calm ; smoke rises vertically . . .	Less than 1
1	Light Air . .	Direction of wind shown by smoke but not by wind vanes	1–3
2	Slight Breeze .	Wind felt on face ; leaves rustle, ordinary vane moved by wind	4–7
3	Gentle Breeze .	Leaves and small twigs in constant motion	8–12
4	Moderate Breeze	Raises dust and loose paper ; small branches are moved	13–18
5	Fresh Breeze .	Small trees in leaf begin to sway ; crested wavelets formed on inland water . .	19–24
6	Strong Breeze .	Large branches in motion ; whistling heard in telegraph wires ; umbrellas used with difficulty.	25–31
7	High Wind . .	Whole trees in motion ; inconvenience felt when walking against wind . . .	32–38
8	Gale	Breaks twigs off trees ; generally impedes progress	39–46
9	Strong Gale. .	Slight structural damage (chimney pots and slates removed)	47–54
10	Whole Gale. .	Seldom experienced inland ; trees uprooted ; considerable structural damage occurs .	55–63

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