

FLIGHT CONTROLS

Introduction

1. The control surfaces of an aircraft are used for manœuvring. The conventional aircraft has three main control surfaces : the ailerons for control in the rolling plane, the elevators for the looping plane, and the rudder for the yawing plane. These surfaces are designed and positioned so as to obtain the greatest effect at all speeds consistent with the role of the aircraft.

Balancing

2. If control surfaces are hinged at their leading edge and allowed to trail from this position in flight, the forces required to change the angle on all except light and slow aircraft would be prohibitive. To assist the pilot to move the controls in the absence of powered or power-assisted controls, some degree of balance is required. There are two main forms of balance : mass balance, and aerodynamic balance.

3. **Mass Balancing.** Mass balancing is used chiefly to prevent flutter of the control surfaces (Section 5, Chapter 1). Balancing is carried out by fixing weights to the leading edge of the control surface so that the centre of gravity of the surface is brought closer to the hinge line. Fig. 1 shows a typical mass-balance installation. On most aircraft, however, the weights are mounted internally.

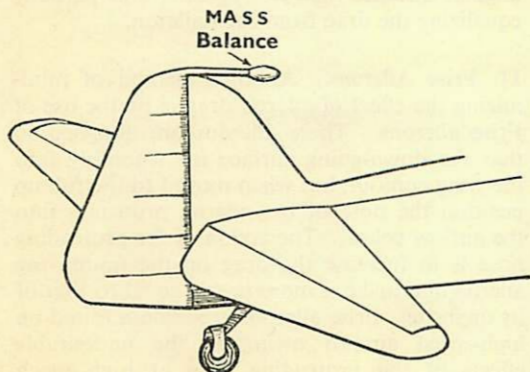


Fig. 1. Typical External Mass Balance

4. **Aerodynamic Balancing.** Aerodynamic balance is achieved in several ways, all of which decrease the force required to move the control in flight. This form of balancing is generally done by hinging the control surface about a line set back from the leading edge. The effort required to move any control surface is determined by the aerodynamic force acting through the centre of pressure of the aerofoil multiplied by the distance from the hinge line. This force is known as the hinge moment of the control surface : the smaller the hinge moment the less is the effort required to move the surface through a given angle at a given speed.

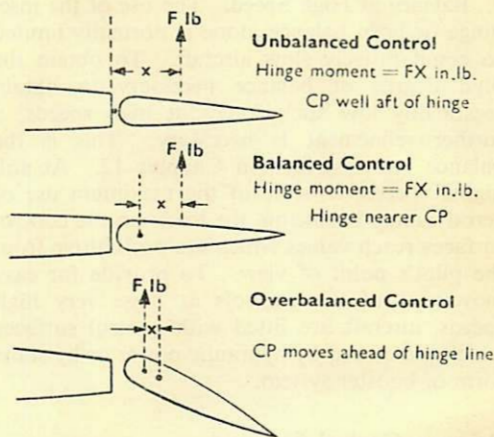


Fig. 2. Overbalance

5. **Overbalance.** If the hinge line is positioned too close to the C.P., any movement of the control surface may result in the C.P. moving ahead of the hinge line. As shown in Fig. 2 this results in the surface moving of its own accord to full deflection ; this serious fault is known as overbalance. Overbalance is detected by the pilot as a decrease instead of an increase in the progressive force required to move the control surface through a given angle. This decrease in force suddenly becomes a reversal when overbalance occurs, so that the pilot has to reverse the original stick force to prevent the control surface from moving of its own accord to full deflection. Overbalance may be mild or severe, depending on the design and flight conditions of the control surface.

6. **Horn Balance.** On some control surfaces, instead of an inset hinge line, aerodynamic balance is achieved by using horn balances, as shown in Fig. 3. These have the same effect as the inset hinge type, as a proportion of the total area lies ahead of the C.P. Horn balances are used mostly on rudders and elevators.

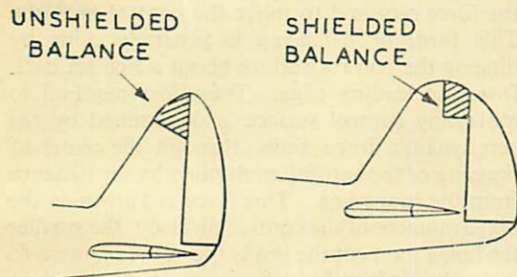


Fig. 3. Horn Balance

7. **Balance at High Speed.** The use of the inset hinge or horn balance alone is normally limited to comparatively slow aircraft. To obtain the high degree of balance necessary to obtain reasonably low stick forces at high speeds, a further refinement is necessary. This is the balance tab described in Chapter 12. At still higher speeds, in spite of the maximum use of aerodynamic balancing, the loads on the control surfaces reach values which are prohibitive from the pilot's point of view. To provide for easy movement of the controls at these very high speeds, aircraft are fitted with control surfaces which are moved by hydraulic power or by some form of booster system.

Primary Control Surfaces

8. **Elevators.** The elevators are hinged to the rear spar of the tailplane and are connected to the control column so that forward movement of the column moves the elevator downward, and backward movement moves the elevator upward. When the control column is moved back and the elevator rises, the effect is to change the overall tailplane/elevator section to an inverted aerofoil which supplies a downward force on the tail of the aircraft and, as seen by the pilot, raises the nose. The opposite occurs when a forward movement is made. Elevators are normally free from undesirable characteristics, but large stick forces may be experienced on some aircraft if the aerodynamic balance of the elevator or the stability characteristics of the aircraft are at fault. The angular movement of the elevator necessary to obtain a given change of aircraft attitude varies with the I.A.S.; at low speeds a large movement

is necessary compared to that required at high speed. This is a natural effect arising from the increased effectiveness of any deflected surface with an increase in speed.

9. **Ailerons.** The ailerons are movable surfaces hinged to the rear spar of the wing and form part of the trailing edge. They are connected to the control column so that when it is moved to the left the port aileron rises and the starboard aileron goes down; thus the lift on the port wing is decreased while that of the starboard wing is increased, resulting in a rolling motion to port in the direction of the movement of the control column. As with the elevators, aileron effectiveness increases with speed. Therefore smaller movements are required to obtain a given rate of roll at high speed than at low speed.

10. **Aileron Drag.** When an aileron is depressed its angle of attack is increased, while that of the opposite aileron is decreased. At the same time the drag of the down-going aileron, which is moving into a region of high pressure, becomes greater than that of the other which is moving into the region of low pressure. When the drag set up by the down-going aileron is appreciably greater than that of the other, the effect is to yaw the nose in the opposite direction to which bank has been applied. Aileron drag is usually more apparent at low speeds because of the larger aileron movements that are required for a given rate of roll. On most aircraft aileron control is possible down to the stall itself, but at this low speed large movements are necessary to correct any changes in lateral level. The adverse yaw due to unequal drag from the ailerons can be reduced by differential movement of the ailerons, so that for a given control column movement the down-going aileron moves through a smaller angular distance than its opposite, thus partially equalizing the drag from each aileron.

11. **Frise Ailerons.** Another method of minimizing the effect of aileron drag is by the use of Frise ailerons. These ailerons are designed so that the down-going surface fits smoothly into the wing contour, but when moved to the full up position the nose of the aileron protrudes into the airflow below. The action of the protruding nose is to increase the drag on the up-moving aileron and make it more nearly equal to that of its opposite. Frise ailerons are seldom found on high-speed aircraft owing to the undesirable effects of the protruding nose at high mach numbers, which seriously impairs the effectiveness of the control.

12. **Aileron Movement at the Stall.** Ailerons cannot always be used to raise a wing which has dropped at the stall. To raise a wing that has stalled and dropped, the aileron on that wing must be moved downwards, thus further increasing the angle of attack and possibly aggravating the stall ; at the same time the aileron drag yaws the nose of the aircraft towards the stalled wing and induces a tendency towards autorotation. When ailerons have this characteristic the wing can be raised with rudder by yawing the nose of the aircraft away from the wing that has dropped. This increases the speed of the dropped wing, and has the effect of reducing its angle of attack. On most high-performance aircraft, however, the directional stability is high and the effect of the adverse aileron yaw is generally innocuous.

13. **Overbalance.** This may occur at any air speed on some aircraft not fitted with power-operated controls, but usually only at the larger control angles. It is shown by a progressive decrease, instead of an increase, of the aileron stick force as the control column is moved, *i.e.* a tendency for the ailerons to move to their full travel of their own accord. In some cases this may happen fairly suddenly.

14. **Snatch.** Snatching usually occurs at or near the stall, or at high mach numbers. It is caused by a continuous and rapid shifting of the centre of pressure of the aileron due to the disruption of the airflow over the surface, resulting in a snatching or jerking of the control, which may be violent.

15. **Aileron Reversal.** When the ailerons are moved, the down-going aileron, acting as an elevator on its wing tip, tends to twist the leading edge of the wing downwards about its torsional axis. At the same time the up-going aileron has the opposite effect on the other wing. At low speeds the rigidity of the wing is sufficient to prevent any distortion, but at higher speeds the ailerons may be sufficiently powerful to distort the wings. The effect of aileron reversal is to decrease aileron effectiveness as the wings are twisted so as to oppose the rolling movement set up by the ailerons. There is a theoretical design speed in excess of the maximum permissible I.A.S. at which the rolling moment drops to zero and beyond which the aircraft would bank in the opposite direction ; this is known as the *reversal speed*. In practice, on some aircraft, the rate of roll, after increasing with speed for a given aileron deflection, begins to decrease as the aircraft approaches the maximum permissible I.A.S. This effect may be quite marked. However, this

should not be confused with the same effect on some aircraft using power-operated controls in which the operating jacks are made to stall intentionally to limit the amount of control deflection that can be applied at high I.A.S.

16. **Aileron Power.** The rate of roll for a given aileron deflection is proportional to the T.A.S. Since at a constant I.A.S. the T.A.S. increases with altitude, it follows that at a given I.A.S. the rate of roll increases with height. Rate of roll also varies inversely with the wing span ; for a given aileron area and deflection the larger the span the lower the rate of roll, hence it is fundamentally more difficult to make a large aircraft as manoeuvrable as a small one.

17. **Flutter.** This is discussed in detail in Section 5, Chapter 1.

18. **The Rudder.** The rudder, which is hinged to the rear of the fin, is connected to the rudder bar. Pushing the right pedal will cause the rudder to move to the right, and in so doing alter the aerofoil section of the fin/rudder combination. This provides an aerodynamic force on the rear of the aircraft which will move it to the left or, as the pilot sees it, the nose will yaw to starboard. Rudder effectiveness increases with speed ; whereas a large deflection may be required at low speed to yaw a given amount, a much smaller deflection is needed at the highest speeds.

19. **Rudder Overbalance.** A fault which may be encountered is overbalance. This is indicated by a progressive lessening of the foot loads with increasing rudder displacement. If, owing to a weakness in design, the aerodynamic balance is too great, it will become increasingly effective as the rudder is moved and may eventually cause it to lock hard over when the centre of pressure moves in front of the hinge line.

20. At large angles of yaw (sideslip) the fin may stall, causing a sudden deterioration in rudder control and directional stability and, at the same time, rudder overbalance. If this is encountered the yaw must be reduced by banking in the direction in which the aircraft is yawing and *not* by stabilizing the yaw by instinctively applying opposite bank. The correct action reduces the sideslip by converting the motion into a turn from which recovery is possible once the fin has become unstalled. Sometimes slight apparent rudder overbalance may be noticed under asymmetric power when large amounts of rudder trim are used to decrease the foot load on the rudder bar. If this happens the amount of rudder trim should be reduced.

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21. **Rudder Tramping.** On some aircraft the onset of rudder overbalance may be shown by "tramping", or a fluctuation in the rudder foot loads. If the yaw is further increased overbalance may occur.

22. **Elevons.** Some tailless aircraft with swept-back wings combine the function of the elevators and ailerons in control surfaces at the wing tips called elevons. These are designed so that a backward movement of the control column will raise both surfaces and so, acting as elevators, they will raise the nose. If the control column is held back and also moved to one side, the surfaces will remain in a raised position and so continue acting as elevators, but the angular position of each surface changes so that the lift at each wing tip is adjusted to cause a rolling moment in the direction that the control column has been moved. If the control column is held central and then moved to one side the surfaces act as normal ailerons; a subsequent forward movement of the control column will lower both surfaces, maintaining the angular difference caused by the sideways movement of the control column, and the nose will drop while the aircraft is rolling.

23. The All-Moving or Flying Tail.

(a) At high mach numbers the elevator loses much of its effectiveness for reasons given in the chapters on high-speed flight. This loss of effectiveness is the cause of a serious decrease in the accuracy with which the flight path can be controlled and in the manoeuvrability. To overcome this deficiency the tailplane can be made to serve as the primary control surface for control in the looping plane. When this is done some form of power assistance is usually employed to overcome the higher forces needed to move the tailplane during flight.

(b) With the flying tail, full and accurate control is retained at all mach numbers and speeds. Forward movement of the control column increases the incidence of the tailplane to obtain the upward force necessary to lower the nose.

(c) On some aircraft the elevator is retained and is linked to the tailplane in such a way that movement of the tailplane causes the elevator, by virtue of its linkage, to move in the usual direction to assist the action of the tailplane. When no elevator is used the whole is known as a **SLABS** tailplane.

24. **The Variable Incidence Tailplane.** This is used on some aircraft as an alternative, and sometimes in addition, to trimming tabs. By suitably varying the incidence of the tailplane any out-of-trim forces can be balanced as necessary. The V.I. tailplane is generally more effective than tabs at high mach numbers. Its method of operation is usually electric, the control being a switch which is spring-loaded to a central off position.

AIR BRAKES

25. High-speed aircraft, having a comparatively high weight and low drag, tend to retain their speed for a considerable time after the engine has been throttled back. Further, having eventually reached the desired lower speed, any slight downward flight path or increase in power causes an immediate and appreciable increase in speed.

26. An air brake is an integral part of the airframe, and can be extended to increase the drag of an aircraft at will, enabling the speed to be decreased more rapidly, or regulated during a descent. Fig. 4 shows typical air-brake installations on a number of aircraft. Some aircraft lower the undercarriage partially or completely to obtain the same effect.

27. Although the area of the air brakes on a typical fighter is small, considerable drag is produced at high speeds. For example, an air brake with an assumed C_D of 1.2 and a total area of about 2.5 square feet produces a drag of about 5,700 lb. when opened at 500 knots at sea level. This figure is indicative of the large loads imposed on an aircraft when flying at high indicated speeds. The effectiveness of an air brake varies as the square of the speed and therefore at about 120 knots the same air brake gives a drag of about 330 lb. only. The decelerating effect of air brakes can be seen from figures obtained from a Meteor N.F.14 flying at 430 knots at low altitude. With the air brakes in and power off the aircraft takes $2\frac{1}{2}$ minutes to slow to 150 knots; with air brakes out the time is reduced to 1 minute.

28. Ideally, air brakes should not produce any effect other than drag, although on some American aircraft the air brakes are designed to produce an automatic nose-up change of trim when opened. In practice, however, the opening of most air brakes is accompanied by some degree of buffet, with or without a change of trim; the strength of these adverse effects is usually greatest at high speeds, becoming less as the speed decreases.

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Effect of Altitude on Air-Brake Effectiveness

29. Air brakes derive their usefulness from the fact that they are subjected to dynamic pressure—the $\frac{1}{2}\rho V^2$ effect—and so provide drag in proportion to their area. At high altitudes, therefore, the effectiveness of all air brakes is much reduced since the drag, which is low in proportion to the T.A.S., takes longer to achieve a required loss in speed, *i.e.* the rate of deceleration is reduced.

30. An air brake which develops, say, 2,000 lb. drag at a stated I.A.S./T.A.S. at sea level will develop the same drag at the same I.A.S. at high altitude; but whereas the T.A.S. at sea level was equal to the I.A.S., the T.A.S. at altitude may be as much as two or more times the I.A.S. Since the drag is required to decrease the kinetic energy (energy of movement), which is proportional to the T.A.S., it is apparent that the decelerating effect of the air brake (proportional to the I.A.S.) is decreased, *e.g.* the time taken to decelerate over a given range of I.A.S. will be doubled at 40,000 ft. compared to that at sea level since the I.A.S. at this height is about half the T.A.S.

BRAKE PARACHUTES

31. Brake parachutes are used to decrease the period of float after rounding out, and the length of the landing run. They are streamed from a point at the rear of the aircraft when the round out is completed.

32. In general, brake parachutes produce enough drag to cause a steady rate of deceleration varying from about $\cdot 25g$ to $\cdot 35g$, depending on the particular installation. Below 60 to 70 knots the drag, varying as the square of the speed, falls to a much lower figure and the wheel brakes become the primary means of deceleration.

33. At high landing speeds, if the brakes were required to produce the same rate of deceleration as the brake parachute, dissipation of the heat generated would require an impossibly large mass of metal without burning out both the brakes and tyres. When the speed has fallen to 60 to 70 knots, however, the normal aircraft braking system can cope comfortably with the inertia of the aircraft while decelerating at $\cdot 25g$ or more.

Parachute Diameter

34. The diameter of the parachute depends on the weight and size of the aircraft. Generally only large service aircraft with high landing speeds will use brake parachutes. Small experimental and research aircraft, however, are often fitted with this device.

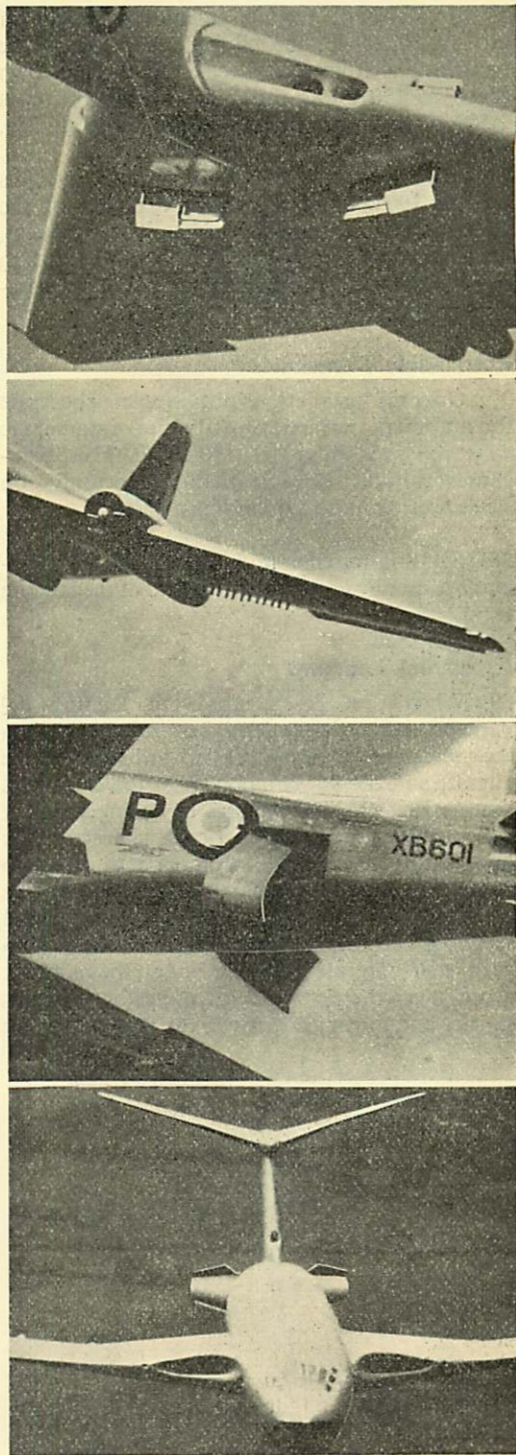


Fig. 4. Typical Air-Brake Installations

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35. For aircraft having a landing weight of around 10,000 lb. the "flying" diameter of the parachute is from 6 to 8 feet. At a touchdown speed of 130 knots this gives a drag of about 2,500 lb., and a rate of deceleration of about .25g.

36. For large aircraft with landing weights around 100,000 lb. the flying diameter of the brake parachute is about 35 feet. This produces, at a touchdown speed of about 150 knots, a drag of some 50,000 lb. and an initial rate of deceleration of about .35g.

Retractable Parachutes

37. On some installations provision may be made for automatic retraction of the brake parachute when the speed falls to 60 to 70 knots. These parachutes can be used as often as necessary on successive circuits and landings.

38. On non-retractable installations the parachute is usually jettisoned at the end of the landing run.

Crosswind Landings

39. When used in a crosswind landing the parachute aligns itself along the resultant between the vectors representing the forward speed of the aircraft and the 90° component of the crosswind vector (Fig. 4). This causes a yawing moment which increases the weather-cock characteristics of the aircraft. For 90° components of up to 20 knots, the effect is small and can easily be countered by the pilot. At higher crosswind speeds it becomes progressively more difficult to keep the aircraft straight. As the aircraft decelerates, the forward speed vector becomes shorter and the angle between the resultant along

which the parachute flies and the path of the aircraft becomes greater, so increasing the tendency to weather-cock.

Jettisoning of Brake Parachute

40. At any time after the parachute has been released it can be disconnected or jettisoned by the pilot in an emergency. This applies both to the retractable and the non-retractable types.

Inadvertent Release in Flight

41. If the parachute is opened inadvertently at high speed, the opening load causes failure of a weak link and the parachute breaks away from the aircraft. If opened too early on the approach it can be disconnected by the pilot.

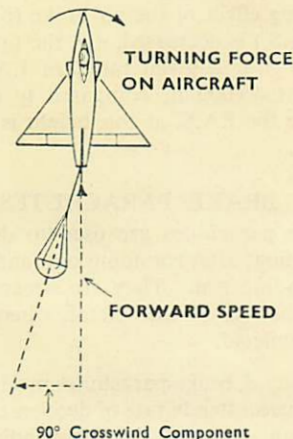


Fig. 5.
Effect of Crosswind on Brake Parachute

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