CHAPTER: 5
AIRCRAFT CONTROL SURFACES

PRIMARY CONTROL SURFACES

The primary control surfaces of an airplane include the ailerons, rudder, and elevator. Secondary control surfaces include tabs, flaps, spoilers, and slats. The construction of the control surfaces is similar to that of the stabilizers ; however, the movable surfaces usually are somewhat lighter in construction. They often have a spar at the forward edge to provide rigidity and to this spar are attached the ribs and the covering. Hinges for attachment are also secured to the spar. Where it is necessary to attach tabs to the trailing edges of control surfaces, additional structure is added to provide for transmission of the tab loads to the surface.

Control surfaces may be constructed of any combination of materials, with the more common combination being a sheet-metal structure (usually an aluminium alloy) covered with metal skin or fabric, a steel structure covered with fabric, or a wood structure covered with plywood or fabric. Each of these types of construction is treated by some method to inhibit the deterioration of the structure and the covering and includes drain holes to prevent water from becoming trapped inside the structure and causing the control surfaces to be thrown out of balance. Methods of joining the components may include metal fasteners as well as adhesives and bonding agents.

Some aircraft are using composite and bonded structures which include the use of honeycomb internal components. These structures are often sealed from the atmosphere and therefore do not include drainage openings in their design.

(i) Aileron

Ailerons are primary flight control surfaces utilized to provide lateral (roll) control of aircraft; that is they control aircraft movement about the longitudinal axis. They are usually mounted on the trailing edge of the wing near the wing tip. Large jet aircraft often employ two sets of ailerons, one set being approximately midwing or immediately outboard of the inboard flaps, and the other set being in the conventional location near the wing tips. The outboard ailerons become active whenever the flaps are extended beyond a fixed setting. As the flaps are retracted, the outboard aileron control system is "locked out" and fairs with the basic wing shape. Thus, during cruising operations at comparatively high speeds, only the inboard ailerons are used for control. The outboard ailerons are active during landing or other slow flight operations. (Fig.5.1) shows a transport aircraft wing with this aileron configuration.

Ailerons for light aircraft are usually constructed with a single spar to which ribs are attached. The majority of currently manufactured aircraft are of all-metal construction with aluminium alloy skin riveted or bonded to the internal structure.

Aileron control systems operated by the pilot through mechanical connections require the use of balancing mechanisms so that the pilot can overcome the air loads imposed on the ailerons during flight. Balancing of the ailerons can be achieved by extending part of the aileron structure ahead of the hinge line and shaping this area so that the airstream strikes the extension and helps to move the surface. This is known as aerodynamic balancing. Another method which may be used is to place a weight ahead of the hinge line to counteract the flight loads. This is known as static balancing. Some aircraft may use a combination of these techniques.

Aircraft such as jet transports use hydraulically operated ailerons and may not employ these forms of balancing. If the transport control system is designed to allow the pilot to operate the ailerons without hydraulic assistance, then some method of balancing or control by control tabs is used.

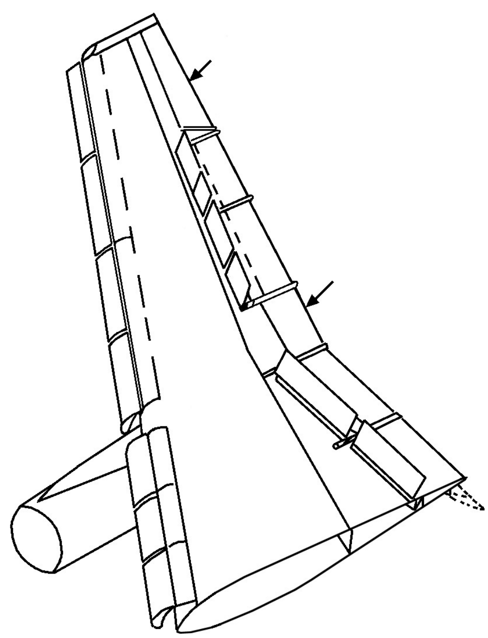


Fig.5.1. The L-1011, uses two ailerons on each wing

The geometry of the control system for the ailerons affects the amount that the ailerons move above or below the neutral setting. (The neutral setting fairs the ailerons with the wing contour). Some aircraft have their ailerons operating symmetrically; that is, they move up the same amount that they move down. Other aircraft have the ailerons operating asymmetrically; that is, the upward-moving aileron moves further than the downward moving aileron. This asymmetrical operation is used in some aircraft designs to reduce the amount of rudder pressure required when making turns. This reduces what is know as "adverse aileron yaw", which is caused by the downward-moving aileron creating an increase in aerodynamic drag, and results in the airplane yawing away from the direction of the desired turn. Aircraft having this arrangement are sometimes said to have differential ailerons.

(ii) Elevators

Elevators are the control surfaces which govern the movement (pitch) of the aircraft around the lateral axis. They are normally attached to hinges on the rear spar of the horizontal stabilizer. The construction of an elevator is similary to that of other control surfaces, and the design of the elevator may be unbalanced or balanced aerodynamically and/or statically. Typical elevator installations for light aircraft and transports are shown in (Fig.5.2 and 5.3).

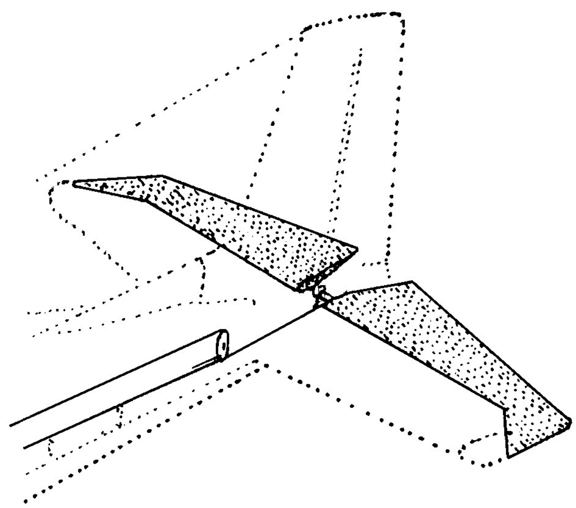


Fig.5.2. The elevator of a light aircraft

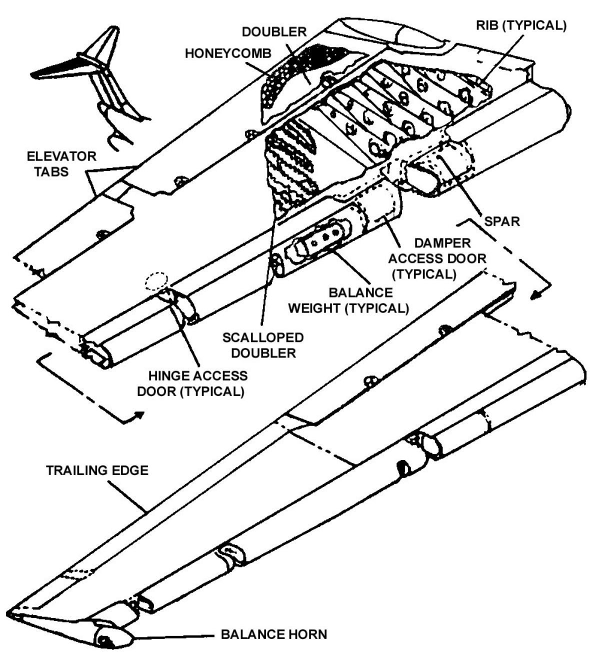


Fig.5.3. The elevator of a DC-9

(iii) Rudder

The rudder is the flight control surface that controls the aircraft movement about its vertical axis. The rudder is constructed very much like other flight control surfaces with spars, ribs and skin.

Rudders are usually balanced both statically and aerodynamically to provide for greater ease of operation and to eliminate the possibility of flutter. It should be noted that some light-aircraft rudders do not use any balancing method. Different rudders for light aircraft are shown in (Fig.5.4) below.

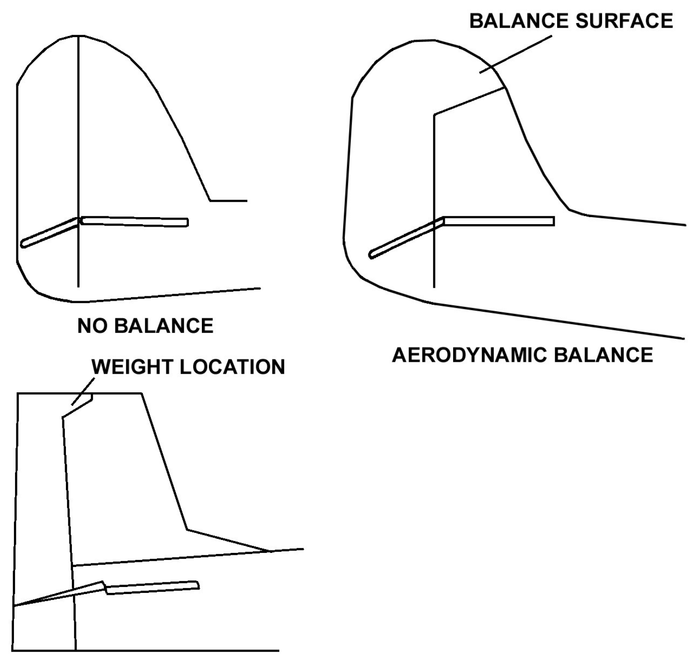


Fig.5.4. Different rudder configuration

Rudders for transport aircraft vary in basic structural and operational design. Some are single structural units operated by one or more control systems. Others are designed with two operational segments which are controlled by different operating systems and provide a desired level of redundancy.

A single-unit rudder is capable of being operated by three different hydraulic systems in the aircraft. A rudder with an upper and a lower segment of which each segment can be operated by a different hydraulic systems.

The rudder with of two segments consists of upper and lower, and each segment consists of a forward and aft section. The forward rudder sections are attached to hinge brackets mounted on the rear spar of the vertical stabilizer. The aft rudder sections are supported by hinge brackets attached to the rear spar of the forward sections. The aft rudder sections are hinged to the forward sections and connected by pushrods to the vertical stabilizer structure. This provides aft-section displacement proportional to forward-section displacement, thus increasing the aerodynamic efficiency of the rudders. Trim and control tabs are not required with this type of rudder design because their functions are performed by the aft sections of the rudder.

SECONDARY CONTROL SURFACES

Because aircraft often are capable of operating over a wide speed range and with different weight distributions, secondary flight controls, also called auxiliary flight controls, have been developed. Some of these surfaces called tabs, allow the flight controls. Other surfaces fall in a group termed high-lift devices which includes flaps, slats and slots. These allow the lift and drag characteristics of the aircraft wing to be changed to allow-slow speed flight for takeoff and landing and high-speed flight for cruising. Still a third group of surfaces are used to reduce lift and generate drag. This group includes spoilers and speed brakes.

The number and complexity of the secondary control surfaces on a particular aircraft depends on the type of operation and flight speeds for which the aircraft is designed. (Fig.5.5) below shows the secondary flight control surfaces found on a typical jet transport aircraft.

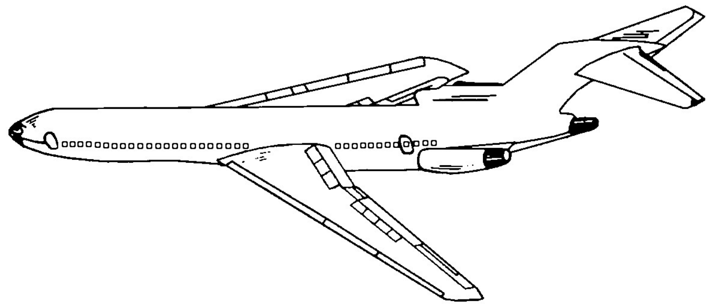


Fig.5.5. The location of secondary flight controls on a Boeing 727

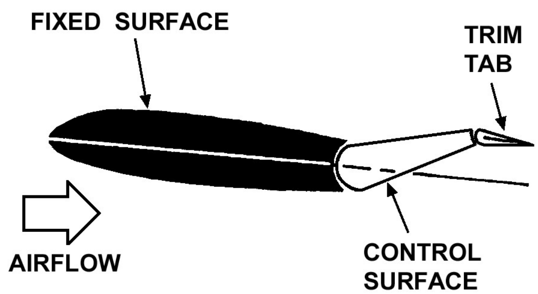


Fig.5.6. Trim tabs must be adjusted opposite to the desired movement of the surface being controlled

Tabs

Tabs are small secondary flight control surfaces set into the trailing edges of the primary surfaces. These are used to reduce the pilot's work load required to hold the aircraft in some constant attitude by "loading" the control surface in a position to maintain the desired attitude. They may also be used to aid the pilot in returning a control surface to a neutral or trimmed center position (Fig.5.6).

(i) Trim Tabs

The term trim tabs describes small secondary flight-control surfaces set into the trailing edges of the primary control surfaces. Tabs are used to reduce the work load required to hold the aircraft in some constant attitude by "loading" the control surface to a neutral or trimmed-center position. (Fig.5.7) demonstrates the tab action. Tabs can be fixed or variable, and the variable tabs can be designed to operate in several different manners.

Fixed Trim Tabs

A fixed trim tab, such as is shown in (Fig.5.7), is normally a piece of sheet metal attached to the trailing edge of a control surface. This fixed tab is adjusted on the ground by bending it in the appropriate direction to eliminate cabin flight control forces for a specific flight condition. The fixed tab is normally adjusted for zero control forces while in cruising flight. Adjustment of the tab is a trial and error process where the aircraft must be flown and the trim tab adjusted based on the pilot's report. The aircraft must then again be flown to see if further adjustment is necessary. Fixed tabs are normally found on light aircraft and are used to adjust rudders and ailerons.

Controllable Trim Tabs

A controllable trim tab is illustrated in (Fig.5.7) Controllable tabs are adjusted by means of control wheels, knobs, or cranks in the cockpit, and an indicator is supplied to denote the position of the tab.

Controllable trim tabs are found on most aircraft with at least the elevator tab being controlled. These tabs are normally operated mechanically, electrically or hydraulically. When the trim-control system is activated, the trim tab is deflected in direction opposite to the desired movement of the control surface. When the trim tab is deflected into the airstream the air tries to push the tab back flush with the control surface. Since the control mechanism prevents the tab from being pushed back flush, the whole control surface is moved.

(ii) Servo Tabs

The servo tabs, sometimes referred to as the flight tabs, are used primarily on the large main control surfaces. A servo tab is one that is directly operated by the primary controls of the airplane. In response to movement of the cockpit control, only the servo tab moves. The force of the airflow on the servo tab then moves the primary control surface. The servo tab, illustrated in (Fig.5.7)   , is used to reduce the effort required to move the controls on a large airplane.

(iii) Balance Tabs

A balance tab is linked to the airplane in such a manner that a movement of the main control surface will give an opposite

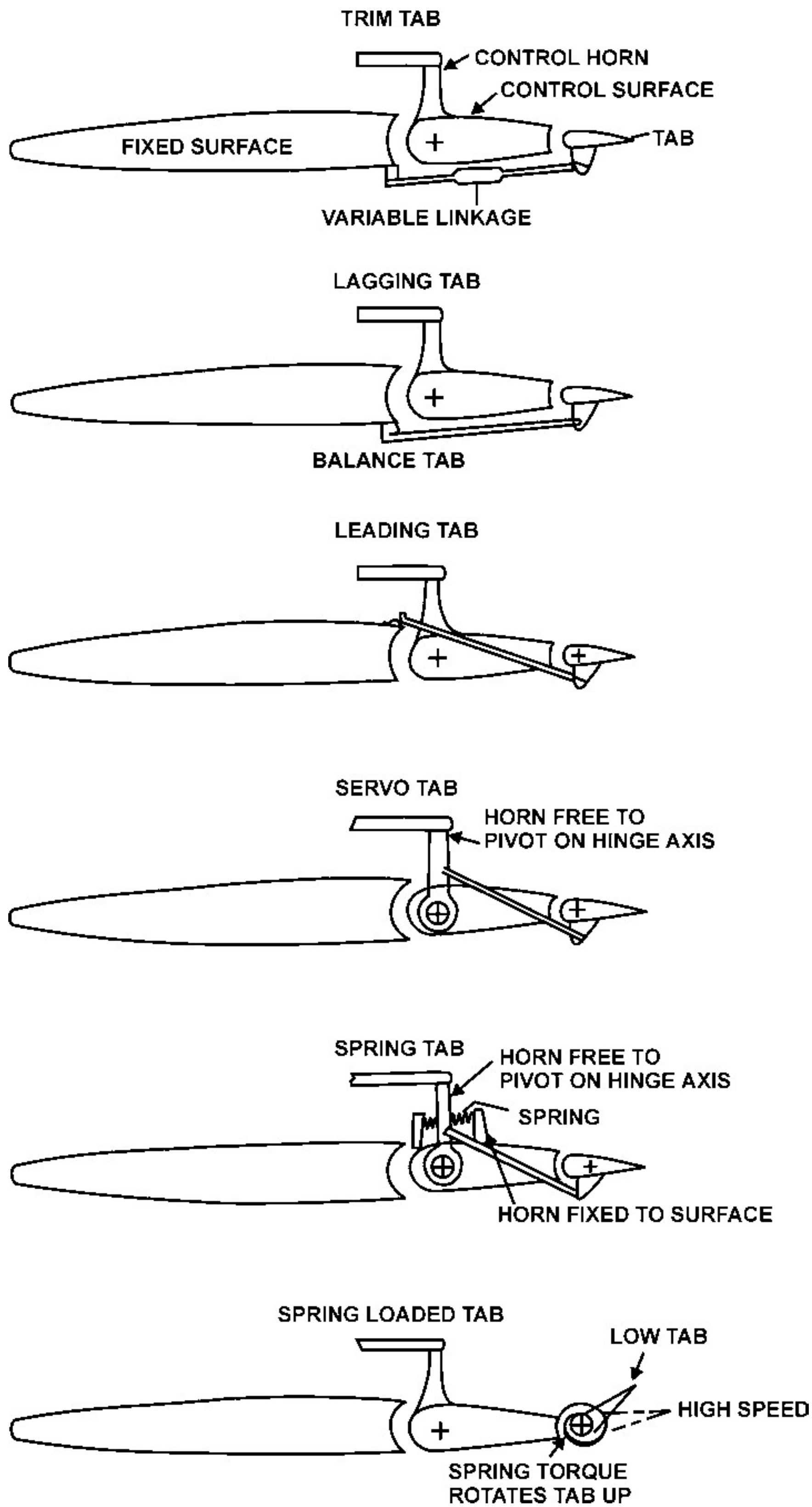


Fig.5.7. Various types of trim tabs

movement to the tab. Thus, the balance tab will assist in moving the main control surface. Balance tabs are particularly useful in reducing the effort required to move the control surfaces of a large airplane. A balance tab is illustrated in Fig. 5.7.

(iv) Spring Tabs

The spring tabs, like some servo tabs, are usually found on large aircraft that require considerable force to move a control surface. The purpose of the spring tab is to provide a boost, thereby aiding in the movement of a control surface. On the spring tab, illustrated in Figure 5.7, the control horn is connected to the control surface by springs.

AUXILIARY CONTROL SURFACES

(i) Slots

How do multi-element aerofoils greatly augment lift without suffering the adverse effects of boundary-layer separation? Hitherto the conventional explanation was that, since the slot connects the high-pressure region on the lower surface of a wing to the relatively low-pressure region on the top surface, it therefore acts as a blowing type of boundary-layer control. This explanation is to be found in a large number of technical reports and textbooks, and as such is one of the most widespread misconceptions in aerodynamics. It can be traced back to no less an authority than Prandtl who wrote:

"The air coming out of a slot blows into the boundary layer on the top of the wing and imparts fresh momentum to the particles in it, which have been slowed down by the action of viscosity. Owing to this help the particles are able to reach the sharp rear edge without breaking away."

(ii) Flaps

The history of flaps is longer, and just as varied, as that of slots. The plain or camber flap works on the same principle as an aileron or other control surface; it is truly a 'variable camber'. Such flaps were used as early as the 1914-1918 war, and the original idea was the same as with slots, to decrease landing speed with flaps down, and retain maximum speed with flaps up. Their early use was almost exclusively for deck-landing purposes. It seemed at first as though the invention of slots, which followed a few years after that war, might sound the death-knell of flaps. Far from it - if anything it has been the other way round, for flaps have become a necessity on modern aircraft. Flaps, like slots, can increase lift - honours are about even in this respect so far as the plain (or camber) flap, or split flap is concerned. But these flaps can also increase drag - not, like slots, at high speed when it is not wanted, but at low speed when it is wanted. But the main difference between the effects of flaps and slots is shown in Fig.5.8; from this it will be seen that whereas slots merely prolong the lift curve to higher values of the maximum lift coefficient, when the angle of attack of the main portion of the aerofoil is beyond the normal stalling angle, the high-lift type of flap increases the lift coefficient available throughout the whole range of angles of attack.

However it is no longer appropriate to compare the relative merits of slots and flaps because in modern aircraft it is usual to combine the two in some form or other; and in this way to get the best of both devices (Fig.5.9). There are a large number of possible combinations, but Fig.5.10 is an attempt to sum up the main varieties, and to describe the effect they have on the maximum lift coefficient, on the angle of the main aerofoil when maximum lift is obtained, why they improve the lift, what effects they have on the drag, how they affect the pitching moment, and so on.

From this figure it will be seen that the simpler flaps such as the camber flap, split flap and single slotted flap give a good increase in maximum lift coefficient at a reasonable angle of attack of the main aerofoil, and therefore a reasonable attitude of the aeroplane for landing; they also increase drag which is an advantage in the approach and landing.

The more complicated types such as the Zap and Fowler flap, and the double-or treble-slotted flap, give an even greater increase in maximum lift coefficient, but still at a reasonable angle of attack; while the even more complicated combinations of slots and flaps give yet greater maximum lift coefficients, but usually at larger angles of attack, and of course at the expense of considerable complication (Fig.5.11).

Blown and jet flaps are in a class of their own since they depend on power to produce the blowing, and this may be a serious disadvantage in the event of power failure. The true jet flap isn't a flap at all, but simply an efflux of air, or a jet stream in the form of a sheet of air ejected under pressure at or near the trailing edge of the aerofoil. This helps to control the boundary layer, and if the sheet of air can be deflected the reaction of the jet will also contribute directly to the lift.

The Krueger and other types of nose flap are used mainly for increasing lift for landing and take-off on otherwise high-speed aerofoils.

Spoilers, air brakes, dive brakes, lift dumpers and suchlike are a special category in that their main purpose is to increase drag, or to destroy lift, or both; moreover, they need not necessarily be associated with the aerofoils (Fig.5.12). They are used for various purposes on different types of aircraft; to spoil the L/D ratio and so steepen the gliding angle on high-performance sailplanes and other 'clean' aircraft; to check the speed before turning or manoeuvring; to assist both lateral and longitudinal control; to 'kill' the lift and provide a quick pull-up after landing; and on really high-speed aircraft to prevent the speed from reaching some critical value as in a dive. They will be considered later as appropriate to their various functions.

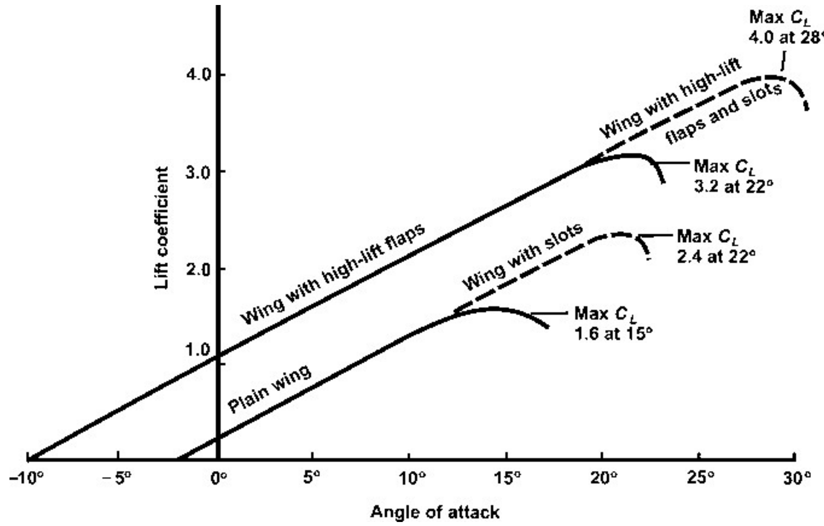


Fig.5.8. Effect of flaps and slots on maximum lift coefficient and stalling angle

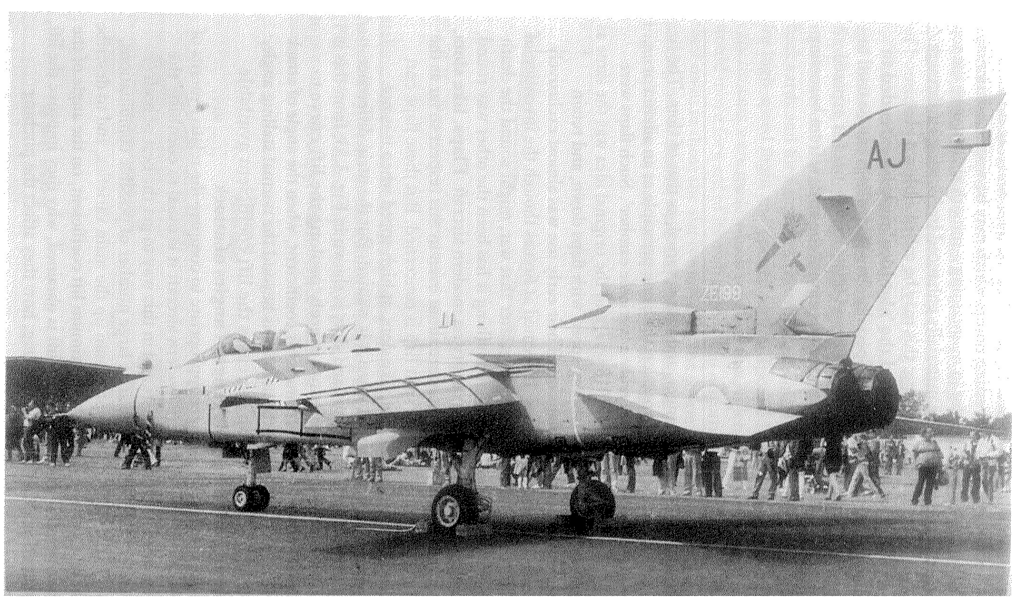
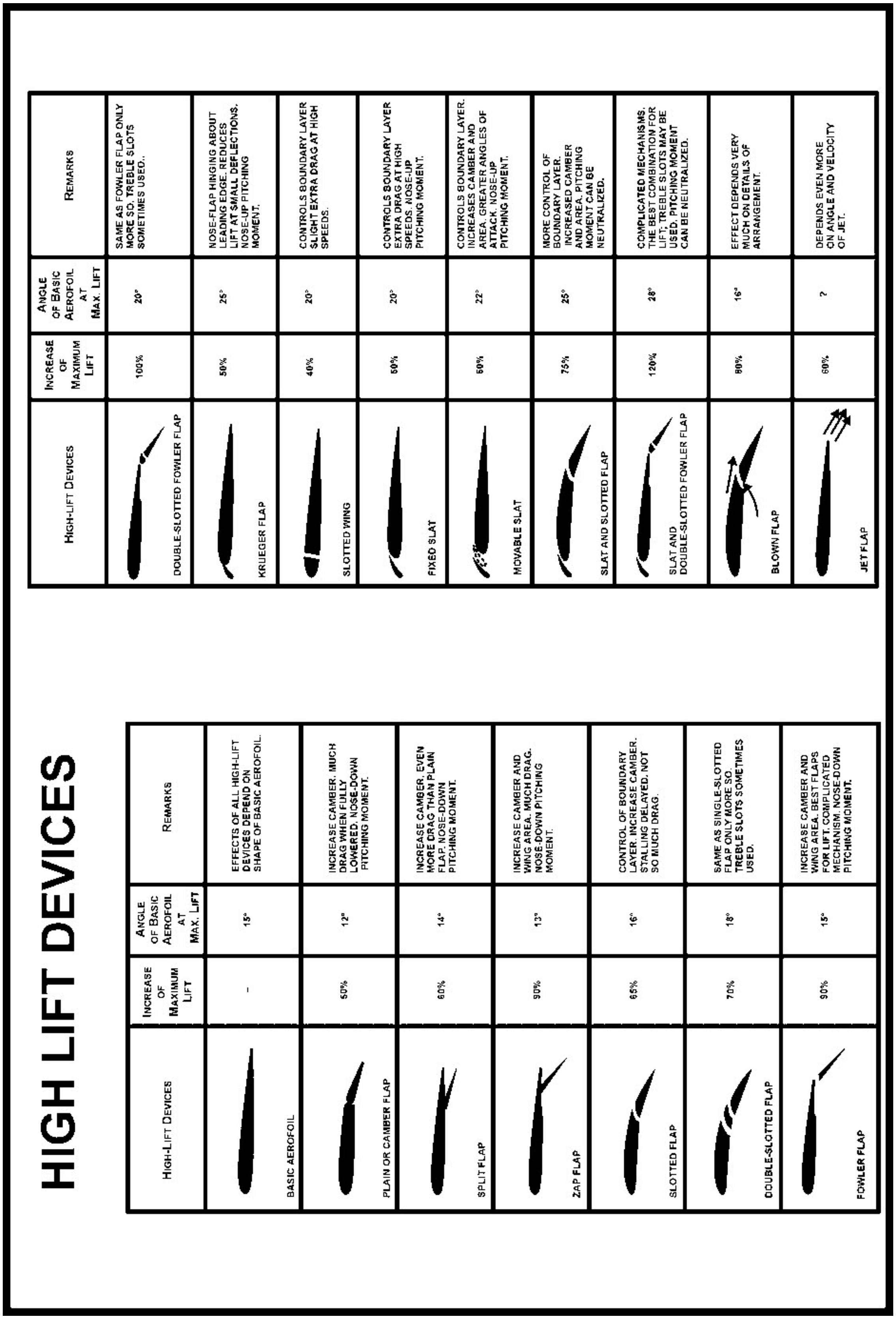


Fig.5.9. Flaps and slats (opposite)
Double-slotted flaps and leading edge slats are used on the Tornado. Because the flaps extend across the entire span, there is no room for ailerons, instead, the slab tailplane surfaces can move differentially as well as collectively, and this 'taileron' serves both for roll and pitch control.



HIGH LIFT DEVICES

High-Lift Devices	Increase of Maximum Lift	Angle of Basic Aerofoil at Max. Lift	Remarks
Basic Aerofoil	–	15°	Effects of all high-lift devices depend on shape of basic aerofoil.
Plain or Camber Flap	50%	12°	Increase camber. Much drag when fully lowered. Nose-down pitching moment.
Split Flap	60%	14°	Increase camber. Even more drag than plain flap. Nose-down pitching moment.
Zap Flap	90%	13°	Increase camber and wing area. Much drag. Nose-down pitching moment.
Slotted Flap	65%	16°	Control of boundary layer. Increase camber. Stalling delayed. Not so much drag.
Double-Slotted Flap	70%	18°	Same as single-slotted flap only more so. Treble slots sometimes used.
Fowler Flap	90%	15°	Increase camber and wing area. Best flaps for lift. Complicated mechanism. Nose-down pitching moment.

High-Lift Devices	Increase of Maximum Lift	Angle of Basic Aerofoil at Max. Lift	Remarks
Double-Slotted Fowler Flap	100%	20°	Same as Fowler flap only more so. Treble slots sometimes used..
Krueger Flap	50%	25°	Nose-flap hinging about leading edge. Reduces lift at small deflections. Nose-up pitching moment.
Slotted Wing	40%	20°	Controls boundary layer slight extra drag at high speeds.
Fixed Slat	50%	20°	Controls boundary layer extra drag at high speeds. Nose-up pitching moment.
Movable Slat	60%	22°	Controls boundary layer. Increases camber and area. Greater angles of attack. Nose-up pitching moment.
Slat and Slotted Flap	75%	25°	More control of boundary layer. Increased camber and area. Pitching moment can be neutralized.
Slat and Double-Slotted Fowler Flap	120%	28°	Complicated mechanisms. The best combination for lift; treble slots may be used. Pitching moment can be neutralized.
Blown Flap	80%	16°	Effect depends very much on details of arrangement.
Jet Flap	60%	?	Depends even more on angle and velocity of jet.

Fig.5.10. High lift devices

Note: Since the effects of these devices depend upon the shape of the basic aerofoil, and the exact design of the devices themselves, the values given can only be considered as approximations. To simplify the diagram the aerofoils and the flaps have been set at small angles, and not at the angles giving maximum lift.

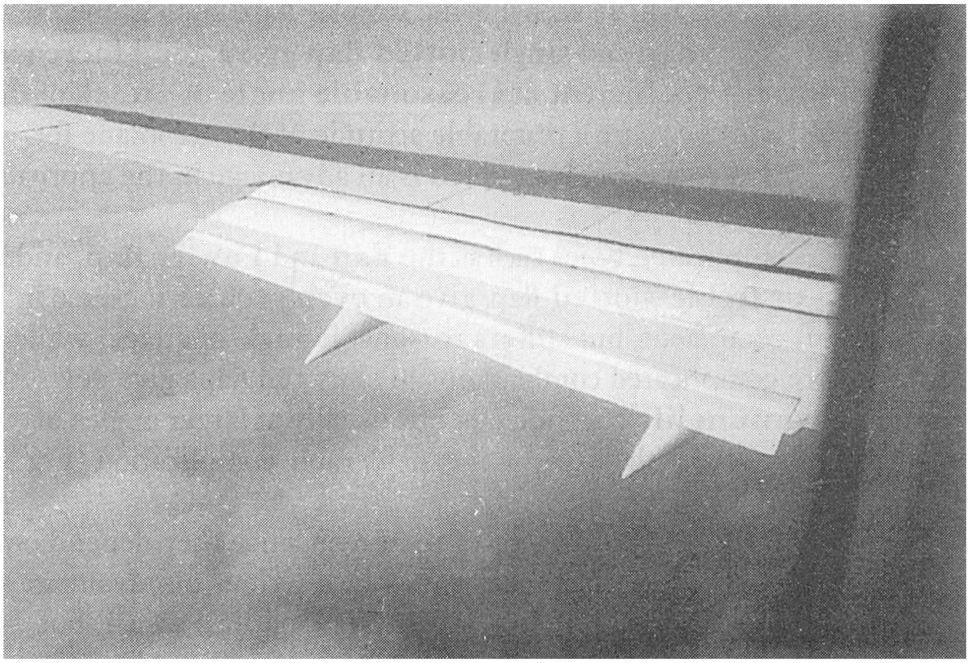


Fig.5.11. Multi-element slotted flaps
Three-element slotted Fowler-type flaps extend rearwards and down as this Boeing 737 prepares to land.

Fig.5.12. Speed brakes
Speed brakes on the wings of the last Vulcan bomber (now sadly retired). The cables of a braking parachute can also just be seen trailing from the rear

(iii) Spoiler

Spoilers, also called "lift dumpers" are control surfaces which are used to reduce or "spoil" the lift on a wing. Spoilers are located on the upper surface of wings and are one of two basic configurations. The more common configuration on jet transports, is to have a flat panel spoiler laying flush with the surface of the wing and hinged at the forward edge. When the spoilers are deployed, the surface rises up and reduces the lift. The other configuration shown in Fig.5.13 is common among sailplanes and has the spoiler located inside the wing structure. When the spoilers are deployed they rise vertically form the wing and spoil the lift.

Flight spoilers are used in flight to reduce the amount of lift that the wing is generating to allow controlled descents without gaining excessiver air speed. Depending on the aircraft design, the spoilers may also be operated by the pilot's control wheel or stick. When the pilot moves the control left or right for a roll movement, the spoilers on the wing toward the center of the turn (upward-moving aileron) move upward and aid in rolling the aircraft into the turn. In some aircraft designs, the spoilers are the primary flight control for roll.

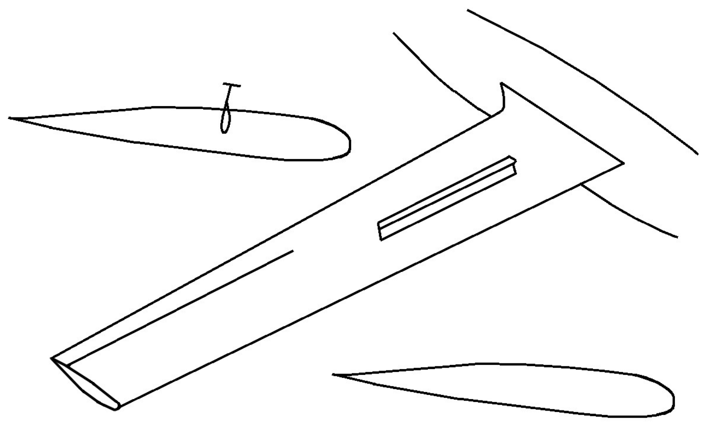


Fig.5.13. Some aircraft, such as sailplanes, have the spoilers arranged so that they rise vertically out of the wing

Ground spoilers are only used when the aircraft is on the ground and are used along with the flight spoilers to greatly reduce the wing's lift upon landing. They also increase the aerodynamic drag of the aircraft's after landing to aid in slowing the aircraft.

Spoilers can be controlled by the pilot through a manual control lever, by an automatic flight control system, or by an automatic system activated upon landing. The typical relative location of flight and ground spoilers is shown in Fig.5.14.

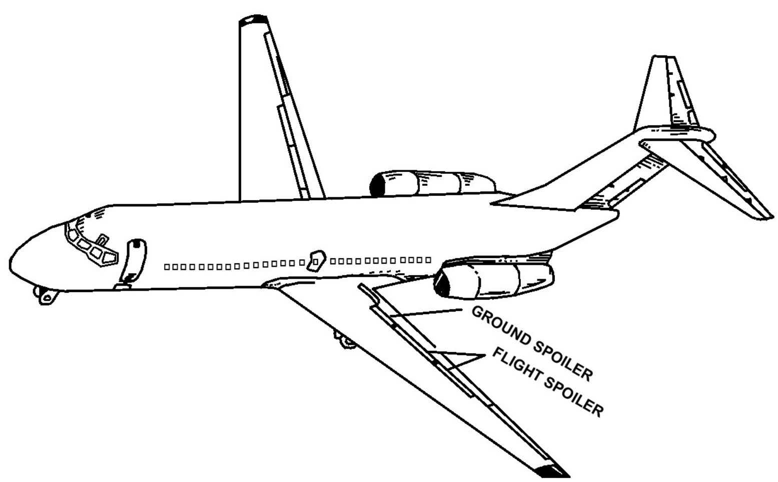


Fig.5.14. Flight spoilers are normally located outboard of ground spoilers

(iv) Speed Brakes

Speed brakes, also called dive brakes, are large drag panels used to aid in control of the speed of an aircraft. They may be located on the fuselage or on the wings. If on the fuselage, a speed brake is located on the top or the bottom of the structure. If speed brakes are deployed as a pair, one is on each side of the fuselage. If located on the wings, speed brakes are deployed symmetrically from the top and the bottom of the wing surface to control the speed of the aircraft as well as to act as spoilers to decrease the lift of the wings. (See Fig.5.15).

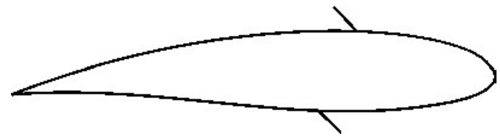


Fig.5.15. Speed brakes on a wing open on the top and bottom of the wing

On some aircraft designs, particularly gliders and sailplanes there may not be any clear distinction between a spoiler and a divebrake because one control surface may serve the purpose of both actions, i.e., to decrease lift and increase drag.

TYPES OF SLOTS

Although there is a large variety of high-lift devices nearly all of them can be classed as slots.

Slots may be subdivided into -

i. Fixed slots
ii. Controlled slots
iii. Automatic slots
iv. Blown slots

We can also classify the effects of both slots and flaps on the characteristics of an aerofoil by saying that their use may cause one or more of the following -

a. Increase of Lift
b. Increase of Drag
c. Change of Stalling Angle
d. Decrease of Lift
e. Change of Trim

If a small auxiliary aerofoil, called a slat, is placed in front of the main aerofoil, with a suitable gap or slot in between the two (Fig.5.16), the maximum lift coefficient of the aerofoil may be increased by as much as 60 per cent (Fig.5.8). Moreover the stalling angle may be increased from 15^0 to 22^0 or more, not always an advantage as we shall discover when we consider the problems of landing. An alternative to the separate slat, simpler but not so effective, is to cut one or more slots in the basic aerofoil itself, forming as it were a slotted wing.

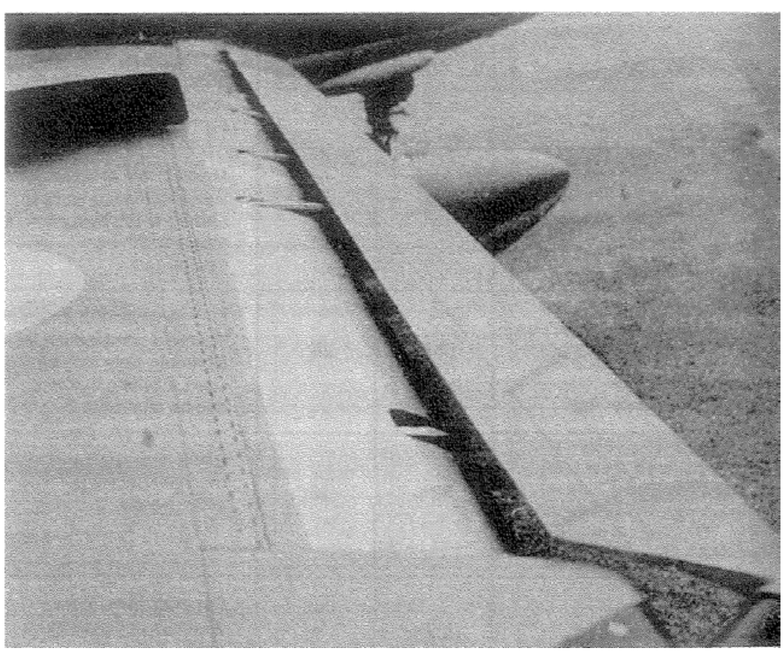


Fig.5.16. Leading edge slat and slot
(By courtesy of Fiat Aviazione, Torino, Italy)

The reason behind these results is clearly shown in Fig.5.17. Stalling is caused by the breakdown of the steady streamline airflow. On a slotted wing the air flows through the gap in such a way as to keep the airflow smooth, following the contour

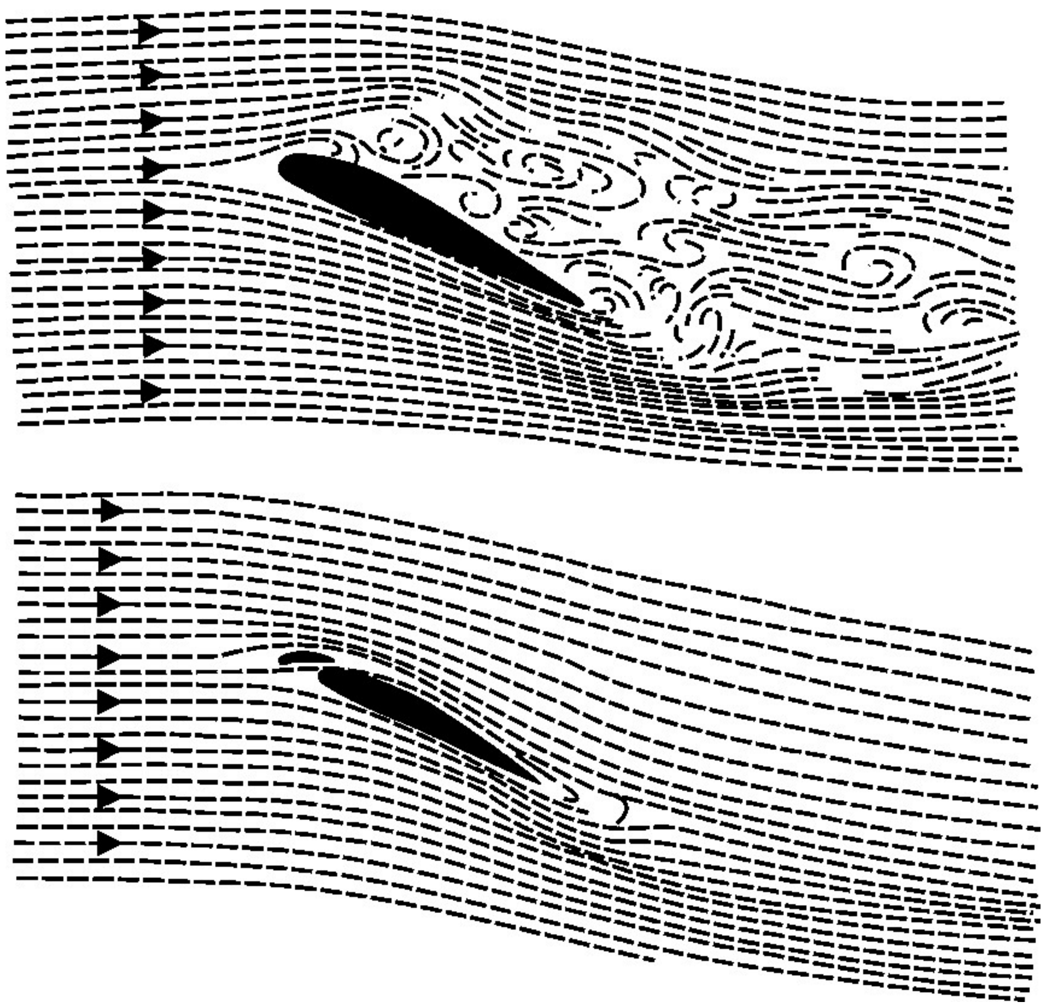


Fig.5.17. Effect of slot on airflow over an aerofoil at large angle of attack

of the surface of the aerofoil, and continuing to provide lift until a much greater angle is reached. Numerous experiments confirm this conclusion. It is, in effect, **a form of boundary layer control** as described earlier.

The extra lift enables us to obtain a lower landing or stalling speed, and this was the original idea. If the slots are permanently open, i.e. **fixed slots**, the extra drag at high speed is a disadvantage, so most slots in commercial use are **controlled slots**, that is to say, the slat is moved backwards and forwards by a control mechanism; and so can be closed for high-speed flight and opened for low speeds. In the early days experiments were made which revealed that, if left to itself, the slat would move forward of its own accord. So **automatic slots** came into their own; in these the slat is moved by the action of air pressure, i.e. by making use of that forward and upward suction near the leading edge. Fig.5.18

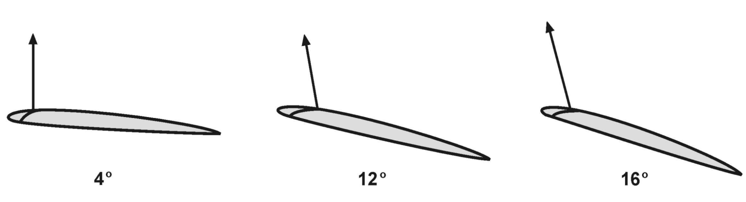


Fig.5.18. Direction of force on slat at varying angles of attack

shows how the force on the slat inclines forward as the stalling angle is reached. The opening of the slot may be delayed or hastened by 'vents' at the trailing or leading edge of the slat respectively (Fig.5.19), and there may be some kind of spring or tensioning device to prevent juddering, which may be otherwise likely to occur.

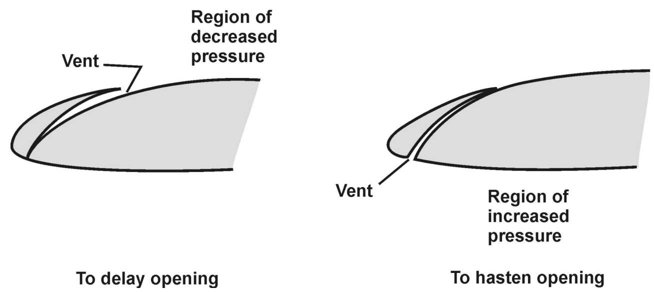


Fig.5.19. Effect of vents on opening of automatic slots

Before leaving the subject of slots - for the time being, at any rate - there are a couple of interesting points which may be worth mentioning. Firstly, the value of the slot in maintaining a smooth airflow over the top surface of the wing can be materially enhanced by blowing air through the gap between slat and wing; this may be called a **blown slot.** Secondly, what might be called the 'slot idea' may be extended to other parts of the aircraft. Specially shaped cowlings can be used to smooth the airflow over an engine, and fillets may be used at exposed joints, and other awkward places, to prevent the airflow from becoming turbulent.

TYPES OF FLAPS

A wing flap is defined as hinged, pivoted, or sliding airfoil, usually attached near the trailing edge of the wing. The purpose of wing flaps is to change the camber of the wing and in some cases to increase the area of the wing, thus permitting the aircraft to operate at lower flight speeds for landing and takeoff. The flaps effectively increase the lift of the wings and, in some cases, greatly increase the drag, particularly when fully extended. Various configurations for wing flaps are shown in Fig.5.20.

I Leadingedge flaps

While flaps are generally located on the trailing edge of a wing, they can also be placed on the leading edge. Leading-edge flaps are normally used only on large transport-category aircraft that need large amounts of additional lift for landing. A leading-edge flap is a high-lift device which reduces the severity of the pressure peak above the wing at high angles of attack. This enables the wing to operate at higher angles of attack than would be possible without the flap.

a. Krueger flap

Another method for providing a leading-edge flap is to design an extendable surface known as the Krueger flap that ordinarily fits smoothly into the lower part of the leading edge. When the flap is required, the surface extends forward and downward, as shown in the second drawing of Figure.5.21.

b. Droop snoot

One method for providing a wing flap is to design the wing with a leading edge that can be drooped, as shown in the top drawing of Figure.5.21.

II Trailing edge flaps

The trailing edge flap is simply a small auxiliary aerofoil, located near the rear of a main aerofoil, and which can be deflected about a given line, where it is hinged. This deflection causes a change in the geometry of the aerofoil, and hence in its aerodynamic characteristics. In the case of a flap designed as a high-lift device, usually only downward deflection is possible, though the amount of deflection is variable. In the case of a flap designed as a control surface, deflection in both senses is possible, though the range of deflection is usually much less. The main types of trailing edge flap are described in principle in the following paragraphs.

a. Camber flap or Plain flap

The camber flap, in effect, acts as if the trailing edge of the wing were deflected downward to change the camber of the wing. Thus increasing both lift and drag. If the flap is moved downward sufficiently, it becomes an effective air brake. The plain flap may be hinged to the wing at the lower side, or it may have the hinge line midway between the lower and upper surfaces.

b. Split flap

The split flap, when retracted, forms the lower surface of the wing trailing edge. When extended, the flap moves downward and provides an effect similar to that of the pain flap. Plain flaps and split flaps may be attached to wing with three or more separate hinges, or they may be attached at the lower surface with a continuous piano hinge.

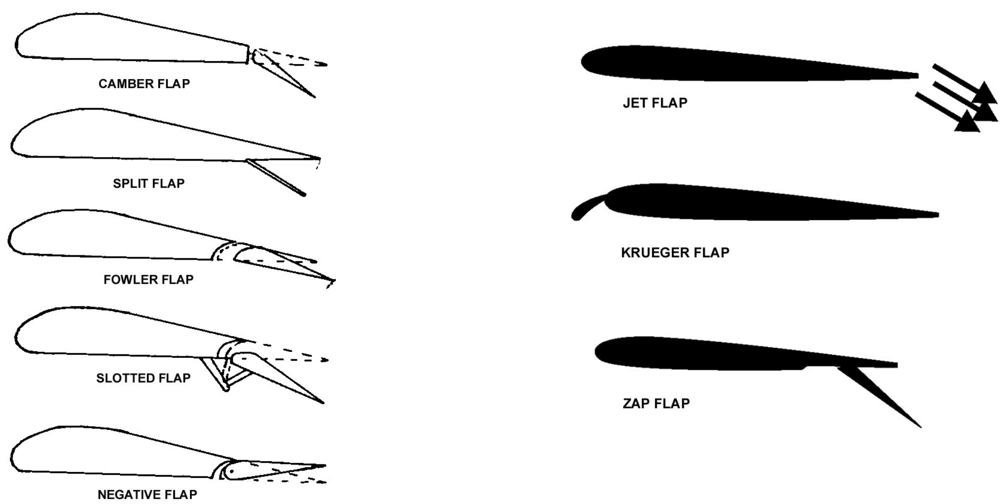


Fig.5.20. Configuration for wing flaps

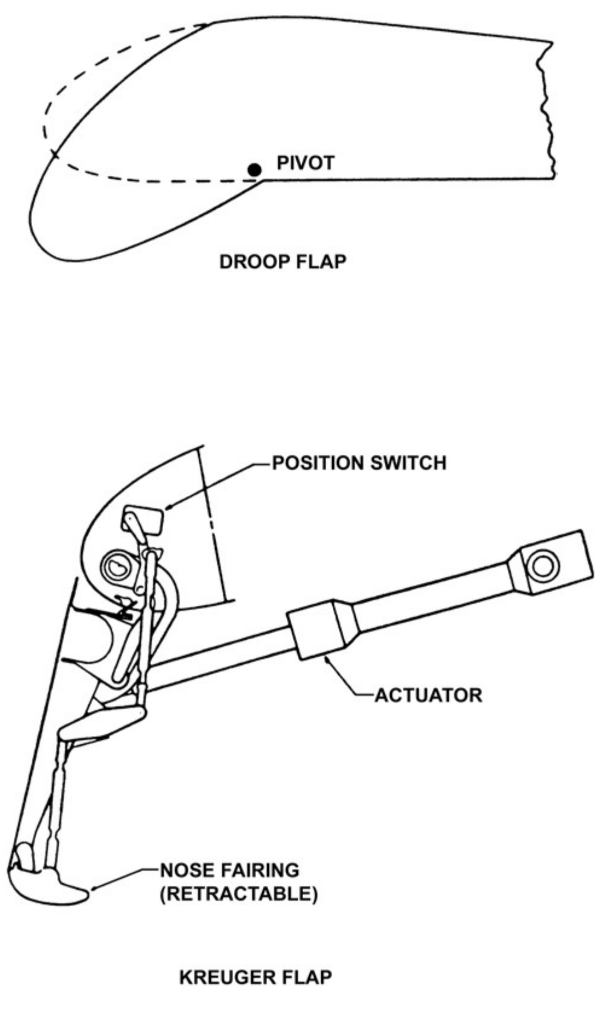


Fig.5.21. Types of leading-edge flaps

c. Fowler flap

The fowler flap and others with similar operation are designed to increase substantially the wing area as the flap is extended, the flap forms the trailing edge of the wing. As this type of flap is extended, it is moved rearward, often by means of a worm gear, and is supported in the correct position by means of curved tracks. The effect of the Flower flap, when extended is to greatly reduce the stalling speed of the aircraft by the increase in wing area and change in wing chamber.

d. Zap flap

Zap flap is a combination both Split flap and Fowler flap.

e. Slotted flap

A slotted flap is similar to a plain flap except that as the flap is extended, a gap develops between the wing and the flap. The leading edge of the flap is designed so that air entering this gap flows smoothly through the gap and aids in holding the airflow on the surface. This increases the lift of the wing with the flap extended.

f. Jet flap

The jet flap consists of a very high speed jet of air blown out through a narrow slit in the trailing edge of the wing. The jet, deflected slightly downwards, divides the upper surface flow from the lower surface flow, and produces an effect on the flow over the wing just like that which would be produced by a very large physical trailing edge flap. There is an additional increment due to the downward component of the momentum of the jet. Experiments with such a device have produced very high lift coefficients.

Some aircraft designs incorporate combinations of the fowler and slotted flaps to greatly increase the lift and drag of the wing. When the flap is initially extended, it moves aft on its track. Once past a certain point on the track, further aft movement is accompanied by a downward deflection which opens up the slot between the flap and the wing. Many jet transport aircraft use this basic design with several slot openings being used to improve the airflow over the wing and flap surfaces. Fig.5.22 illustrates this type of flap combination.

A few aircraft, particularly sailplanes, incorporate a negative flap capability into the flap control design so that the flap can be raised above its neutral position. This changes the airfoil shape and allows the aircraft to fly at a higher speed with reduced drag.

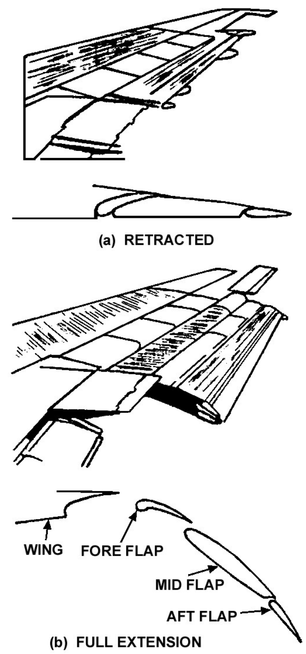


Fig.5.22. The retracted and extended position of the flap segment in a typical flap system

BOUNDARY LAYER SUCTION

While blowing energizes the boundary layer in order to prevent separation, the principle of suction is the removal of the slowly moving air in the boundary layer, so that there in no layer to separate. Small holes, flush with the surface, are made in the surface of the aerofoil upstream of the separation point, and the air in the boundary layer is sucked into the wing through these holes. However, from this point onwards the boundary layer will re-form and thicken, and separation may still occur at some point downstream. To prevent this a series of suction holes must be made at various chord wise positions, as indicated in Fig.5.23. The logical extension of this idea is the use of a porous wing surface, with suction applied every- where on the surface.

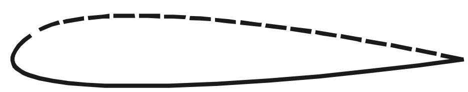


Fig.5.23.

In addition to preventing separation, suction may also be used to prevent transition, and hence to keep drag low. Such a device would appear to be of particular interest in conjunction with the use of low drag wing sections. The principle behind the design of a low drag section is the maintenance of laminar flow. The disadvantage inherent in such designs is that separation occurs very readily when the incidence is increased by even a fairly small amount above the design value. Suction could be helpful both in maintaining laminar flow and in preventing separation.

BOUNDARY LAYER BLOWING

The principle of boundary layer blowing is similar to that of the leading edge slot. Highspeed air is blown into the boundary layer through a narrow slit in the upper surface of the aerofoil, where it re-energizes the boundary layer and prevents separation. Since the velocity of the air fed in this way is so much higher than the speed of the air passing through a leading edge slot, or a slotted flap, blowing will generally prove much more effective. The stall can be delayed almost indefinitely by this means. In addition, The jet of air has the effect almost indefinitely by this means. In addition, the jet of air had the effect of increasing the circulation round the wing, thus giving a direct lift increment at all incidence

The slot may be near the nose of the aerofoil, so that the blowing affect the whole of the upper surface, as in Fig.5.24. Alternatively, the slot maybe situated just upstream of the nose of a plain flap. In this position, the upstream of the slot will be affected to some extent by induction, but the main object is to prevent separation of the flow over the upper surface of the flap. Thus device is known as the blown flap, and is illustrated in Fig.5.25.

Fig.5.24.

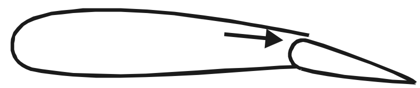


Fig.5.25.

The circulation effect is still present, though less important. There is some advantage in this device compared with that of slot placed further forward in that, in the latter case, the effect of blowing may be lessened by the time the flow reaches the rear of the aerofoil, where separation is most likely.

VORTEX GENERATORS

Many devices are used by the designer to control the separation or breakaway of the airflow from the surface of the wing - all these devices, in one way or another, over one part of the wing or another, have this in common, that they are intended to prevent or delay this breakaway. How? Well, that depends to some extent on the device, and we will consider vortex generators first (Fig.5.26).

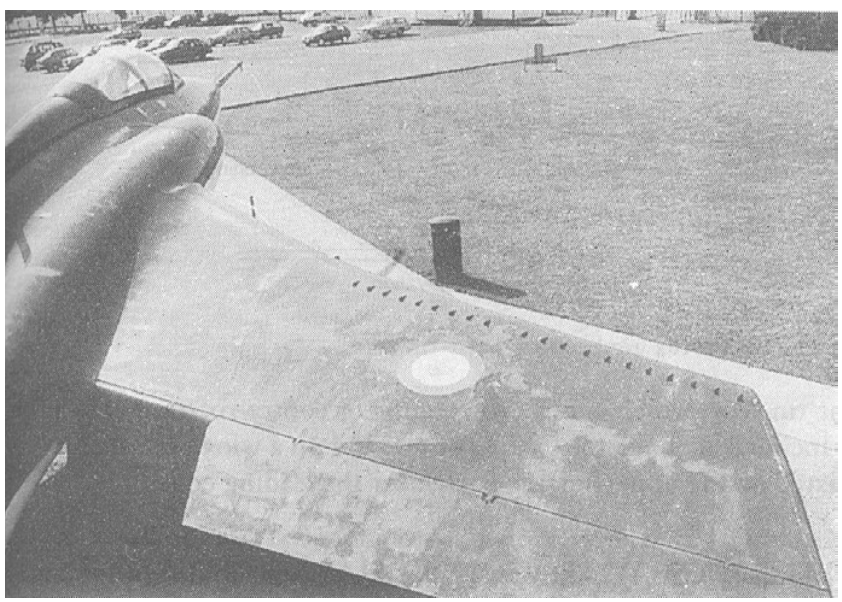


Fig.5.26. Vortex generators

The fundamental reason for the breakaway is that the boundary layer becomes sluggish over the rear part of the wing section, flowing as it is against the pressure gradient. The formation of a shock wave makes matters worse; the speed in the boundary layer is still subsonic which means that pressure can be transmitted up stream, causing the boundary layer to thicken and, if the pressure rise is too steep, to break away from the surface. Now vortex generators are small plates or wedges, projecting an inch or so from the top surface of the wing, i.e. three or four times the thickness of the boundary layer. Their purpose is to put new life into a sluggish boundary layer; this they do by shedding small lively vortices which act as scavengers, making the boundary layer turbulent and causing it to mix with and acquire extra energy from the surrounding faster air, thus helping it to go farther along the surface before being slowed up and separating from the surface. In this way the small drag which they create is far more than compensated by the considerable boundary layer drag which they save, and in fact they may also weaken the shock waves and so reduce shock drag also; and the vorticity which they generate can actually serve to prevent buffeting of the aircraft as a whole - a clever idea indeed,

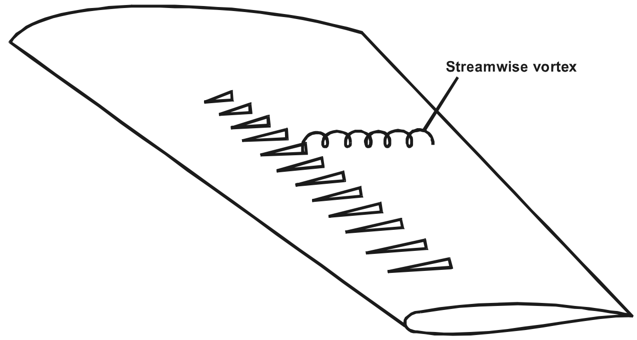


Fig.5.27. Vortex generators: bent-tin type.

and so simple. The net effect is very much the same as blowing or sucking the boundary layer, but the device is so much lighter in weight and simpler. The greater the value of the thickness/chord ratio the more necessary does some such device become.

There are various types of vortex generator; Fig.5.27 illustrates the bent-tin type, which may be co-rotating or contra-rotating. The plates are inclined at about 15^{o} to the airflow, and on a wing are usually situated on the upper surface fairly near the leading edge.

■■■