CHAPTER I.

AERODYNAMIC PRINCIPLES.

6. Most good riggers have a knowledge of the aerodynamic laws that govern the flight of heavier-than-air craft. No attempt is made in this chapter to explain these laws, but brief explanations of the terms in common use are given as a guide. Those interested in the theory of flight are referred to Air Publication 129, Flying Training Manual, Part I, and other publications where the subject is more fully dealt with. For further explanations of the nomenclature and the definitions of the expressions used in connection with aeroplanes and aerodynamics which are not mentioned here, reference should be made to the "British Standard Glossary of Aeronautical Terms."

The Atmosphere.

7. It is general knowledge that the earth is surrounded by a layer of colourless and invisible gas known as air. It is usual, for particular purposes, to speak of this layer as being about 10 miles thick, but it would be impossible to draw a line where the air actually ends because the atmosphere presumably "shades off" very gradually into the space that exists between our earth and other bodies. The air is most dense near the ground, and becomes more and more rarified as the distance from the ground increases. The air has certain properties, the variation of which affect the flight of all types of aircraft, and of these properties the most important is perhaps that of "density."

Air density, pressure, and temperature.

8. Before any definite figures can be specified for the density of the air, some standard conditions of barometric pressure and temperature must be stated, because the air density is directly affected thereby. It is usual to take, as a standard, the pressure which corresponds to a mercury barometer reading of 760 mm., or 29·92 in., which is equivalent to 14·7 lb./sq. in. The standard temperature adopted varies somewhat, but is generally accepted as 60° Fahrenheit or 15° Centigrade at sea level, decreasing by 2° Centigrade (or its equivalent in degrees Fahrenheit) per thousand feet of elevation. The density of the air under these standard conditions of pressure and temperature is ·0766 lb./cub. ft., which, stated in a simpler way, means that 13 cub. ft. of air weigh nearly 1 lb.

9. The pressure of the air at sea level varies with atmospheric conditions, so that a pressure-measuring instrument, such as an aneroid or an altimeter, will not read zero height at ground level unless the barometer reading is 29·92 in. and the aerodrome is at sea level. The aneroid reading changes at sea level by approximately 90 ft. per 0·1 in. change in barometer reading. In order to obtain a true comparison, all full-scale tests must be made at the same air pressure, that is, the same altimeter reading, which is not necessarily at the same height from the ground. Given the same air pressure, the air density will change with every alteration of temperature ; therefore the air temperature must also be observed so that results can be converted to standard conditions.

10. Amongst the other properties of air is that of humidity, which can be defined as amount of water vapour present in the air. The effects of humidity on the flight of an aeroplane are negligible, and therefore no corrections are made for this condition.

Aerofoils.

11. An aerofoil is a structure analogous to the wing of a bird, designed to obtain reaction from the air approximately at right angles to the direction of its motion. This reaction is recorded in fig. 1 by a line AC, which leans a little backward from the normal to the direction of motion. This line represents the resultant force, which is usually resolved into

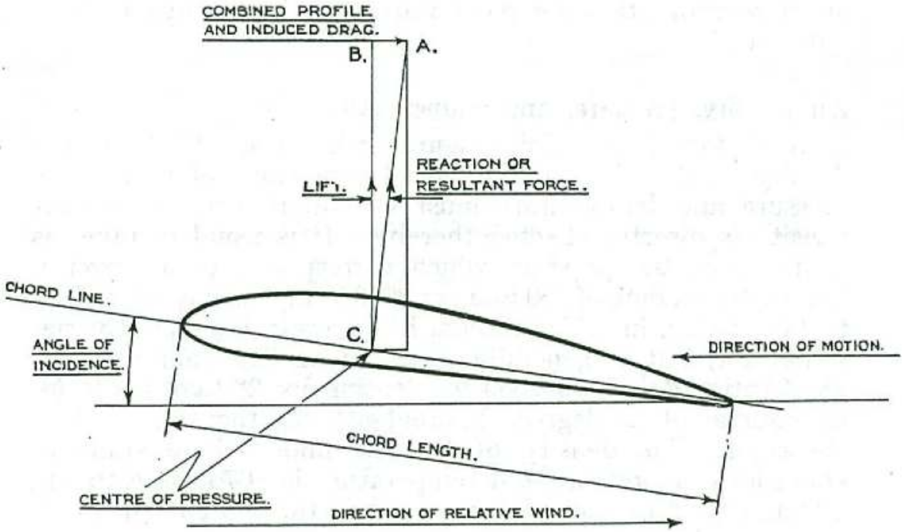

FIG. 1.—Diagram of forces of an aerofoil.

two forces known as lift and drag, represented by BC and BA respectively. The lift and drag of an aerofoil are the most important of its characteristics.

Lift.

12. The lift can be defined as that component of the resultant force which is perpendicular to the direction of the relative wind.

Drag.

13. The drag of an aerofoil may be defined as that component of the resultant force which is parallel to the direction of the relative wind.

Aerofoil section.

14. The aerofoil sections employed are sometimes symmetrical about a line drawn through the leading and trailing edges, but they are more often cambered. An aerofoil is cambered when its centre line is curved, and the camber is usually denoted as the maximum height of the aerofoil centre line above and at right angles to the chord line. For convenience, this height is usually expressed as a fraction of the chord. There are many types of aerofoil sections employed, all of which have slightly different characteristics. Thin wing sections of low camber have least drag, but thick and high camber sections usually give greater maximum lift coefficents. Another rather important characteristic of an aerofoil is its centre of pressure travel. This characteristic varies with each section employed, and is practically non-existent in symmetrical sections.

15. Two of the curves in fig. 2 show how the lift and drag of an aerofoil vary with the angle of incidence (i.e., the angle between the chord of the aerofoil and the direction of motion) when the speed at which the air passes over the wing is kept constant. The lift is seen to be roughly proportional to the incidence up to about 14°, at which angle it reaches a maximum and the aerofoil is said to stall. The drag has been constantly rising and rises very rapidly after the stall. The third curve shows the ratio of lift to drag. The most efficient aerofoil is clearly one that gives the highest value of this ratio. It is also clear that that an aerofoil is most efficient at the angle corresponding to maximum lift/drag, i.e., at 3° to 4° in this case.

Chord.

16. The chord of an aerofoil is the line passing through the centres of curvature of the leading and trailing edges, the length of the chord being the distance between these edges.

This will be more clearly understood if read in conjunction with the description of incidence given in para. 19.

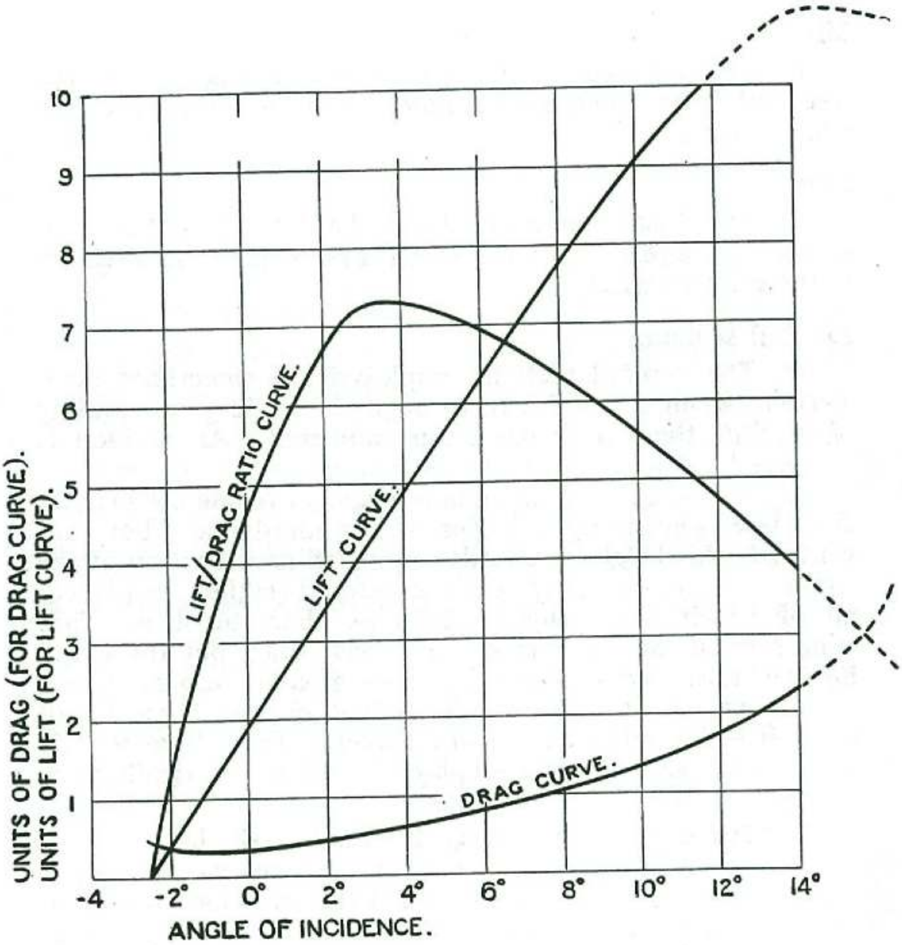

FIG. 2.—Lift and drag curve.

Centre of pressure.

17. The lift of an aerofoil is usually considered as being composed of an infinite number of small forces or pressures acting upwards at all points of the surface. A pressure distribution curve for a typical aerofoil is given in fig. 3. If all these small forces are combined and considered as the action of a single force, the point where the line of action of this force cuts the chord is known as the centre of pressure, as indicated in fig. 1. The position of the centre of pressure is usually given as a percentage of the chord from the leading edge. For all types of aerofoil, other than one with symmetrical section, the position of the centre of pressure varies

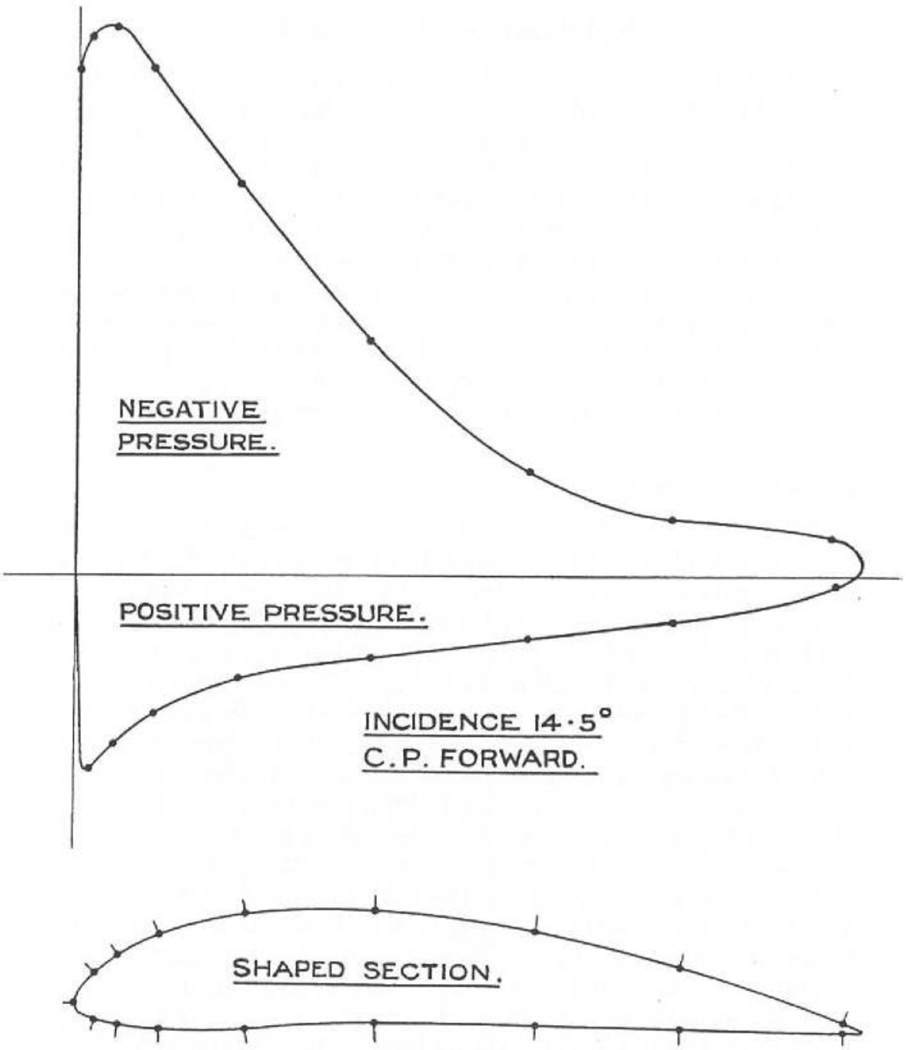

Fig. 3.—Pressure distribution curve.

with the incidence. When the aerofoil is at an angle of no lift, that is, at such an incidence that no resultant upward or downward force is being applied to the aerofoil, the centre of pressure is theoretically at an infinite distance behind the aerofoil, and as the angle is increased the centre of pressure travels forward. The normal centre of pressure travel varies with the different aerofoil sections used, but for a symmetrical section the position is constant over a large range of angular movement. This is advantageous from the aspect of the strength of the members involved, but the symmetrical type of section is not the most efficient as a lifting surface.

SUPPORTING SURFACES.

18. The supporting surfaces of an aeroplane are those which directly contribute to the sustaining of the aeroplane in the air, as considered apart from the control surfaces. Theoretically there is no reason why an aeroplane should not have as many main supporting surfaces as desired, but on the score of general efficiency and the cost of production and maintenance, modern aeroplanes seldom have more than two. The supporting surfaces of an aeroplane are usually termed the planes, and when determining the size and disposition of these parts the chief considerations, apart from the shape of the aerofoil in cross section, are the incidence, span, chord, dihedral, stagger, gap and sweepback.

Incidence, angle of.

19. Theoretically, the angle of incidence is the angle between the chord line, as defined in para. 16, and the direction of the relative wind. Practically, this angle cannot be measured by the rigger, so for rigging purposes an equivalent angle is used which is measured from the horizontal. When the underside of the plane is concave, so that when applied a straightedge will take up a definite attitude with relation to the true chord line, then the angle of incidence normally given to the rigger is the angle between the horizontal and the top surface of a straightedge held up against the underside of the plane at a rib when the aircraft is in rigging position. This angle is measured by a clinometer. When the underside of the plane is convex, then the angle of incidence cannot be defined by this method; therefore it is usual to take as the angle of incidence the angle made by the top surface of a straightedge and the horizontal, when the straightedge is held up against the surface of the plane in such a position as to be parallel with the chord line. The distances from the top surface of the straightedge to the centres of curvature of the leading and trailing edges will then be equal. It is usual, however, for special incidence boards to be supplied for use with bi-convex sections, and detailed rigging instructions are generally available.

Span.

20. The span, as indicated in fig. 4, is the overall distance from wing tip to wing tip. The efficiency of the planes near the tip is considerably less than the efficiency over the centre portion of the plane. An aerofoil which has a long span in comparison with its chord will, area for area, be more efficient than an aerofoil which is comparatively short and wide.

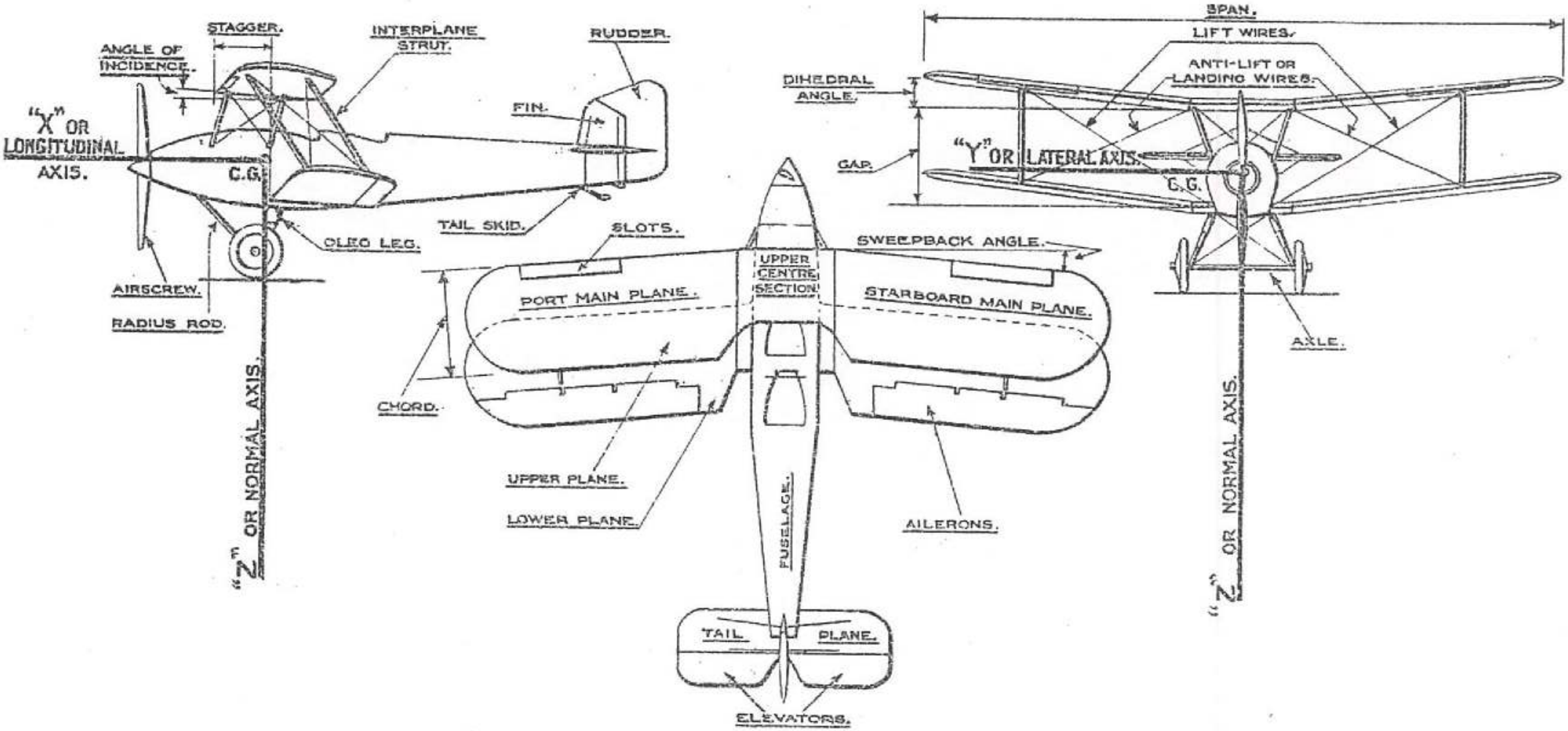

FIG. 4. AIRCRAFT TERMS.

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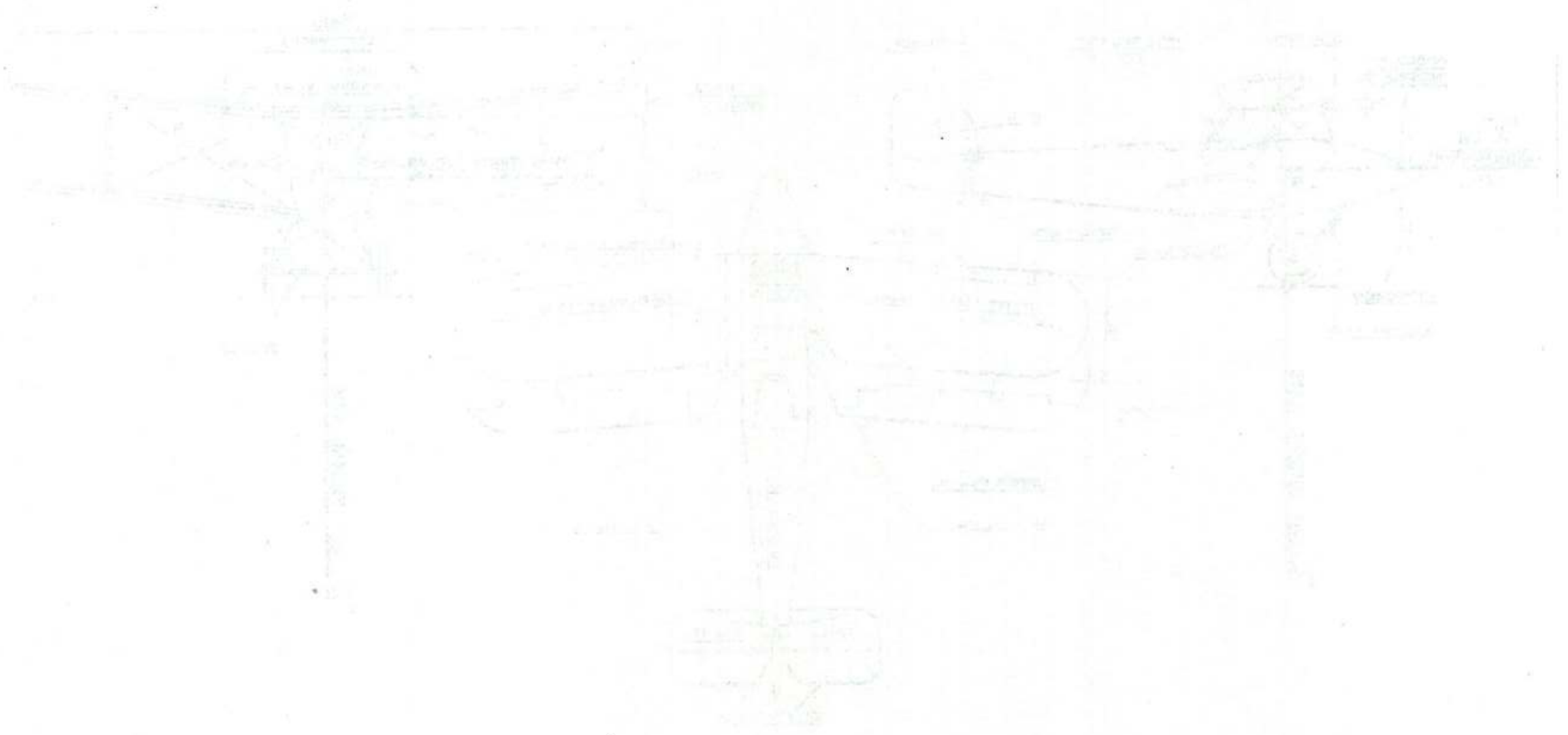

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Aspect ratio.

21. The ratio of the span to the chord of a plane is called the aspect ratio, and, as explained above, planes which have high aspect ratio, that is, with a big span and a small chord, are more efficient than those with a low aspect ratio.

Gap.

22. There is another consideration which affects the efficiency of biplanes and that is the distance between one plane and the next immediately above or below it. This distance, shown in fig. 4, is termed the " gap " and is important from the point of view of the interference with the air flow over one plane caused by the plane above or below it. A small gap tends to reduce the efficiency of aerofoils. The top planes are always more efficient than the bottom planes, which brings about the common arrangement of large upper and smaller lower planes. The gap is usually measured directly from the leading edge of one plane to the leading edge of the other, and, owing to the sweepback effect due to dihedral may vary according to whether the measurement is taken at the centre section or the wing tip.

Dihedral.

23. In order to obtain additional stability in flight, many aeroplanes have their planes inclined upwards with relation to the transverse axis. The dihedral, in geometry, is the angle between any two planes, and a dihedral angle of an aeroplane is shown in fig. 4, and is the angle formed between the upwardly inclined plane and a horizontal line taken from any point. If inclined upward, the dihedral is positive ; if downward, the dihedral is negative. As a negative dihedral would detract from the inherent stability of the aeroplane it is never employed.

Stagger.

24. In order, amongst other considerations, to reduce the interference owing to the close proximity of the planes to one another, one plane is often brought further forward with relation to another. In these circumstances the planes are said to be staggered, and the amount of stagger is measured by dropping a plumbline over the leading edge of the upper plane, when the aeroplane is in rigging position, and measuring from the plumbline to the leading edge of the lower plane. The stagger is almost invariably measured at the centre section. When the upper plane is in advance of the lower plane then the stagger is stated to be positive. Negative stagger occurs when the lower plane is in advance of the upper plane, and is a very rare occurrence in modern design. In addition to the various aerodynamic considerations involved, stagger is employed by the designer to obtain a larger field of view for the crew.

Sweepback.

25. In many aeroplanes the main planes in plan view are inclined backward as shown in fig. 4, thereby making an angle of less than 90° with the fore-and-aft centre line of the fuselage. The planes are swept back to give better longitudinal stability, and in spite of the fact that it introduces certain constructional difficulties, the practice is fairly common. It is not usually necessary for the rigger to check sweepback on the planes as this is usually fixed by the attachment fittings. A check for symmetry of the planes in plan view is all that is normally required.

CONTROLLING SURFACES.

26. In order to be of practical value, an aeroplane should be controllable under all conditions of flight which it is likely to encounter. There are quite a number of possible forms of control for aircraft, but no system has proved quite as simple and effective as that which is now practically universal. Generally speaking the flight of an aeroplane is controlled by means of subsidiary aerofoils so disposed about the aircraft that they provide control about the three principal axes. The control surfaces normally fitted are ailerons, elevators and rudders. Ailerons control the rolling movements which have the longitudinal axis as a pivot, the elevators affect movements having the transverse axis as a pivot, while the rudder controls yaw, or movements pivoted about the normal axis.

Ailerons.

27. Ailerons are aerofoils used for causing an aeroplane to roll about its longitudinal axis. The normal type of aileron is shown at A, fig. 5, and as will be seen, it forms a hinged continuation of the main aerofoil section near the wing tip, and often has some form of balancing surface. The action of ailerons is virtually to increase the angle of incidence of the wings on one side and decrease it on the other, thereby increasing or decreasing the lift. The rolling and yawing forces produced by the downward movement of an aileron are approximately equal to those produced by an equal upward movement of the aileron. Above stalling incidence the rolling forces remain about the same for equal movements, but the yawing, or drag force is greatly increased on the wing where the

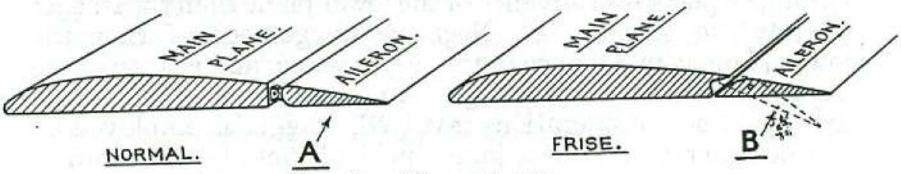


FIG. 5.—Aileron types.

aileron is down. For this reason, many ailerons are fitted with a mechanical differential action, so that, as the control column is moved right over, the elevated aileron continues its movement until the stop is reached, but the depressed aileron ceases its angular movement and in some cases even slightly reverses its motion at a point which gives the maximum rolling movement. A normal system of aileron control is shown in fig. 81.

28. There are some forms of aileron, such as the Frise shown at B, fig. 5, in which a similar action is obtained aerodynamically. With this type the ailerons on both sides move through equal angles and are effective at angles closer to the stalling angle than would be the case with a conventional type. In a normal arrangement the leading edge of the aileron is situated approximately level with the lower surface of the plane, whilst the hinge position is about a quarter of the chord of the aileron back from the leading edge. The exact aerodynamic considerations involved for the various types of differential aileron systems are a little obscure, but the aim of all systems is the same, i.e., to obtain the desired rolling moment as free as possible from yawing moment.

Elevators.

29. The elevators usually take the form of horizontal control surfaces, which form a continuation of the tail plane and are hinged to the rear spar. The action of this type of elevator is virtually to vary the camber of the combined tail plane and elevator surface, by means of which the pitching of an aeroplane in flight is controlled. If the incidence of the tail plane is adjustable, the range of control can be varied, and any desired fore-and aft trim can be maintained without constant pressure being exerted on the controls. Elevators usually have some form of aerodynamical balance, the conventional type being the horn balance. In some designs the horn balanced portion is shielded by the tail plane over the smaller angles of movement as indicated in fig. 64, or partly shielded. This latter arrangement is provided to avoid the snatch which is often evident when the leading edge of the balanced portion protrudes above or below the surface of the tail plane itself.

Fins and rudders.

30. Fins and rudders are provided in order to control the yawing of an aeroplane and give additional lateral stability. These surfaces are arranged vertically and usually form part of the tail unit. The fins are normally attached to a sternpost at the rear end of the fuselage, and are so positioned that, in conjunction with the rudder, they form aerodynamically a

variable camber aerofoil. The rudders are usually hinged to the sternpost and are sometimes aerodynamically balanced, the balanced portion being sometimes shielded by the fin over the smaller angles of movement. Normal arrangements of fins and rudders are shown in figs. 50 and 66. The object of the shielding is to obviate overbalancing which is possible during the first few degrees of movement.

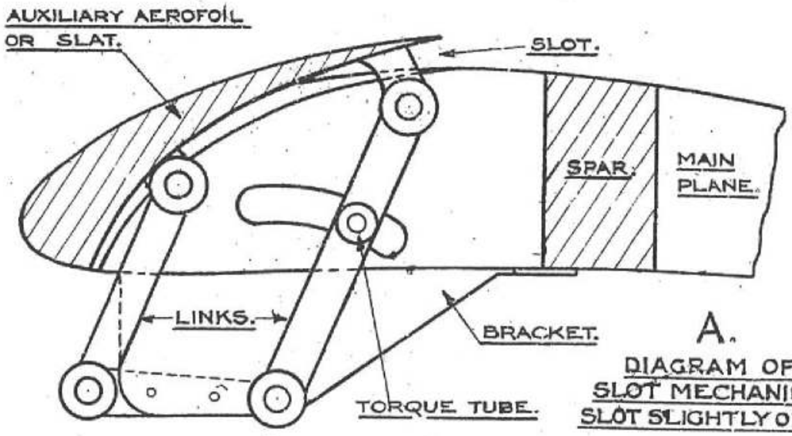
Slots.

31. Slots are a device for varying the air flow over the surface of an aerofoil, by the use of an auxiliary aerofoil, or slat, set parallel to and in front of the leading edge of the main aerofoil. The slot is, strictly speaking, the gap between the main and the auxiliary aerofoils, the size of the gap being regulated by the movement of the auxiliary aerofoil. As the gap or slot is its essential feature, it has given its name to the device as a whole. Slats may be fixed, manipulative or automatic, and their use may be to increase lift of the wing, or to contribute to the lateral stability and control. The auto control slot is the type generally used on Service aircraft. This is a type which automatically opens when the incidence of the wing exceeds a given angle and closes when the wing returns to a given angle. Fig. 6A shows diagramatically a typical arrangement of an automatic slot in which the auxiliary aerofoil is free to take up any position as determined by the resultant force on the slot due to the incidence of the main aerofoil. Fig. 6B shows in diagrammatic form the lines of action of the resultant forces due to various angles of incidence of the main aerofoil. The action of the slot is that, when the main aerofoil is stalled or near stalling, the slat will be in a forward position, as indicated in fig. 6B, thus directing a flow of air through the slot and over the main aerofoil which mitigates the burbling or eddying taking place, which is characteristic of the unslotted wing at stalling incidence.

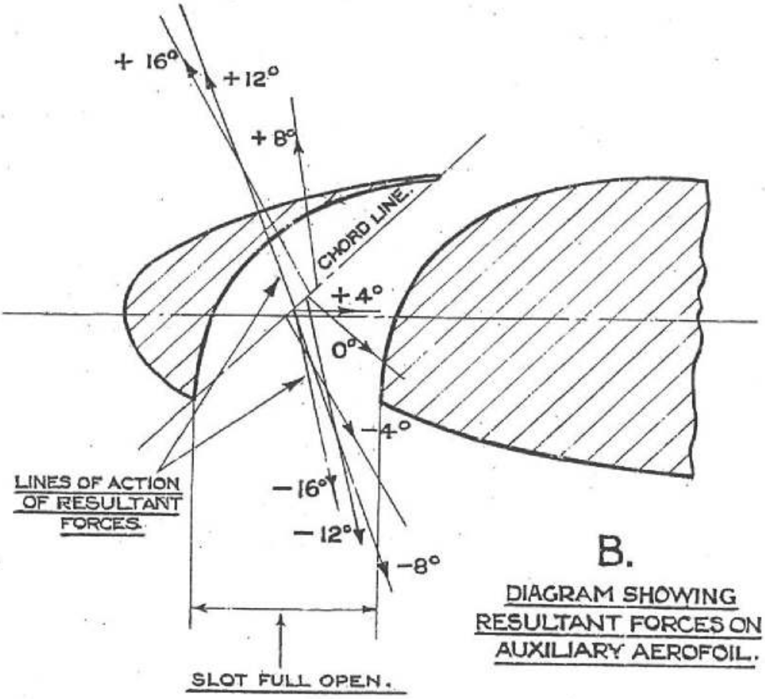
32. There are several conditions which appear to affect the successful functioning of the auto control slot, but the gap arranged between the trailing edge of the auxiliary aerofoil and the main aerofoil when the slot is closed would seem to be the most important. The amount of gap affects the opening point of the slot owing to the transference of the negative pressures from the upper side of the main aerofoil on to the underside of the auxiliary aerofoil.

AEROPLANES.

33. There are several types of heavier-than-air craft, but the type in normal use is the aeroplane. Aeroplanes can be classified under the headings of land planes, amphibians, and seaplanes, and the seaplane can again be subdivided into float planes and flying boats. Aeroplanes are usually either



A.
DIAGRAM OF SLOT MECHANISM SLOT SLIGHTLY OPEN.



B.
DIAGRAM SHOWING RESULTANT FORCES ON AUXILIARY AEROFOIL.

FIG. 6. AUTOMATIC SLOT DIAGRAM.

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Malby & Sons, Photo-Lith.

monoplanes or biplanes, although theoretically there is no reason why an aeroplane should not have as many supporting surfaces as desired.

Stability.

34. A stable aeroplane is one which tends to return to the same state of motion after disturbance, without movement of the controls by the pilot. An unstable aircraft is one which will not return to the same state of motion after disturbance without assistance. Longitudinal stability is the stability of the motions of the aeroplane in the plane of symmetry, that is, of the rise or fall, forward motion and pitching in the direct line of flight with the planes horizontal. Lateral stability is that of the motions of rolling, yawing and sideslipping, which always occur in combination. The longitudinal and the lateral motions can occur independently or they may occur together.

Yawing.

35. Yawing is the inclination from side to side of the direction of motion of the aeroplane out of the plane of symmetry, that is, turning about the vertical axis which passes through the centre of gravity of the aeroplane. and is normally controlled by the rudder.

Rolling.

36. Rolling is a movement usually controllable by the ailerons, and is the angular movement or turning of the aeroplane about the fore-and-aft axis.

Pitching.

37. Any movement in the plane of symmetry in which the aeroplane is turned about an axis through the C.G. perpendicular to the plane of symmetry is termed pitching, and is normally controllable by the elevators.

Nose and tail heavy.

38. When an aircraft has a tendency to lower or raise its nose in flight it is considered to be in a " nose heavy " or " tail heavy " condition. An aeroplane which is nose or tail heavy can usually be corrected by adjustment of the tail plane.

" One wing down."

39. This is an expression denoting that the aeroplane is out of trim laterally, and has a tendency for one wing to drop. This condition is generally due to incorrect rigging.

Slipstream.

40. The stream of air which is discharged aft by a revolving airscrew is termed the " slipstream." Particularly on single-engined aircraft, the slipstream very appreciably affects the

aircraft in flight, owing to the effect on the control surfaces of the tail unit and sometimes owing to the restricted space between the body and the centre sections of the planes. Special precautions have usually to be taken in securing all parts subjected to the effects of the slipstream.

Down-wash.

41. The current of air deflected downwards relative to the aeroplane by an aerofoil or other body is called the down-wash. In certain conditions it is possible for the down-wash of one plane to interfere considerably with the air flow of a plane below it.

Centre of gravity.

42. The position of the centre of gravity of an aeroplane is of very great importance and definitely affects the stability and controllability of the aircraft. The centre of gravity of an aeroplane is that point through which the resultant of the weights of all its component parts passes in any position that the body may assume. The position of the centre of gravity of an aeroplane is determined in the manner described in Appendix I of this publication. It is very necessary that the fore-and-aft limits for the position of the centre of gravity, as given in the certificate of airworthiness, should not be exceeded.

Drag (Total).

43. The total drag is the resistance induced by the aeroplane along the line of flight, and includes not only the drag of the planes, but also the parasitic drag of the fuselage, undercarriage, struts, and generator, etc.

Drift.

44. The drift of an aeroplane is the movement sideways or crabwise relative to the ground, usually caused by a side wind. Drift is usually measured as an angle between course steered and the actual ground track traversed.

Stalling Speed.

45. An aircraft is said to be at stalling speed when the airspeed is at the minimum necessary to support it in the air. In these circumstances the angle of incidence corresponds to the maximum lift coefficient of the planes.

Service ceiling.

46. The Service ceiling is that height at which the rate of climb has fallen to a certain defined limit (e.g., 100 ft./min.). The absolute ceiling is the limit of height attainable in standard atmosphere under specified conditions.