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AERODYNAMICS 1

CHAPTER 7 – FLIGHT CONTROLS

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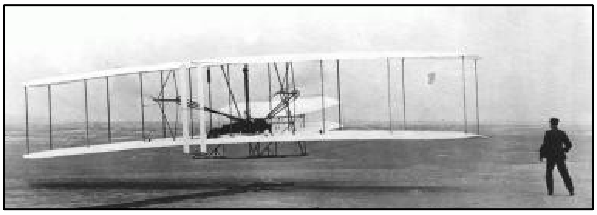
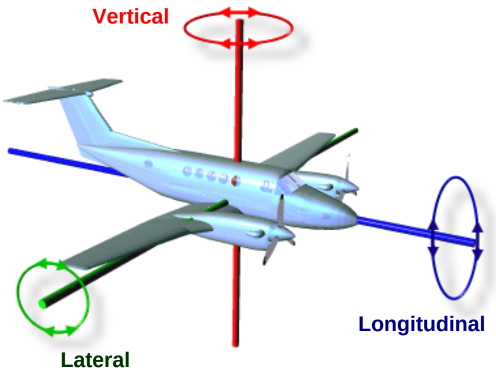
AN INTRODUCTION TO FLIGHT CONTROLS

INTRODUCTION

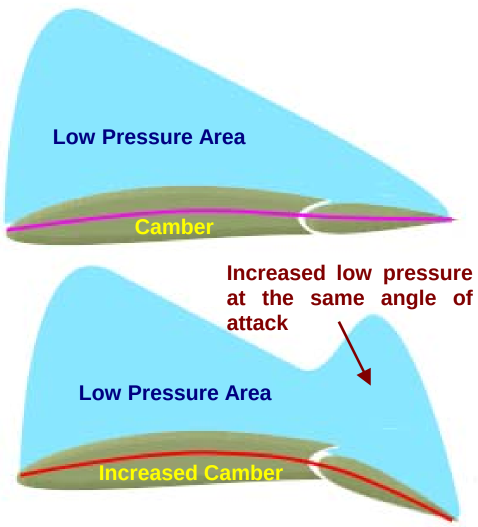
After early aircraft designers mastered the art of building surfaces that would yield sufficient lift to support the airplanes, their greatest problem was to gain adequate and positive control of the airplane during all the phases of flight.





Initially, the pilots had to shift their weight ***(thereby changing the aircraft's centre of gravity in relation to its aerodynamic centre)***, when they wanted to manoeuvre, but later control surfaces were developed that could control the aircraft around each of its three axis using controls in the aircraft.

Principles

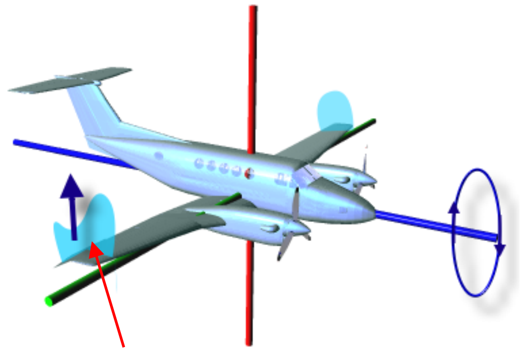


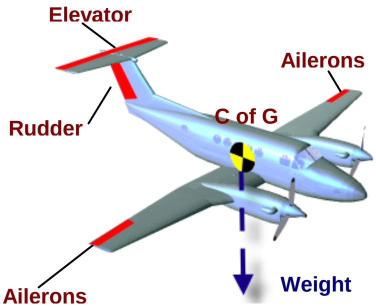
An increase in camber of an aerofoil will increase the value of the C_L. The principle is therefore to change the camber of the aerofoil, and the amount of lift, which is produced by this increase.

This change in camber is effected by control surfaces such as ailerons, elevators and the rudder.

According to Newton's third law, for every action there is an opposite and equal reaction. The changing in the C_L of an aerofoil by means of control surfaces can thus create aerodynamic moments that will rotate the aircraft about each of its three axes.

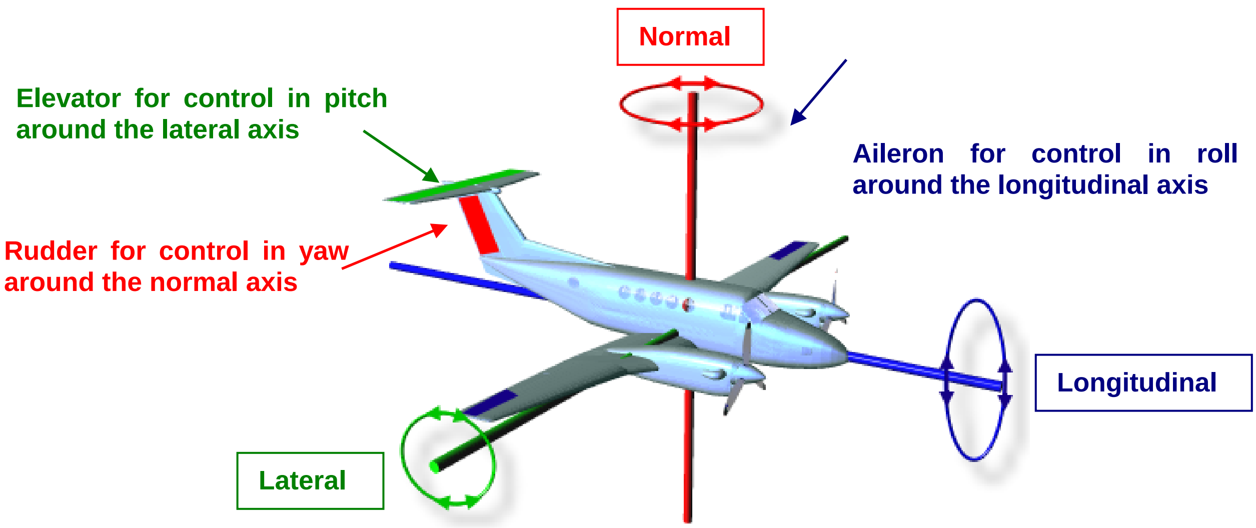
The control surfaces are usually positioned at the extremities of the aircraft so that they have the longest possible moment arm about the Centre of Gravity (C of G) of the aircraft.

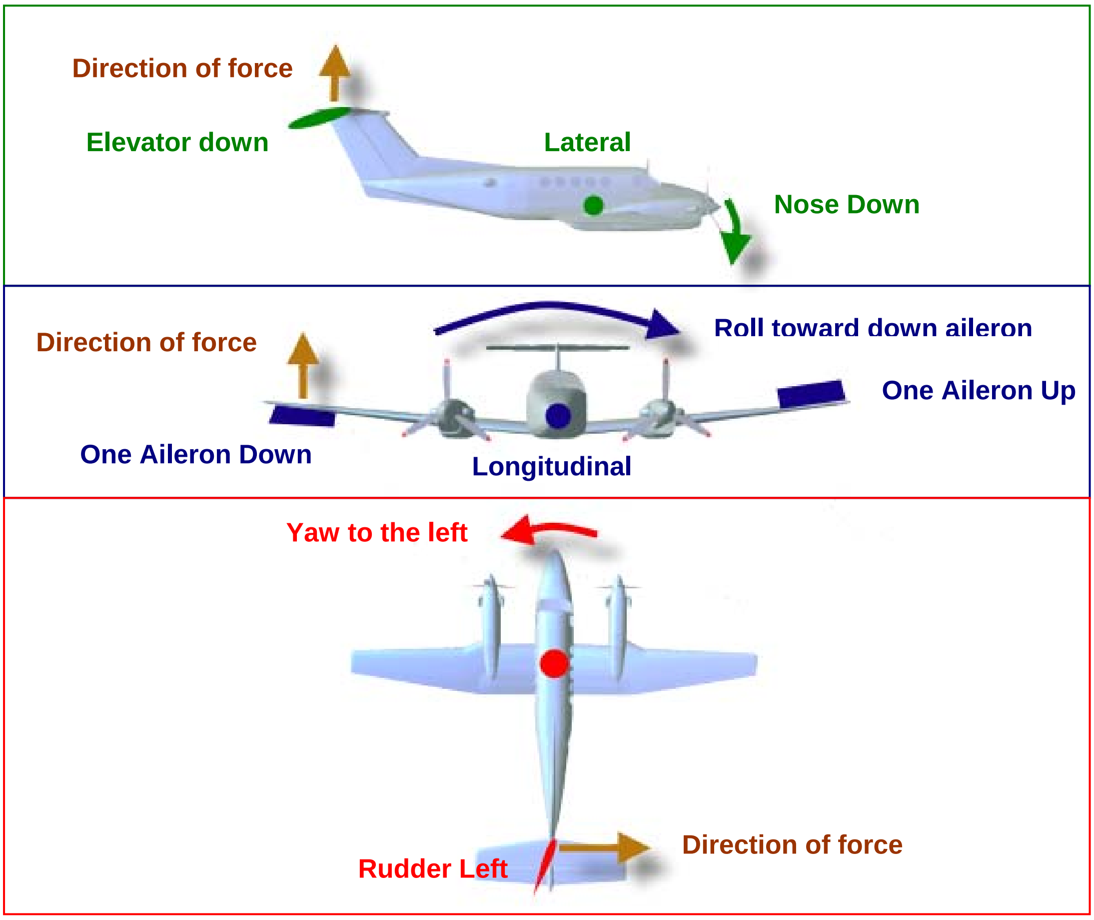




AXES OF ROTATION

In normal aircraft design, there are normally three separate control systems for manoeuvring the aircraft around its three axes.

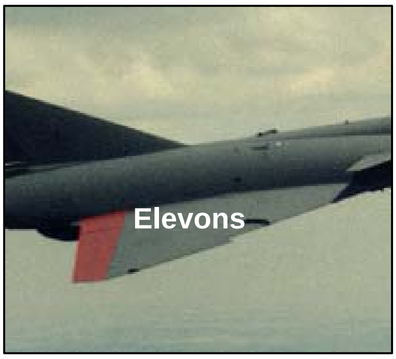


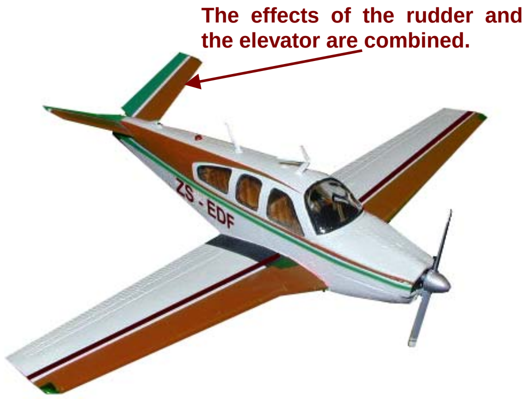


TYPES

On some aircraft the effect of two of these controls is combined into a single set of control surfaces, examples include:

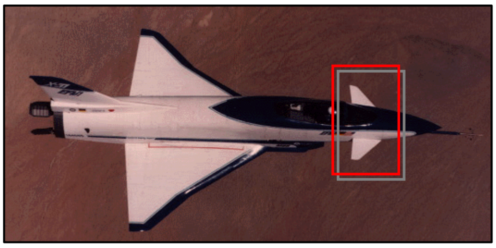
Elevons - The effects of the elevators and the ailerons are combined. This is mostly found on high-speed aircraft with a delta configuration.





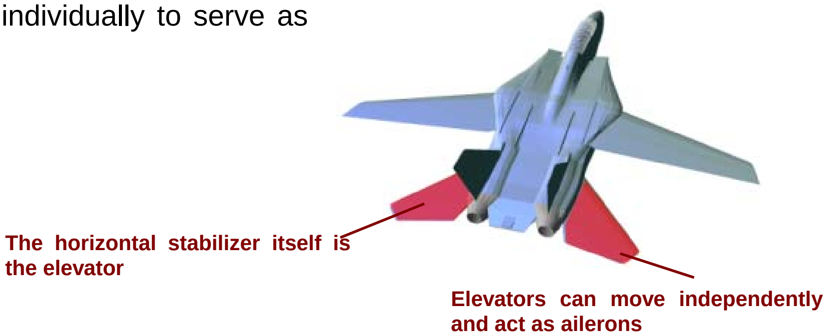
Ruddervators/Elerudders - Another method whereby controls are combined, is found in a design where the horizontal and vertical stabilizer are combined, an example is the "V-Tail" Beechcraft Bonanza.

Canards - On the latest generation fighter aircraft that are required to be agile, the canard configuration is often used. In this design the moveable horizontal control surface at the nose of the aircraft acts as an elevator.



Although it tends to be a somewhat unstable configuration, canards have the advantage that they are outside the region where shock waves occur and are not affected by downwash from the wings. Computers and "fly by wire" controls compensate for the instability.

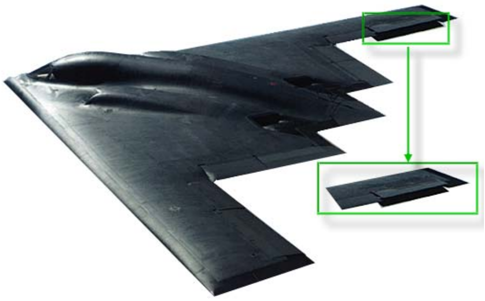
Tailerons - The Grumman F 14 "Tomcat" uses tailerons. The elevators move individually to serve as ailerons as well.



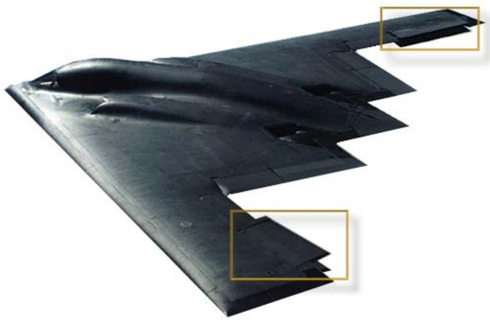
Combinations - Certain aircraft designs also forced engineers to use controls for more than two applications. This is a design feature on the B2 Bomber, where as well as normal deflection, the control surfaces can also split to cause drag on the airframe when required.

Role : Ailerons

Role : Elevators



Role: Rudder, one splits and the aircraft yaws in that direction. In this example the aircraft will yaw right



Role: Air Brakes both split and act as an air brake.

FACTORS AFFECTING THE CONTROLS

It is desirable that each set of control surfaces should produce a moment only about its designated axis ***(e.g. Ailerons around the longitudinal axis).*** The ability of the control to perform its role is a design function and the following are some factors affecting this ability:

- **Size and shape of the control.**
- **Deflection angle.**
- **EAS^2 (Effect of Speed)**
- **Moment arm (distance from the Centre of Gravity).**

An aircraft that is past the design and building stage and already in operation, has fixed characteristics affecting control power and effectiveness ***(designed and built this way)***, and some, which can be changed while operating the aircraft ***(variables).***

- ***Fixed Factors:*** The aeroplane designers fix the **size and shape**, while the **movement in the Centre of Gravity (CG)** is also so small that the moment arm can also be considered to be constant.

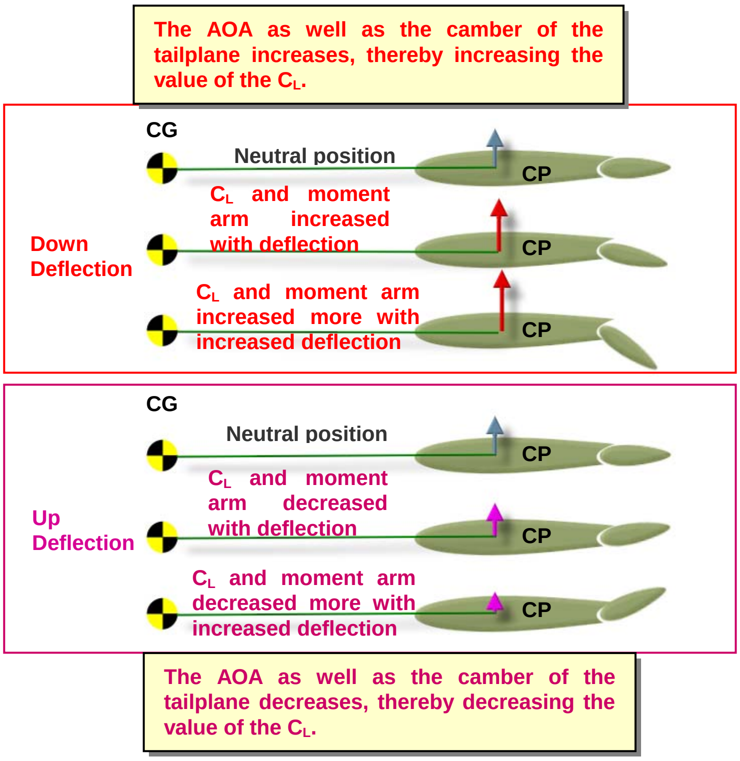
- ***Variable Factors***: There are only two variables that can be changed while the aircraft is flying - **the deflection angle** of the control surface and the **speed** at which the aircraft is flying.

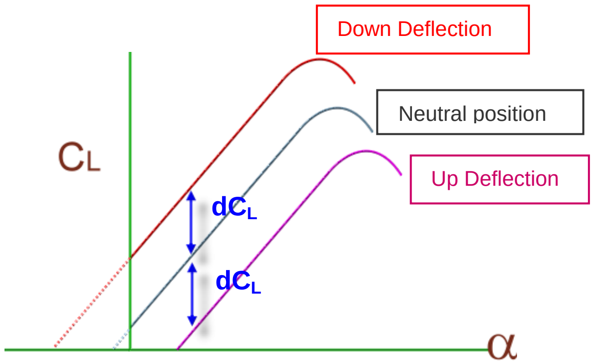
Because the fixed factors cannot be changed, there is no need to discuss them, and this discussion will focus on the Variable factors.

DEFLECTION ANGLE

When a control surface is deflected, it changes the value of the C_L of that aerofoil ***(increase or decrease)*** which in turn creates or affects the moment ***(movement)*** around the CG of the aircraft.

The greater the deflection, the more the change in C_L, and the greater the change in the moment around the CG.





The moment produced is thus:

The product of the change in lift ***(aerofoil)*** dC_L **multiplied by the** moment arm to the CG.

EFFECT OF SPEED

From the lift formula, it can be seen that **the aerodynamic forces** produced on an aerofoil vary as the **square of the speed.**

$$F = C_L \tfrac{1}{2} \rho V^2 S$$

By way of an example to explain this, let us assume that all factors in the lift formulae apart from **speed** are not considered.

The ∝ sign is used because the other factors are being ignored.

$$4 \propto C_L \tfrac{1}{2} \rho\, 2^2 S$$

If the value of V is 2, the value of AF is 4 (4 is the square of 2).

$$16 \propto C_L \tfrac{1}{2} \rho\, 4^2 S$$

If the value of V is 4, the value of AF is 16 (16 is the square of 4).

The **F** increment ***(and also the moment)*** will thus vary as the square of speed ***(EAS^2)***.

Applied to the control surface, it can be seen that as V is increased, **F** is increased ***(directly proportional).***

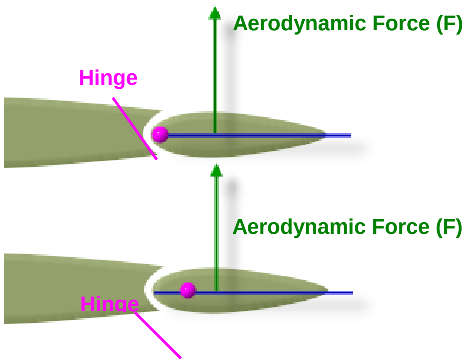
As **F** is increased the deflection angle required to give a specified attitude change or response will be less ***(inversely proportional to F).***

<u>The practical implication of this is as follows:</u>

When an aircraft's speed is reduced by half, the pilot will have to increase the control deflection four times to achieve the same response in pitch, roll or yaw from the aircraft.

CONTROL FORCES

Control forces refer to the force that the pilot has to exert on the control column in order to effect control surface movements. These forces depend on the moment produced around the control hinge line, as well as the mechanical linkage between the control column and the control surface.



Hinge Moment = FX

As the value of FX decreases (i.e. the Hinge Moment), the force opposing the deflection is decreased; allowing easier deflection of the surface.

These control forces must be both **logical** and **manageable**:

<u>Logical</u> - The force needed to deflect the control must:

- Increase as the deflection angle increases ***(Increase in F).***
- Increase as the speed of the aircraft is increased ***(Increase in F).***

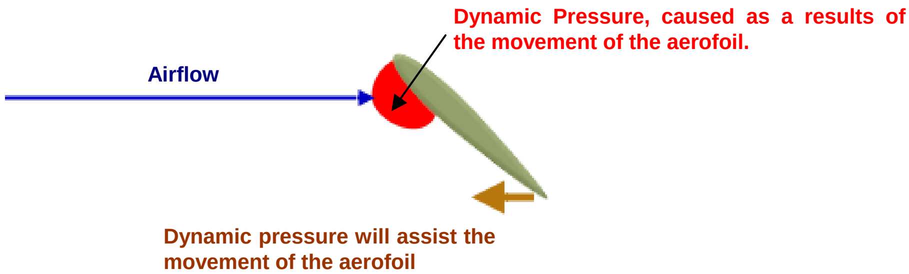
Manageable - The magnitude of the control force must be within the comfortable physical capabilities of the pilot.

BALANCING

If control surfaces are hinged at their leading edges, the control forces required to deflect the controls will be too large to overcome in all, but the smallest and slowest aircraft. This excludes aircraft equipped with powered or power assisted controls.

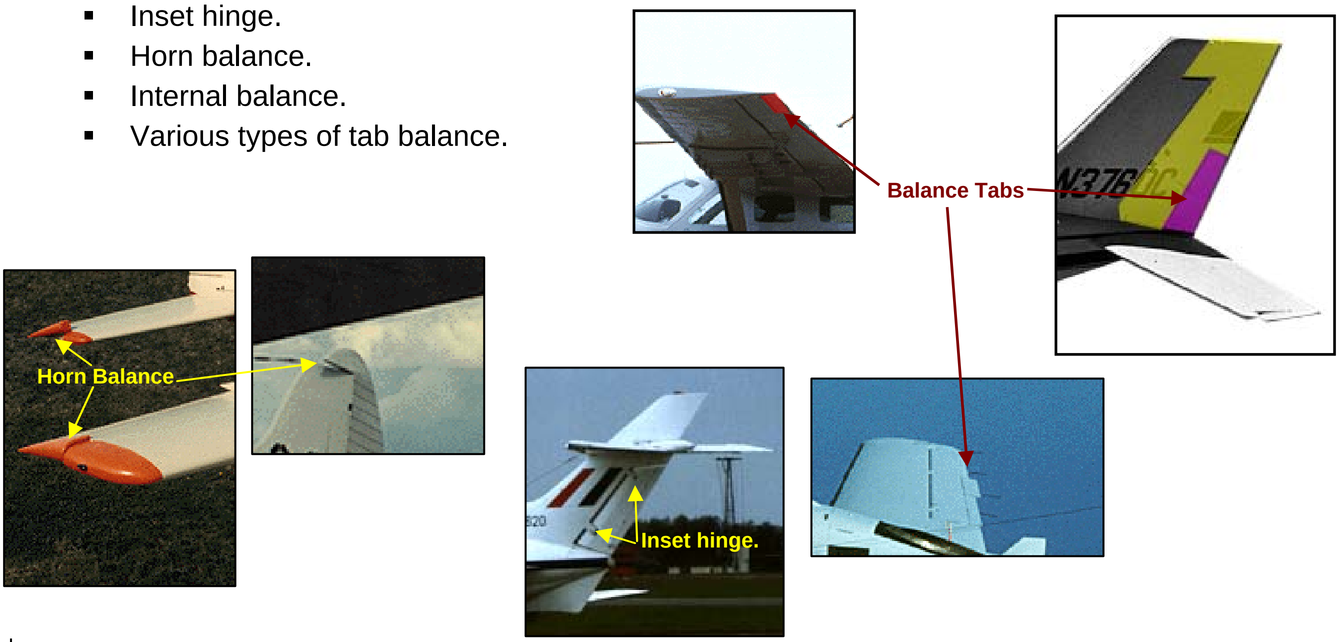

Bigger aircraft have power-assisted controls

In order to assist the pilot to move the controls in the absence of powered assistance, the dynamic pressure of the air stream can be used to reduce the hinge moments of a control surface.

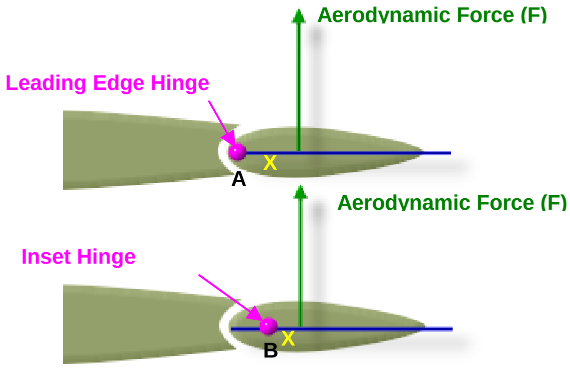


This concept is referred to as aerodynamic balancing. The most common forms of aerodynamic balance are:

- Inset hinge.
- Horn balance.
- Internal balance.
- Various types of tab balance.



INSET HINGE

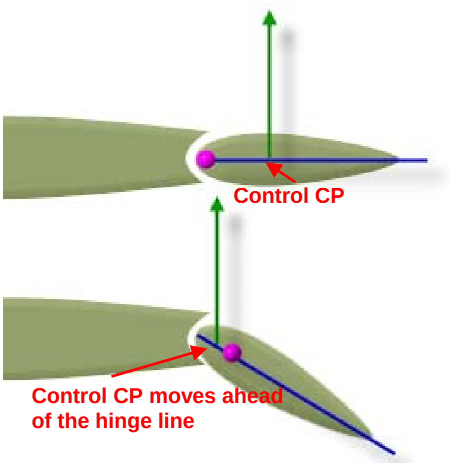


With the hinge at point A,
Hinge moment = FX.

With the hinge at point B,
Hinge moment = FX.

With the hinge at point B, the ***hinge moment will decrease***, where this is done on a control surface, it is named an **inset hinge.**

OVER BALANCE

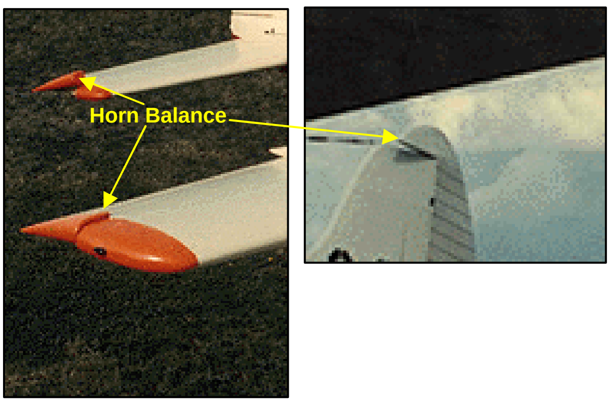


If the hinge line is located at such a position that the CP of the control surface can move ahead of the hinge line ***(when the angle of attack increases, the CP moves forward)***, the hinge moment would assist the control movement and the control will then be over-balanced.

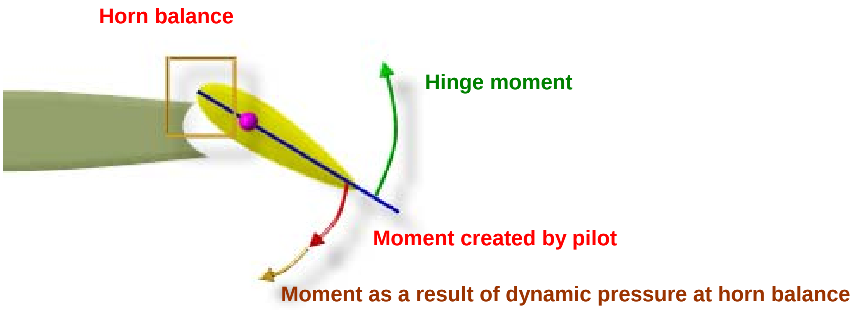
These types of balancing methods were used before power assisted controls were introduced.

HORN BALANCE

Another type of aerodynamic balancing is horn balancing. This is probably the first type of balancing developed. The horn is basically an area located **ahead** of the hinge line, which creates a moment that opposes the hinge moment developed by the control surface.



The moment developed by the horn acts in the same direction as the moment developed by the pilot.



Two types of horns are generally used:

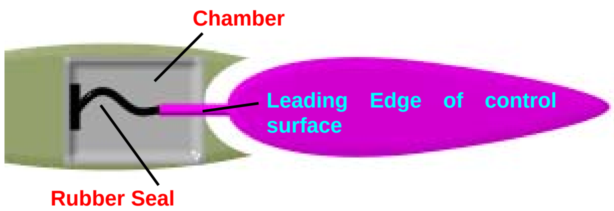
The unshielded horn: protrudes directly into the air stream.

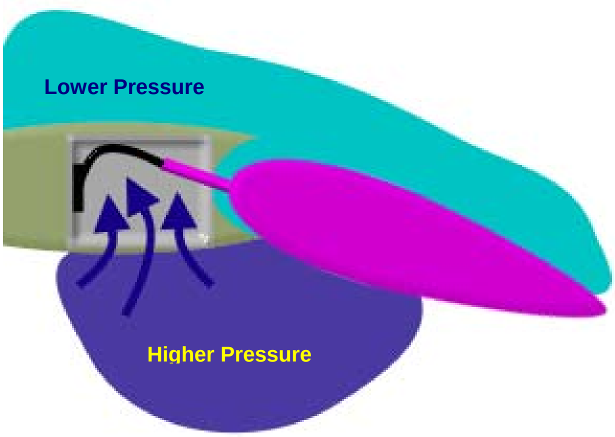
The shielded horn: is shielded by the aerofoil and only protrudes into the air stream when the control surface is deflected.

INTERNAL BALANCE

Another type of aerodynamic balance is the internal balance.

With this method, there is a chamber inside the aerofoil and this chamber is divided in half by a flexible rubber seal that joins the leading edge of the control surface to the opposite wall of the chamber.





As the control surface is deflected, the pressure on the side deflected into the airflow increases and a lower pressure on the opposite side. As this happens the pressure on the side deflected into the airflow enters the chamber in the aerofoil and exerts a force on the rubber seal ***(as a result of the lower pressure on the other side of the seal).***

The seal is connected to the leading edge of the control surface, and the result of the movement of the seal creates a moment that opposes the hinge moment.

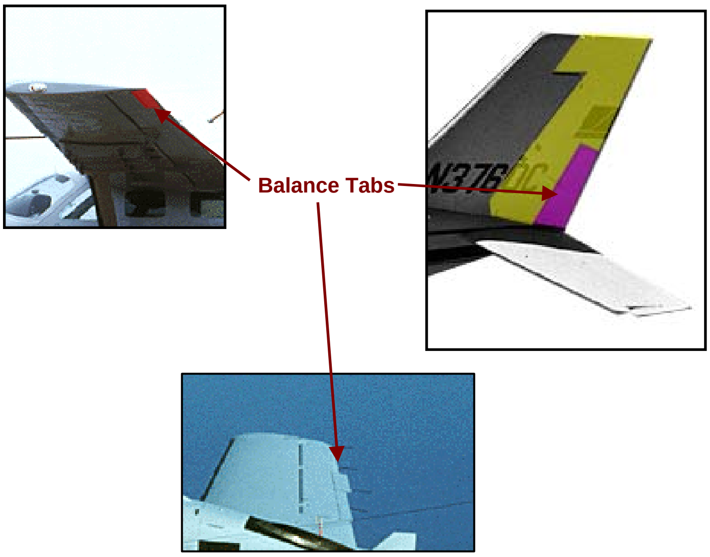
The moment produced here is however weaker than the hinge moment, thus only reducing the force that the pilot has to apply to the control column. ***(In some cases the strength of this moment arm can be reduced even further by venting air pressure above and below the rubber seal.)***

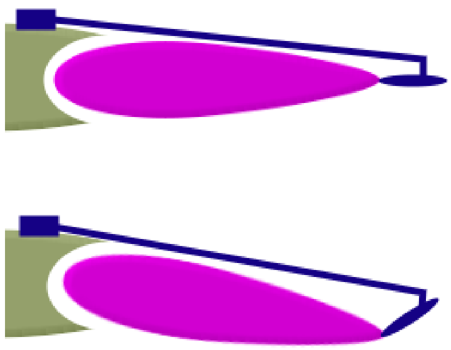
BALANCE TABS

Balancing control surfaces by means of balance tabs is another method used in the aviation industry.

A tab is a small hinged surface on the trailing edge of the control surface. In general the tab is not under the control of the pilot, but its angle is changed whenever the control surface is deflected. The tab will generally move in the opposite direction to the control surface, and in doing so will act against the hinge moment, and reduce stick load. There are different tabs, which are used, and the differences are based predominantly on the manner in which they are deflected. These include:

- **Geared Tabs**
- **Servo Tabs**
- **Spring Tabs**
- **Dual purpose Tabs**





Tab movement opposes the hinge moment

DESIGN REQUIREMENTS

There are three important factors to consider when designing the controls of an aircraft, these are:

- Control Forces
- Control movements.
- Control harmony.

CONTROL FORCES

It is of the utmost importance that the **control forces** on the control column or the "stick" should be balanced. If the **control forces** are too light or too heavy it will influence the operation of an aircraft drastically.

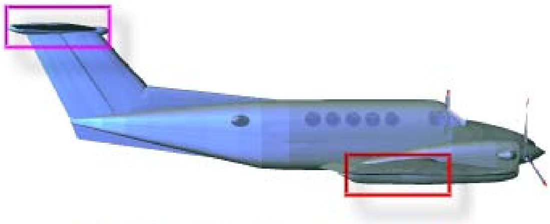
HEAVY CONTROL FORCES

The pilot will have difficulty in manoeuvring the aircraft. Too much attention and effort will be required in physical aircraft handling. Concentration and attention in applying the aircraft in its specific role will suffer.

LIGHT CONTROL FORCES

The pilot will be able to overstress the aircraft easily because the physical effort required to deflect the control column will be very little. Too much attention will have to be given to ensure the aircraft is operated within its design limitations.

CONTROL MOVEMENT

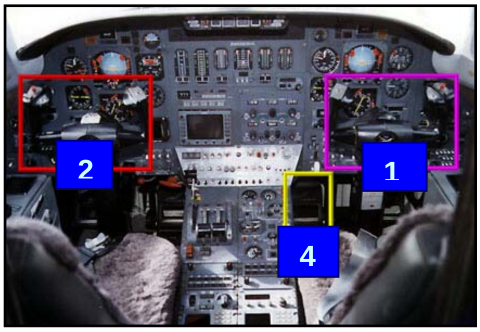


If the control yoke or stick movements are too small in relation to the amount of deflection of the control surfaces, the controls will be too sensitive.

The opposite also holds true: If the control yoke or stick movements are too large, the cockpit space will be too restricted and will not allow full deflections of the control surfaces.

CONTROL HARMONY

A very important factor in a pilot's assessment of the overall handling characteristics of an aircraft lies in the "**harmony**" of the controls with respect to each other. The pilot uses arms and legs ***(legs are stronger than his arms)*** to control an aircraft.



In order to create a harmonized feeling on the flight controls, the effort required to deflect the rudders with your feet will have to be more than the effort required to deflect the elevators with your arms.

Furthermore, it is also true that a human being can exert more force with his arms in a push/pull motion than in a sideways movement of the arms. In order to harmonize the feel on the controls, the force required to deflect the elevators ***(a push/pull action)*** will have to be more than the force required to deflect the ailerons ***(a sideways movement of the arms)***.

A method often used in aircraft design, is to arrange for the **aileron**, **elevator** and **rudder** forces to be in the ratio **1**: **2**: **4**

CONTROL SYSTEMS

INTRODUCTION

For a pilot to have effective control over his aircraft, he must have an effective means of obtaining the desired deflection angles from the control surfaces of the aircraft. This is achieved by means of a control system, which determines forces and movements to obtain the correct deflection. A conventional control system is composed of three parts:

- Pilot operated steering mechanism,
- Control Surfaces, and
- Linkage system to link steering mechanism and control surfaces.

PILOT OPERATED SYSTEMS

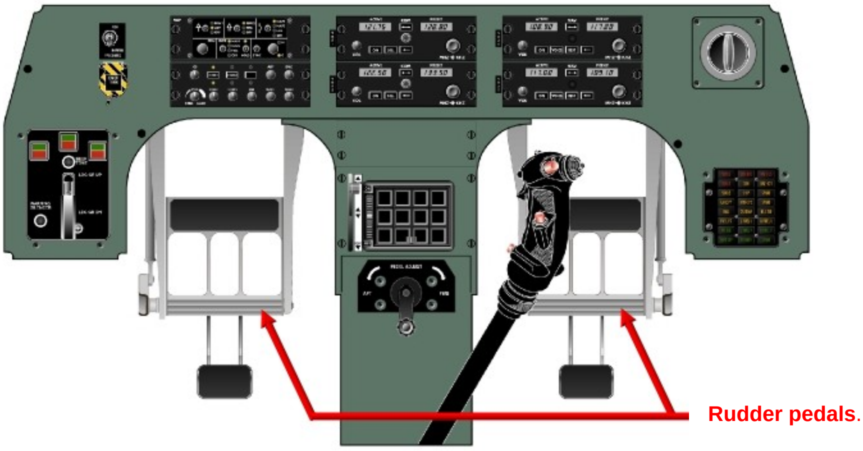
There are three types of steering mechanisms:

Control column or "joystick". Most fighters and military trainers use this type of mechanism. It is a control stick mounted perpendicular to the cockpit floor and it operates both the ailerons and elevators.

The flying controls are duplicated on the right-hand side.

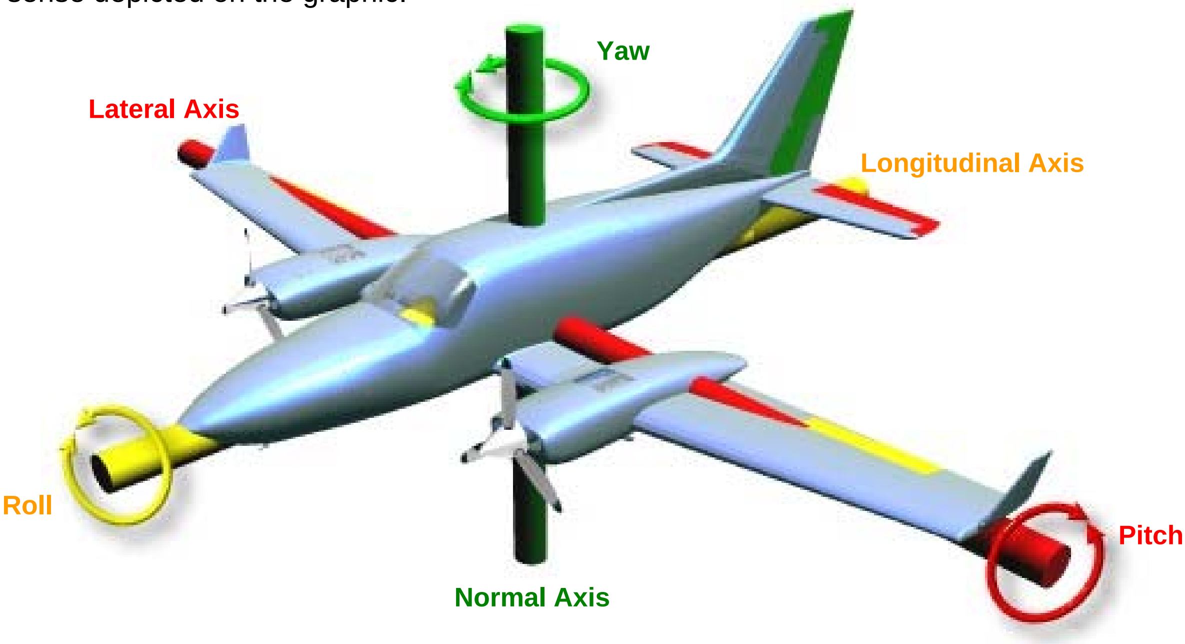
Yoke or wheel. Many modern light aircraft and most heavy transports and bombers ***(with the exception of the B-1 and B-2)*** use this type of mechanism. The yoke allows more force to be placed on the control. Control in pitch is the same as the stick and to roll, the wheel is turned in the direction of the intended turn.

Rudder pedals. All aircraft have rudder pedals and control in the yawing plane is achieved by applying pressure on the applicable pedal to yaw the aircraft to that side.



CONTROL SURFACES

The primary control surfaces are the **ailerons**, **elevators** and **rudders** and work in the sense depicted on the graphic.



For a pilot to be aware of how the aircraft is responding to his inputs, the control system must provide him with some sort of feedback. However, the amount of feedback the pilot receives when making a deflection, depends on the type of linkage system used.

LINKAGE SYSTEMS

CONVENTIONAL MECHANICAL LINKAGE

This is purely a mechanical linkage and uses only aerodynamic balancing and stick gearing to aid the pilot's inputs.

POWER AUGMENTED OR POWER BOOSTED LINKAGE

Here a hydraulic system works in parallel with the conventional system, but it gives a fixed amount of force to supplement the inputs from the pilot.

POWERED LINKAGE

Balancing forces change with circumstances such as speed and altitude, and conventional systems that provide a constant feel have proved very expensive to build. Powered systems are much simpler and cheaper to use. The controls are connected to electrically or hydraulically operated motors that select a deflection angle that is proportional to the input from the pilot.

RECENT DEVELOPMENTS

FLY-BY-WIRE

Modern fighters ***(such as the F-18, Rafale and Eurofighter)***, transports ***(such as the Airbus A-320, A-340 and C-17)*** and bombers ***(Rockwell B-1 and Northrop B-2)*** make use of fly-by-wire.

The pilot uses a "side-stick" and normal rudder pedals that are connected to a computer or in some cases up to 4 computers. The computer analyses the input from the pilot and determines the size and velocity of the deflection. The computer also provides feedback to the pilot in the form of "artificial feel".

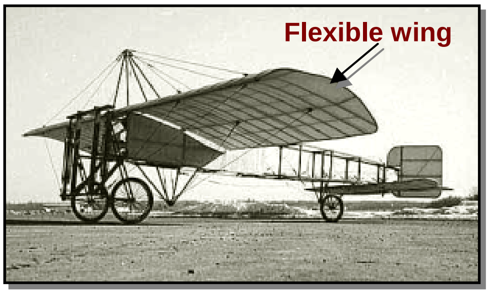
STABILITY AUGMENTATION SYSTEMS

Some aircraft are so unstable that, if controlled by conventional means, they will disintegrate in fractions of a second. What is needed is some kind of electronic aid that can maintain the stability of the aircraft while enabling a pilot to fly the aircraft.

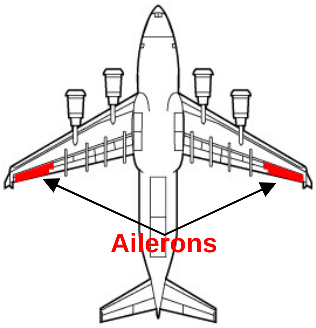
In the case of the X-29 ***(featured in this graphic)***, which is used by NASA for forward swept wing experiments, the aid is in the form of a 4 x redundant fly-by-wire system that has the ability to make more than 30 corrections per second.

AILERONS

INTRODUCTION



The Wright Brothers were amongst the first aviators that realized the importance of having some form of lateral control over an aircraft. The first aircraft were made of wood and canvas. Due to this relative flimsy construction, early forms of lateral control were achieved through wing warping.



As long as wings remained flimsy and flexible, the practice of wing warping represented no problems, but as aircraft became more rigid, another form of lateral control was needed. Glenn Curtis, an aviation pioneer in the USA developed the aileron, a moveable aerofoil on the trailing edge of the outboard area of the wing.

Since then various methods of lateral control have been tried and tested, but the aileron remains the most effective way of controlling an aircraft in the rolling plane.

Considering the fact that an aileron gives a steady rate of movement for almost all the time it is applied, a conventional aileron is known as a rate control.

The stick force required to initiate a manoeuvre may be less than, or greater than the stick force required to sustain the manoeuvre.

A response is usually termed as being favourable when the initiation force is slightly greater than the force required to sustain the manoeuvre, the difference being up to 10% of the force required for sustaining the manoeuvre.

On some modern fighter aircraft, controls are deflected for very short periods of time. It often happens that the aileron deflection is already taken off before the balanced rate of roll is obtained. In a situation such as this, do you think that an aileron can still be described as a rate control? NO

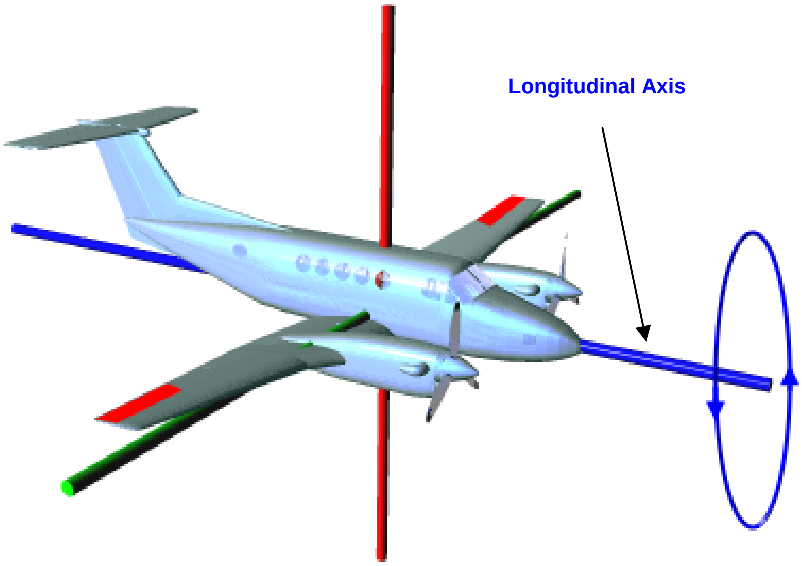
In a case such as this, the aileron is not producing a steady rate of roll, but for the short period it is deflected, it is producing a rate of roll that is always increasing. In this case the aileron is described as an acceleration control.

Ailerons are one of the primary control surfaces and have three primary functions:

- ***Directional Control***. When aileron is applied and a certain bank angle is reached, the lift vector tilts and a measure of centripetal force is produced. This will bring about a change in direction and the aircraft will thus turn.

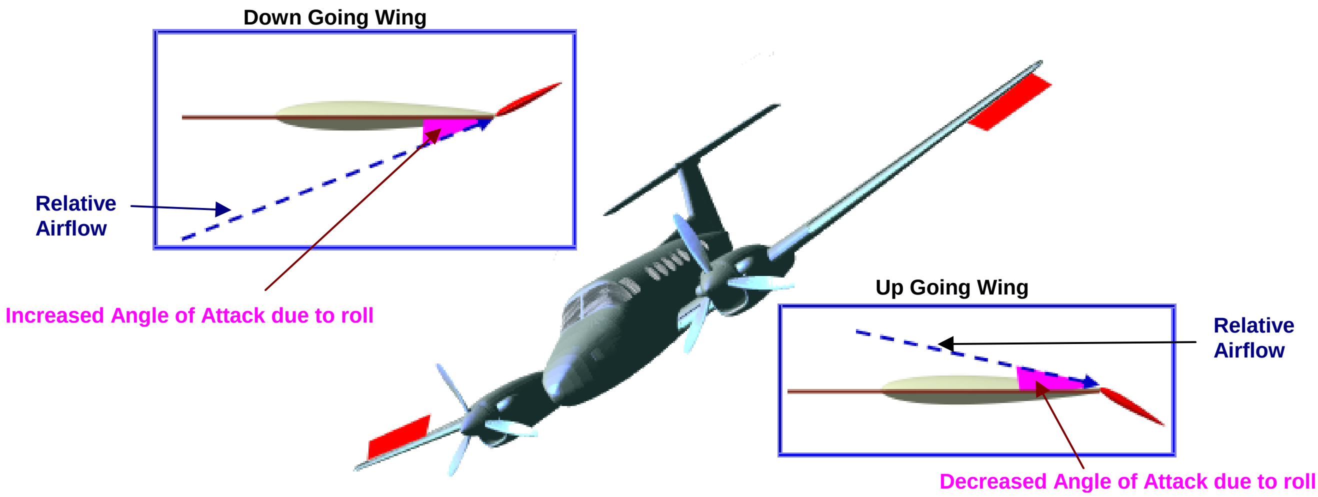
- ***Rotation about the Longitudinal axis***. If sufficient aileron deflection is made at a high enough speed, the aircraft will not change direction, but roll around its longitudinal axis and complete what is known as a straight roll.

- ***Lateral Stability***. An aircraft is neutrally stable in the rolling plane. Should an aircraft therefore experience turbulence and be rolled through say 30°, there will be no immediate restoring moment to return the aircraft to the straight and level attitude. If this should happen a few seconds before landing, it could have disastrous results, but ailerons provide the pilot with the necessary lateral control to avoid such accidents.



DAMPING IN ROLL

When aileron is applied, a rolling moment is created about the longitudinal axis of the aircraft, which is opposed by damping in roll moment. The greater the rolling moment, the greater the damping moment. ***(Until the rate of roll reaches a steady value as dictated by the damping in roll effect)***.



As an aircraft starts to roll about its longitudinal axis, an additional component of the free stream flow is created that changes the relative angle of attack of the wings. When an aircraft is rolling about its longitudinal axis, the angle of attack of the down-going wing will increase.

As the wing starts to rotate, an additional component of the free stream flow is created that changes the relative angle of attack of the wings. The down-going wing experiences an increase in angle of attack due to the rolling component.

The up-going wing on the other hand experiences a decrease in its angle of attack due to the rolling

The extra lift produced by the down-going wing plus the reduced lift produced by the up-going wing will tend to oppose the roll about the longitudinal axis. This opposing of the roll is known as damping in roll. *The greater the rate of roll, the greater the damping*.

Eventually the rolling moment produced by the ailerons will be exactly balanced by the damping moment and the aircraft will attain a steady rate of roll.

Usually the time taken for the rolling moment and the damping moment to reach a balanced state is very short *(less than one second)*. Thus for most of the time that ailerons are being used, they are giving a steady rate of roll response and this is known as *steady state response*.

FACTORS EFFECTING AILERON RESPONSE

However, a given aileron deflection does not necessarily produce a given value of steady rate of roll, because there are certain factors that modify aileron response. They are:

- Effect of forward speed.
- Effect of altitude.
- Aero-elastic distortion.
- Aileron response at low speeds.

EFFECT OF FORWARD SPEED

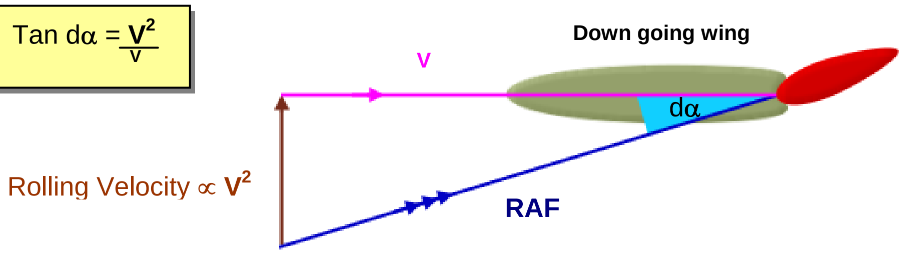
The effect of forward speed on the response of ailerons is two fold with the one affecting the other.

$$F = C_L \tfrac{1}{2} \rho V^2 S$$

- Firstly, **F *(moment) is proportional*** **($\propto$)** to $\mathbf{V^2}$**.** This applies to the rolling velocity due to aileron power as well ***(the more aileron is deflected, the higher the rolling power).*** This moment would result in the aircraft continuously rolling about the longitudinal axis as speed increases. In reality this does not happen, and the reason for this is the damping in roll, which is also affected by speed.

- The damping in roll effect is as a result of the change in angle of attack (dα) of the down going wing, ***(which is caused by the rolling velocity in forward flight).*** Therefore, for a given aileron deflection, a steady roll rate depends on the damping angle (dα).

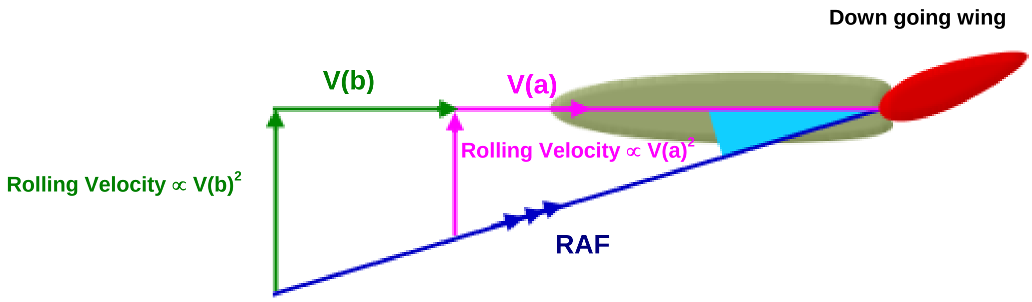
  If, for a given aileron deflection, a steady roll rate depends on damping angle (dα) and: $\boxed{\text{Tan } d\alpha = \frac{V^2}{V}}$



From the formulae $\quad \text{Tan } d\alpha = \dfrac{V^2}{V} = V \quad$ This means that the relationship between

***Damping in roll and forward speed is linear*.**

However, where the damping moment increases as the first power of V, the rolling moment increases as $\mathbf{V^2}$. This means that if aero-elasticity and compressibility are ignored, ***the rate of roll increases in the same ratio as the forward speed for a given aileron deflection.*** It is because of this that the aircraft does not roll uncontrollably as speed increases.

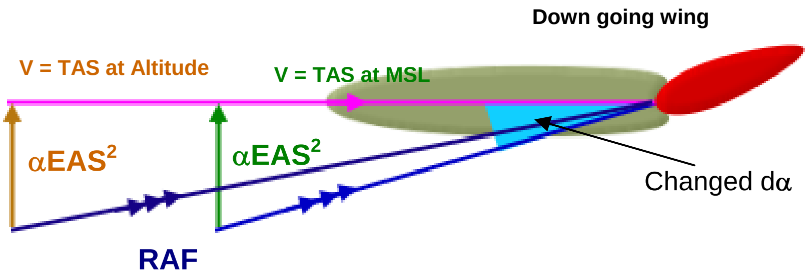


EFFECT OF ALTITUDE

Altitude affects aileron response in that the damping in roll effect is modified.

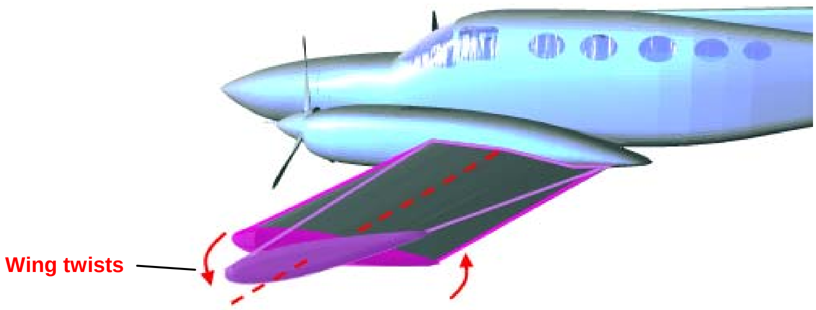
As altitude increases, the forward speed ***(TAS)*** increases for the same or constant EAS^2. As can be seen on the graphic if TAS increases, the damping angle dα decreases and the damping in roll effect reduces for the same EAS^2.

When the damping in roll decreases due to an increase in altitude, the steady roll rate increases for a given deflection at a constant EAS^2.



AERO-ELASTIC DISTORTION

Because the wings are usually the least rigid part of an airframe, they may twist or bend when the ailerons are deflected. This distortion may affect stability and control in all three planes and reduce the ultimate rate of roll available at high speeds.



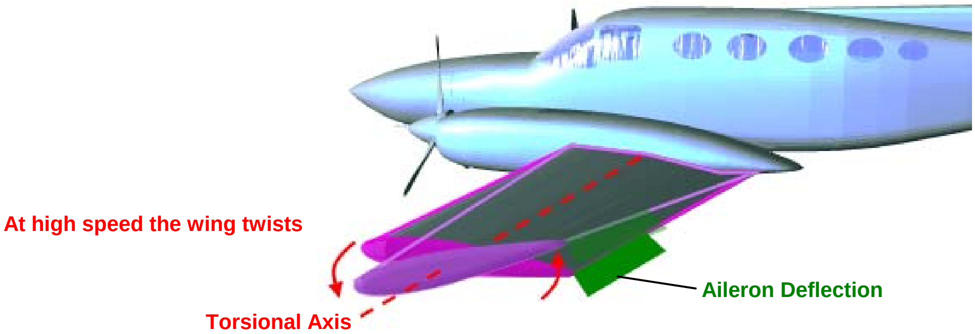
The torsional rigidity of the wing depends on the wing structure and may prevent distortion at low speeds; however aileron power increases as EAS^2, while the torsional stiffness of the wing structure remains constant.

The aero-elastic distortion due to ailerons can be divided into three categories:

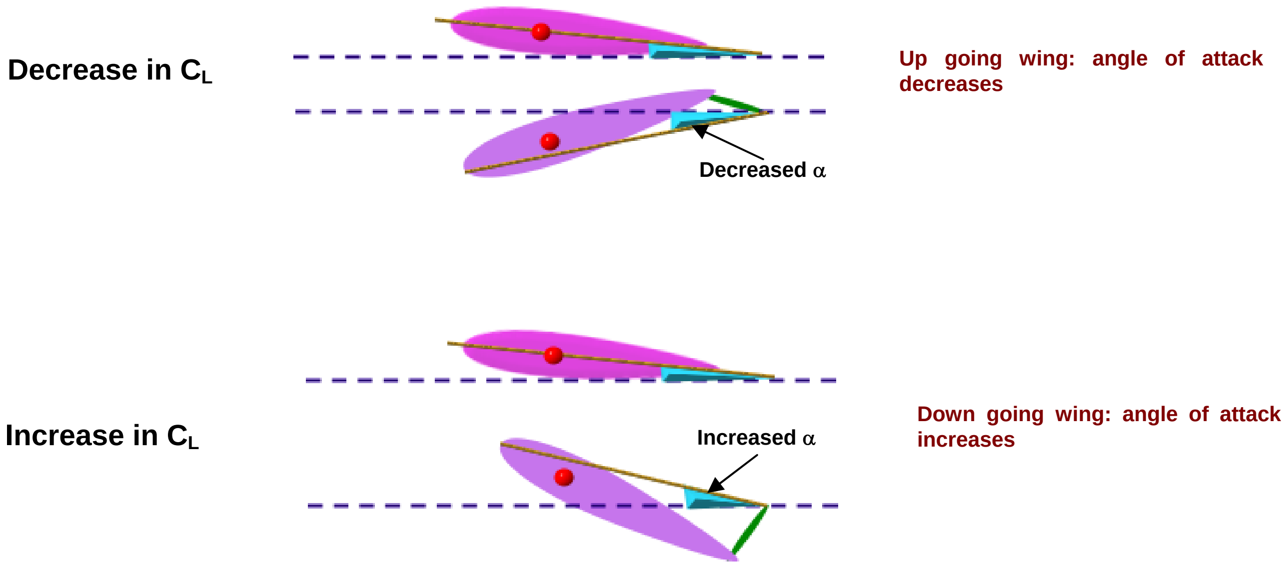
- Aileron Reversal
- Torsional Aileron Flutter, and
- Flexural Aileron Flutter.

AILERON REVERSAL

When the aileron is deflected the wing structure will want to rotate round the torsional axis. The torsional rigidity of the wing structure will prevent the distortion at low speeds, but at high speeds the aileron power overcomes this rigidity and the wing begins to twist.



As the wing begins to twist, the angle of incidence is changed and on the up-going wing the angle of attack will decrease (leading to a decrease in C**L**), while on the down-going wing the angle of attack will increase. The overall effect is that the roll rate is reduced at high speeds.

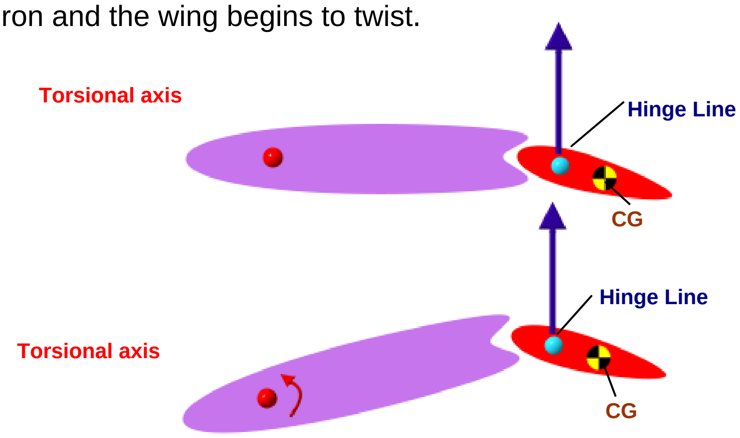


When the reversal speed is reached, the $\mathbf{C_L}$ increase due to the aileron deflection is nullified by the opposing twisting moment of the wing. The lift from both wings will be the same - despite the aileron deflection - ***and the roll rate will be zero***. At still higher speeds, the aircraft will roll in the opposite direction than the aileron is deflected. **(The reversal speed is normally outside the safe flight envelope of an aircraft. However at high forward speeds the effects of aero-elastic distortion may become apparent as a reduction in roll rate.)**

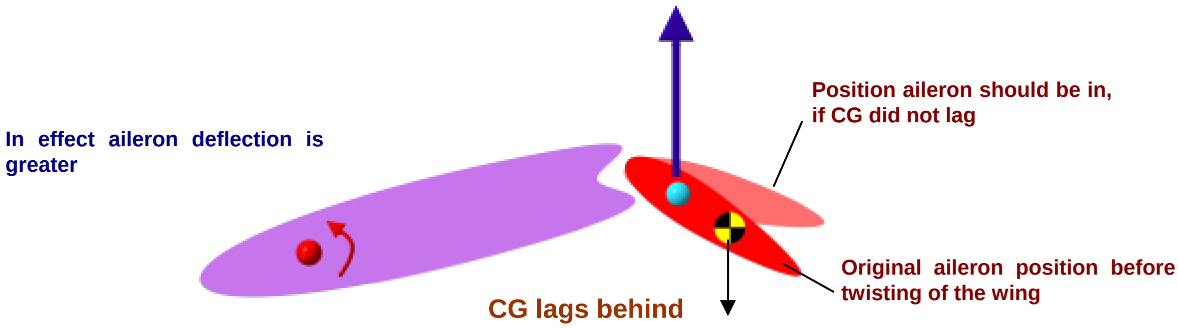
TORSIONAL AILERON FLUTTER

Torsional Aileron Flutter is also due to a twisting moment that is caused by the force an aileron exerts on the wing structure when deflected.

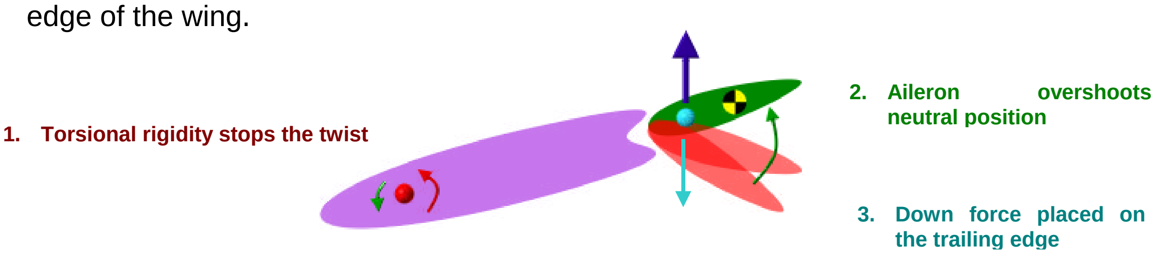
When the aileron is deflected downwards, an increased lifting force is exerted on the hinge line of the aileron and the wing begins to twist.



As the wing twists about the torsional axis, the trailing edge rises and takes the aileron up with it. As the CG of the aileron is behind the hinge line, it tends to lag behind due to its inertia. Aileron lift is increased and so is the twisting moment of the wing.



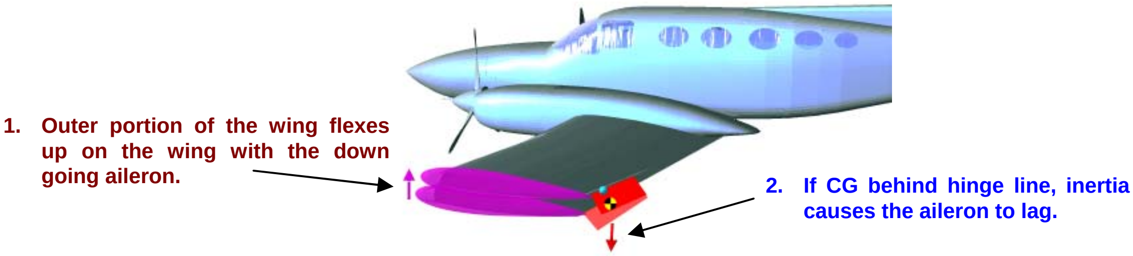
The torsional rigidity of the wing arrests the twisting moment imparted on it by the aileron force. However the air loads, the stretch of its control circuits and its upward momentum cause the aileron to overshoot the neutral position and place a down load on the trailing edge of the wing.



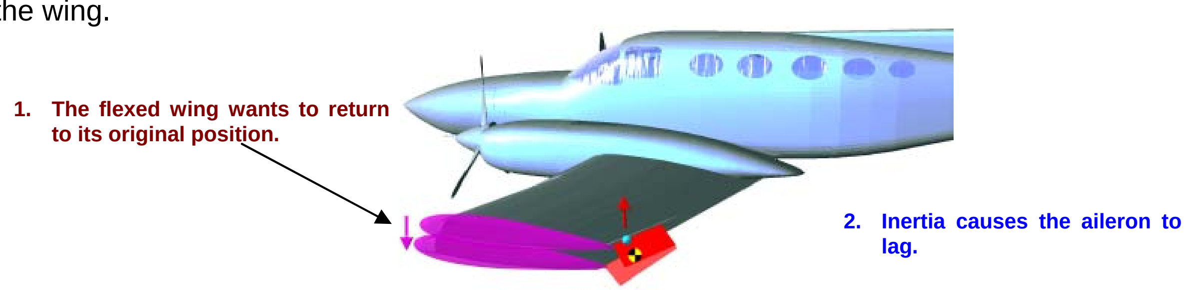
The wing stores the energy due to the twist and the aileron reverses the aerodynamic load due to its new position. These two factors now cause the wing to twist in the opposite direction and repeat the cycle.

FLEXURAL AILERON FLUTTER

Flexural aileron flutter is similar to torsional flutter, but is caused by the lagging ailerons as the outer portions of the wings flex or bend when ailerons are deflected.



When the ailerons are deflected down, the outer portion of the wing will flex up. If the CG is behind the hinge line, inertia will cause the aileron to lag behind and move down as the wing moves up. The aerodynamic force produced by the aileron further assists the flexing motion of the wing.



As with torsional flutter, the wing stores the energy due to the flexing and arrests the movement. The wing now wants to return to its original position and as it moves down, the aileron lags behind again and the flexing moment takes place in the opposite direction. This sets up an oscillating motion of the wing tips. ***(Oscillating motion:** **When flexural aileron flutter sets in, the wing tips start to oscillate and tend to follow a path that represents a sine curve. If re-enforced or undamped, the oscillation can be come violently destructive).***

PREVENTION OF AERO-ELASTIC DISTORTION

All forms of flutter are extremely dangerous because the extent of each successive vibration is greater than that of its predecessor. A structure may bend beyond its elastic limit or even fail within a few seconds if the flutter is not prevented. It is therefore important that aero-elastic distortion be prevented.

Mass-balancing. Mass-balancing the ailerons so that their CG is on or slightly ahead of the hinge line will prevent torsional aileron flutter. The distribution of the weight along the complete leading edge of the aileron ***(in the form of a leading edge spar)*** will stiffen the aileron and prevent a concentrated weight starting a torsional vibration.

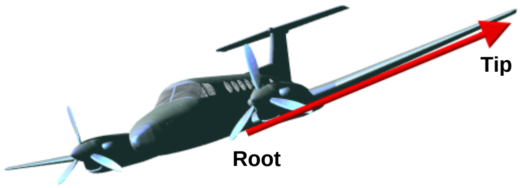
Irreversible controls. Controls that are irreversible such as powered controls will prevent flutter because the movement of the aileron in the opposite direction than the deflection is not possible. ***(Normally aircraft with fully powered controls and no manual reversion, do not require balancing. Control surfaces of all other aircraft are mass-balanced to prevent aero-elastic distortion).***

Increase in structural rigidity. By strengthening the wing structure, the rigidity of the wing is increased, but this is normally accompanied by a hefty weight penalty.

AILERON RESPONSE AT LOW SPEEDS

It is important for an aircraft to stall progressively from wing root to wing for the following reasons:

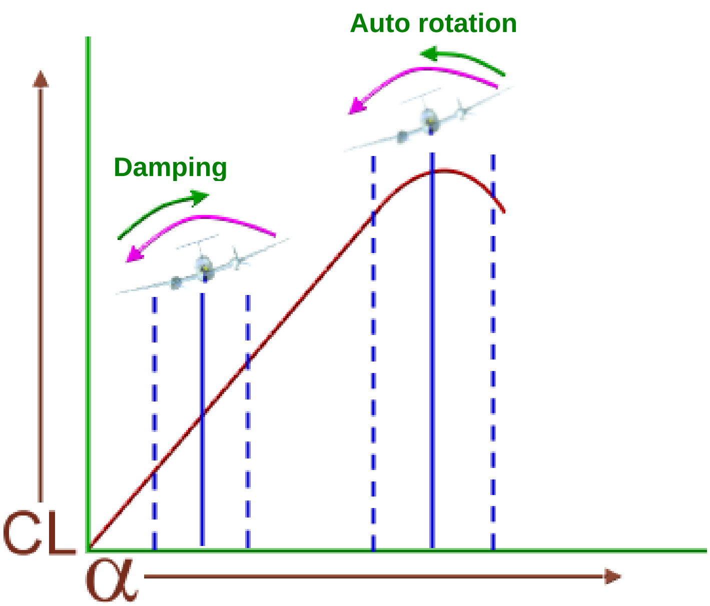
- To induce early pre-stall buffet symptoms over the tail surface.
- To retain aileron effectiveness up to the critical angle of attack.



- To avoid a large rolling moment that would arise if one wing tip should stall before the other (wing drop).

When ailerons are deflected down, it leads to an increase in camber and a slight decrease in critical angle for that section of the wing ***(normally the tip)***. It is therefore very important for the wing to stall from wing root to wing tip so as to retain aileron effectiveness right up to the stall.

Should the wing tip stall first and the effectiveness of the down-going aileron be lost, a roll reversal will not necessarily occur. The up-going aileron usually retains its effectiveness and will therefore still produce a conventional although lesser response.



The factor that has the greatest effect on aircraft response at high angles of attack is the damping in roll effect.

When an aircraft rolls at normal speeds, the angle of attack of the down-going wing is increased and of the up-going wing decreased; causing the damping in roll. At low speeds or close to the stall, the damping in roll effect is reversed and the change in rolling moments actually assists the rotation. This leads to what is known as **AUTOROTATION**.

At low speeds large deflections are necessary in order to achieve the desired rate of roll.

However, at low speeds a wing is normally already operating at relative high angles of attack.

At these low speeds and high angles of attack, an aileron that is deflected down will operate very close to the critical angle of attack and the following may occur:

- Aileron Snatch.
- Aileron Overbalance.

AILERON SNATCH

Aileron snatch usually occurs at or near the stall ***(or at high Mach numbers)*** and is caused by the rapid and continuous shifting of the centre of pressure of the aileron due to the disruption of the airflow over the surface. This results in a sometimes violent snatching or jerking movement of the control.

If at some stage the centre of pressure moves ahead of the hinge line towards the leading edge, the restoring moment of the aileron is lost and the snatch can be aggravated.

It can also lead to a rapid increase in the angle of attack of the aileron and the resultant force can be such that the control stick is literally snatched out of one's hand in the direction of the applied deflection.

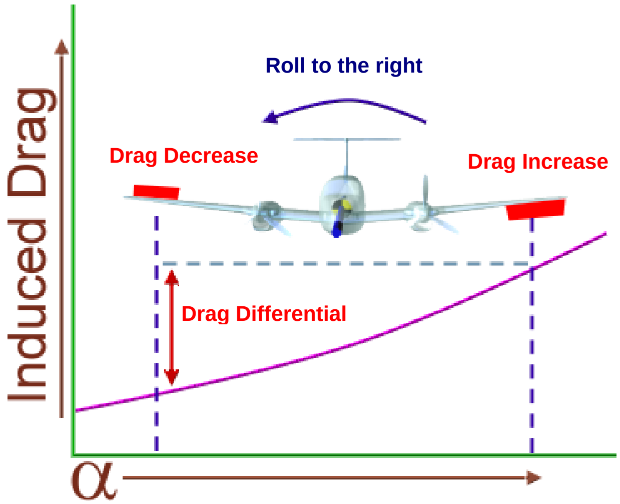
AILERON OVERBALANCE

On some aircraft the stick force required to increase the aileron deflection, reduces as the control angle of the aileron increases.

This is due to increased aerodynamic balance as the deflection angle increases and more of the section of the aileron ahead of the hinge line protrudes into the airflow. At some stage the control force required to increase the deflection angle will become zero. Beyond this deflection angle the ailerons will move to their full travel position of their own accord.

Overbalance may be confused with snatch, but remember that with snatch the control forces do not decrease gradually before the stick starts to move on its own - the onset is sudden and more often than not very violent. Aileron overbalance can occur fairly suddenly at any speed on aircraft not fitted with power-operated controls.

ADVERSE AILERON YAW



To explain this concept, we'll use the practical example of an aircraft that has applied aileron to roll to the right.

At the down-going aileron (up-going wing) the vortex drag and boundary layer drag increases.

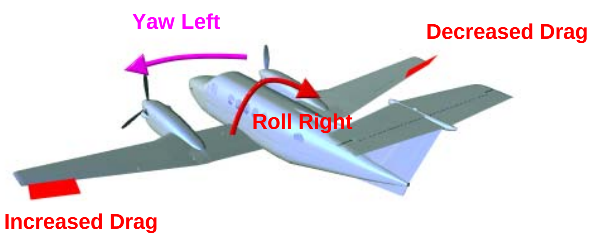
However, at the up-going aileron (down-going wing) the vortex drag decreases although the boundary layer drag may still increase.

Due to the change in the drag forces, a drag differential exists between the up- and down-going ailerons.

The drag differential produces a yawing moment that causes the aircraft to yaw in the opposite direction to the applied roll.

Adverse aileron yaw is a very noticeable secondary effect resulting from aileron application and an important reason for the incorporation of a rudder on an aircraft. It can however be reduced by including one or more of the following design features:

- ***Differential ailerons.***
- ***Frise-type ailerons.***
- ***Coupling of controls.***
- ***Spoilers.***



DIFFERENTIAL AILERONS

With differential ailerons, for a given stick deflection the up-going aileron ***(on the down-going wing)*** is deflected through a larger angle than the down-going aileron ***(on the up-going wing)***.

The effect of this is to increase the form drag on the up-going aileron to greater extent than on the down-going aileron. Therefore the drag differential is much smaller and the adverse aileron yaw is reduced.

Frise-type Ailerons

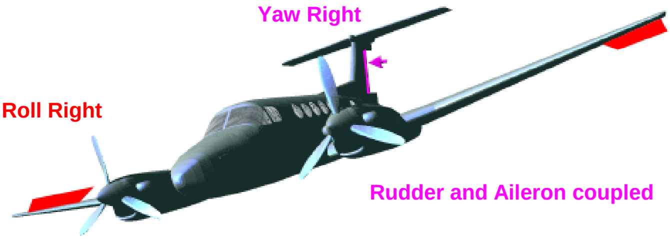
With this type of aileron the "nose" of the up-going aileron protrudes into the airflow below the wing when deflected.

This arrangement not only increases the drag on the down-going wing, but also assists the aerodynamic balancing of the ailerons.

COUPLING OF CONTROLS

When a control produces a response in a plane other than that desired, it is termed a cross-coupling response.

One way of solving this, is to couple the controls so that when ailerons are deflected for a roll to starboard, the coupled rudder also deflects to starboard.

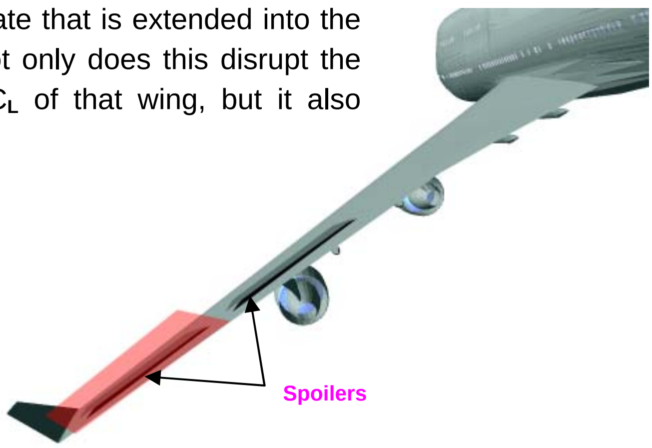


By coupling the ailerons and rudder, the rudder can produce an appropriate yawing moment in response to the ailerons being deflected. Some aircraft use this method to reduce or eliminate adverse aileron yaw.

SPOILERS

A spoiler is a device in the form of a flat plate that is extended into the airflow on top of the down-going wing. Not only does this disrupt the airflow over the wing and decrease the C_L of that wing, but it also increases the form drag of that wing.

Some aircraft use spoilers as the only means of lateral control at high speeds. The increase in drag when deployed, yaws the aircraft into the turn and not out of the turn as ailerons do.



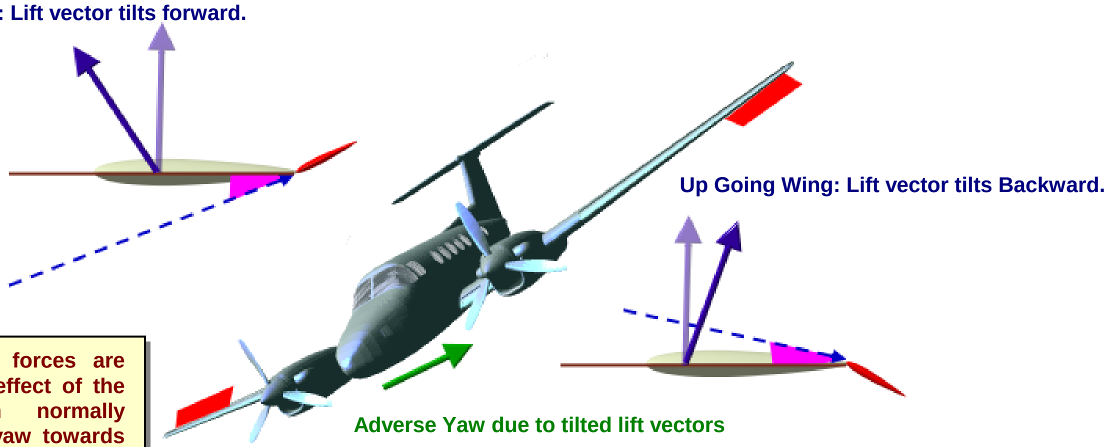
Drag due to spoilers: Spoilers can also be used as airbrakes or lift dumpers. When the spoilers on both wings are deployed together during flight, they act as airbrakes; although there are usually also additional spoilers that are only used for that purpose. During landing spoilers normally act as lift dumpers that destroy the lift over the wing to shorten the landing roll.

Lateral control: Most modern fighters and jet transport aircraft use spoilers as the primary means of lateral control. Only at low speed are the spoilers used in conjunction with the ailerons. The advantage of using only spoilers is that the whole of the trailing edge of the wing can be used for high lift devices.

CROSS-COUPLING RESPONSE

The increase in angle of attack on the down-going wing also increases lift and drag whereas on the up-going wing lift and drag decreases due to the decrease in angle of attack. Keep in mind that by definition the lift force is perpendicular and the drag force parallel to the relative airflow on each wing.

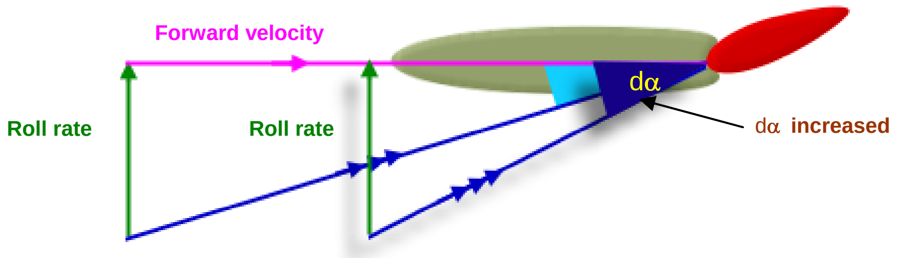
Due to the change in angle of attack, ***the lift forces tilt forward on the down-going wing*** and ***backward on the up-going wing***. The projections of these lift forces onto the yawing plane of the aircraft; produce an adverse yawing moment towards the up-going wing.



The effect of the lift forces are partially offset by the effect of the drag forces, which normally produce a favourable yaw towards the down-going wing.

If for a given roll rate ***(rolling velocity),*** forward speed is decreased, dα will increase. Thus, for a given roll rate, dα will be greatest at low air speeds.

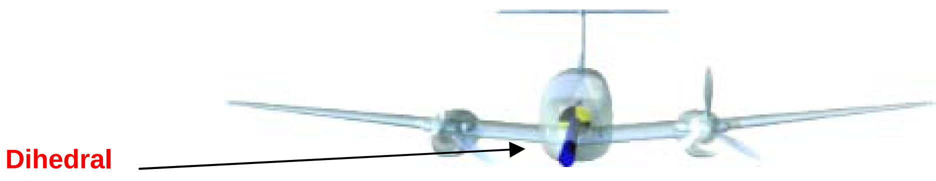
The adverse yaw due to roll, will therefore be greatest at low speeds, but will eventually become favourable at some high forward speed.



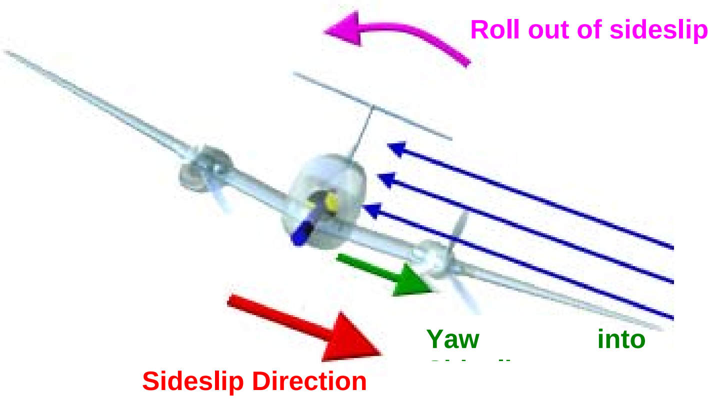
RESPONSE TO SIDESLIP

When an aircraft is in a sideslip, it is physically flying sideways while at the same time flying forward. In a sideslip to port, the airflow strikes the aircraft from the port side and the bottom. There are two effects that have an influence on the aircraft while in a sideslip.

As can be seen from the graphic, the airflow strikes the aircraft from below and therefore the aircraft will tend to roll out of the sideslip due to the "dihedral effect" of the wings.

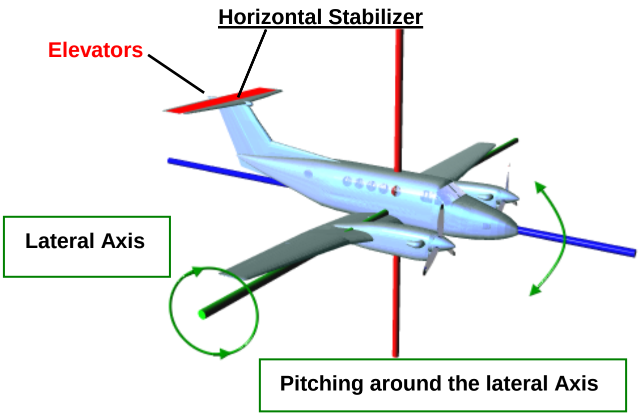


However, on conventional aircraft the roll out of sideslip due to the "dihedral effect" is dominated by the yaw into the sideslip. This is due to the airflow striking the rear of the fuselage and vertical stabilizer ***(Keel of the aircraft).***

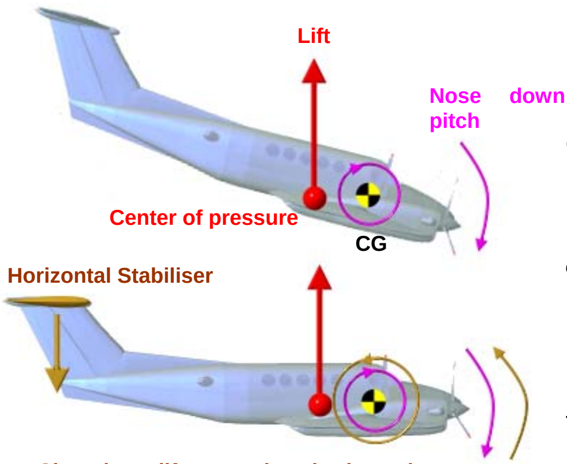


ELEVATORS

INTRODUCTION



The elevators control the pitching moment of the aircraft about its lateral axis.

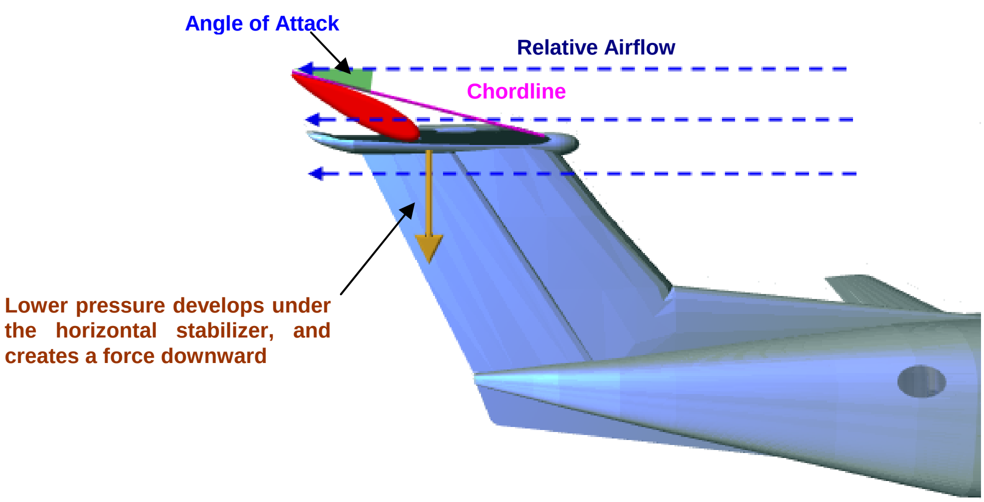


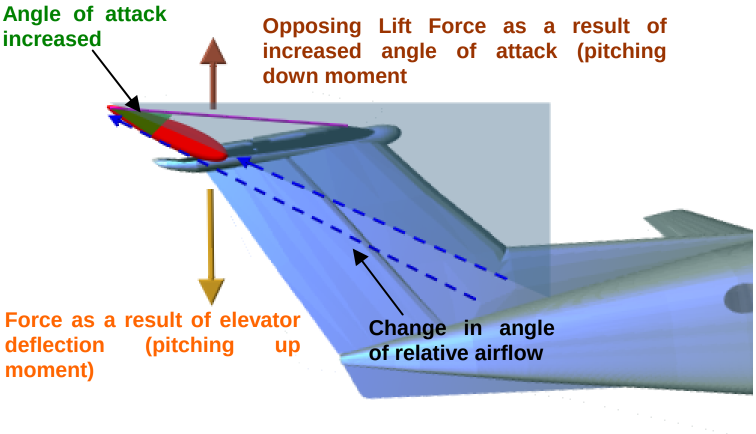
Changing lift on the horizontal stabilizer, the pitch can be altered

In normal balanced flight, the aircraft has a nose down pitching moment as the centre of pressure is located behind the centre of gravity. This moment is opposed by the horizontal stabilizer ***(of which the elevator is usually part).***

By changing the amount of lift developed by the horizontal stabilizer, the pitching moments about the lateral axis can be altered as required.

When an elevator is deflected upwards in order to create a pitching moment, it creates a local low pressure underneath the horizontal stabilizer that acts in the opposite direction to the lift developed by the main wing.





The force causing the tailplane to move downward alters the angle at which the RAF strikes the horizontal stabilizer; which results in an **increase in angle of attack** on the horizontal stabilizer.

This increase in angle of attack has the result of either reducing the lift force created from the initial deflection, or creating a lift force in the opposite direction to the force created from the initial deflection. This opposing moment is known as damping in pitch.

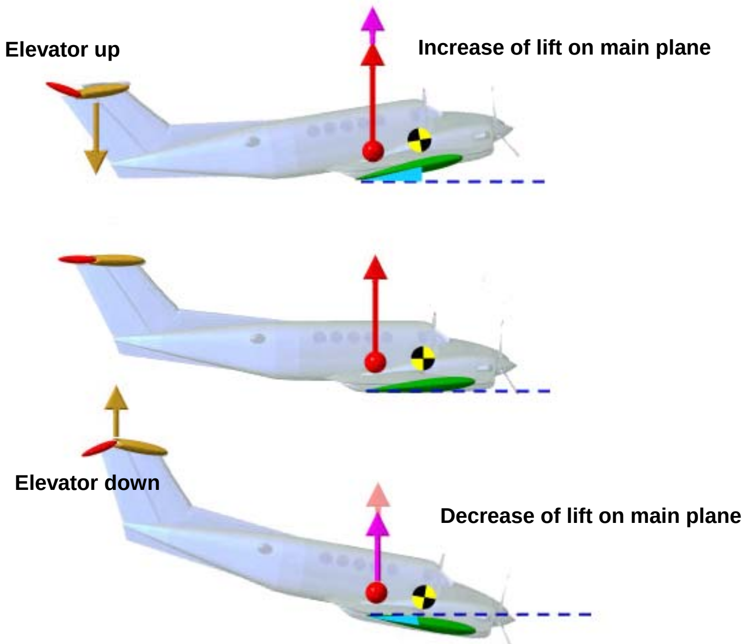
The response to an elevator deflection is a steady state change in the angle of attack of the aircraft with no transient time - thus no acceleration in rate of pitch. Whenever it is deflected it causes a steady change of attitude. **Elevators are therefore described as displacement controls**.

The pitching moment produced by the elevators is opposed by the damping in pitch as well as the longitudinal stability of the aircraft.

PRINCIPLE OF OPERATION

Elevators are normally free from undesirable characteristics. They are usually symmetrical in section with straight or concave sides and a favourable mass distribution.

If the elevator is deflected upwards the overall tail plane/elevator section is changed into an inverted aerofoil and this produces a measure of negative lift over the whole tail plane. The negative lift supplies a downward force, which results in a nose-up rotation around the lateral axis. The angle of attack of the main plane is increased and this in turn leads to an increase in lift. The opposite occurs when the elevator is deflected down.



FACTORS AFFECTING ELEVATOR RESPONSE

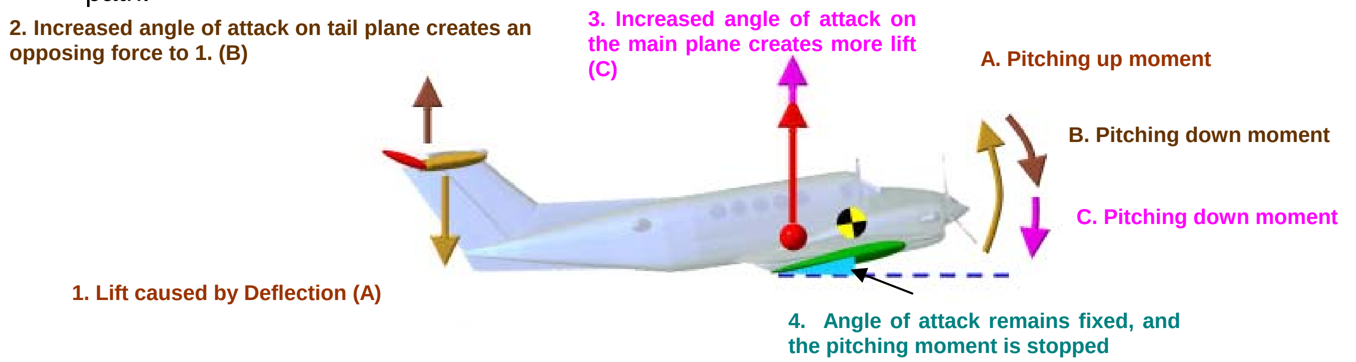
When a pilot makes a rearward movement on the control column or stick, the aircraft starts to rotate around its lateral axis (it starts to pitch). The response of the aircraft in the pitching plane is affected by the following factors:

- Longitudinal Damping.
- Position of the CG.
- Ground Effect.

LONGITUDINAL DAMPING

The pitching moment produced by the elevators is opposed by aerodynamic damping in pitch and longitudinal stability. Deflected elevators cause a rotation that increases the restoring moment ***(from both the tail and wing)*** and rapidly damps the moment produced by the elevator.

Due to this large damping force, the angle of attack remains constant ***(no further rotation)*** ***with a constant deflection***. and due to the increased lift, the aircraft tends to follow a curved flight path.



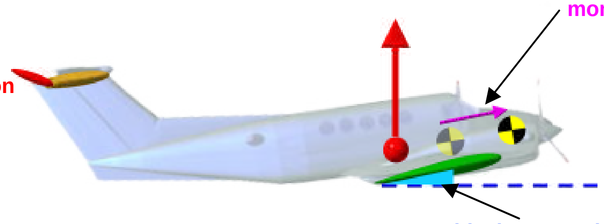
If the deflection is maintained, the aircraft will attempt to maintain this new angle of attack.

POSITION OF THE CENTRE OF GRAVITY

The position of the centre of gravity (CG) determines the tail moment arm. To ensure satisfactory handling throughout the entire speed range of an aircraft, the CG has to be kept within a certain limited range.

The further forward the CG moves, the more stable the aircraft becomes ***(because of the greater restoring moment of the tail and wing)***.

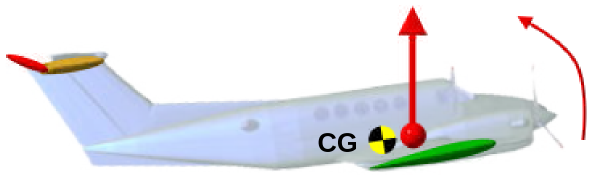
At a constant deflection angle, a smaller angle of attack on the main plane results, the further forward the CG moves. If the CG moves too far forward, the aircraft becomes excessively stable and the elevator will become more and more ineffective as speed decreases.



ANGLE OF ATTACK

- The rate of pitch or response per constant elevator deflection decreases as the CG moves forward; therefore the angle of attack change per unit time reduces.

- If the wing lift vector should move forward to a position ahead of the CG, the lift vector will act as a balancing moment instead of a restoring moment. With the lift force now acting as a balancing moment, damping is reduced and the aircraft tends to become very unstable. With the aircraft in an unstable condition, a small elevator deflection will produce a very rapid pitching moment. This pitching moment will increase in force until the pilot has to push forward on the control stick to hold a constant angle of attack.

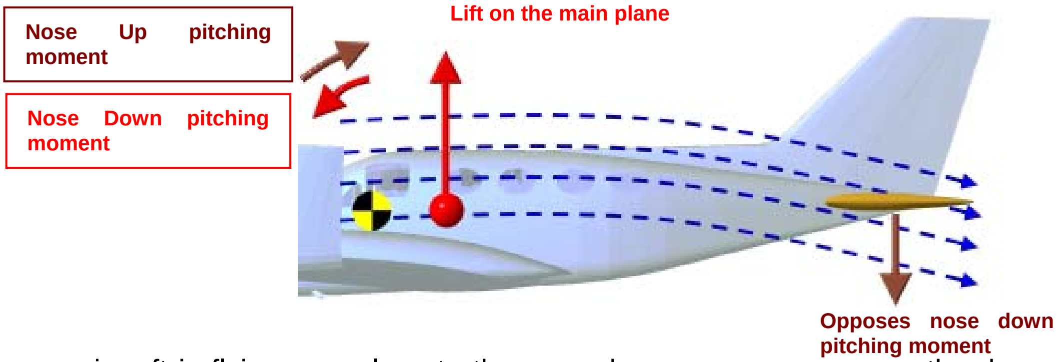


UNSTABLE AIRCRAFT

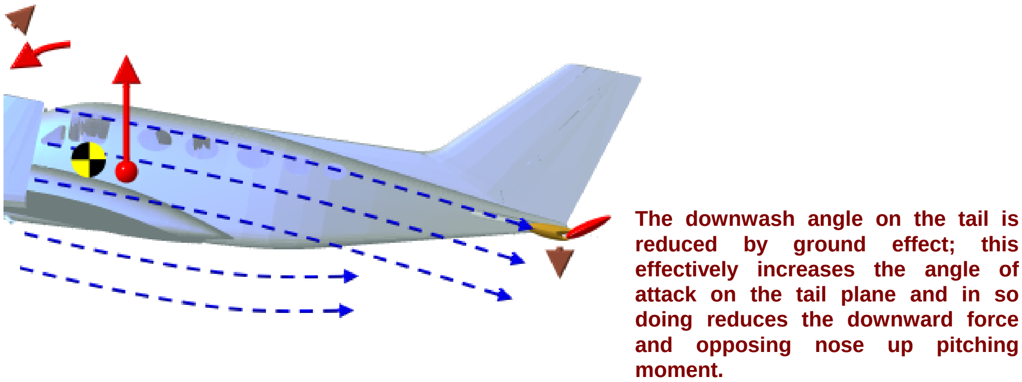
Modern high performance aircraft such as the F-16, F-18 and the new generation fighters such as the Rafale and Eurofighter 2000 are very unstable in this sense - in order to give them excellent manoeuvrability. These type of aircraft can however not be flown without some sort of stability augmentation system.

GROUND EFFECT

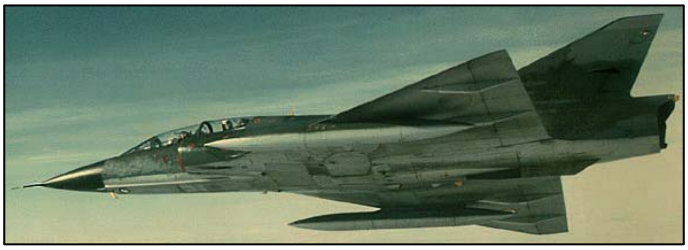
When an aircraft is in straight and level flight at altitude, the downwash on the tail plane provides longitudinal stability, by creating a lift force below the tail surface ***(opposing the nose down pitching moment)***.



When an aircraft is flying very close to the ground ***(during landing or take-off)***, the downwash is reduced considerably and the elevators tend to feel less responsive. An aircraft will remain in ground effect for as long as it is flying at a height that is less than half a wingspan above the ground.



The opposing nose up pitching moment ***(tail down moment)*** is also reduced by the forward movement of the CG. In order to compensate for this, some aircraft require a backward movement of the CG (usually by transferring fuel) to ensure that the elevator movement is sufficient to achieve the correct landing attitude.



This reduced tail down moment means that larger elevator deflection is required to achieve the landing attitude than is required to reach the same attitude at height.

ELEVATOR REQUIREMENTS

Elevators should satisfy the following requirements:

- Elevators must provide sufficient control in pitch to be able to pitch the aircraft to the angle of attack for C_{Lmax}.
- Elevators must provide sufficient control in pitch to enable the aircraft to take-off.
- Elevators must provide sufficient control in pitch to enable the aircraft to land.

PITCHING THE AIRCRAFT TO C_{LMAX}

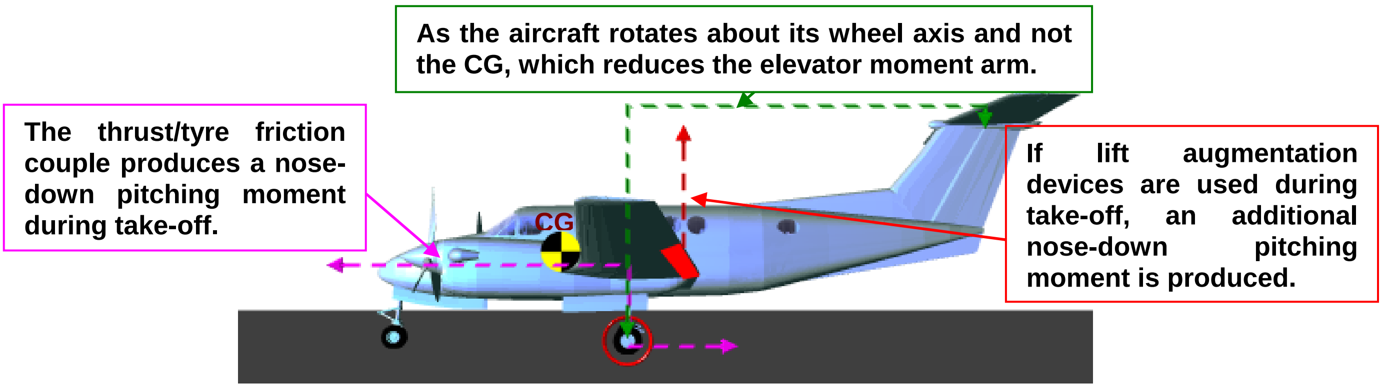
Most modern aircraft have the ability to reach the C_{Lmax} of the wings in flight. To be able to do this, the elevators must produce enough negative lift to overcome the restoring moments of both the tail and wings at high angles of attack.

A large enough tail-down pitching moment can be produced to rotate the aircraft to the critical angle of attack and stall the aircraft if so desired. It is essential that training aircraft be able to reach the angle for C_{Lmax} so that pilots can be shown how the aircraft handles and reacts.

Some tricycle undercarriages, light aircraft used by flying clubs, have undersized and underpowered elevators to make the aircraft virtually "unstallable" ***(the aircraft cannot be flown to the critical angle)***.

SUFFICIENT PITCH ON TAKE-OFF

In order to keep the take-off speed as low as possible, the aircraft must be pitched to the highest practical angle of attack possible. To achieve this large pitching moment, the elevator must produce large amounts of negative lift. There are however some factors that reduce the pitching moment during take-off:



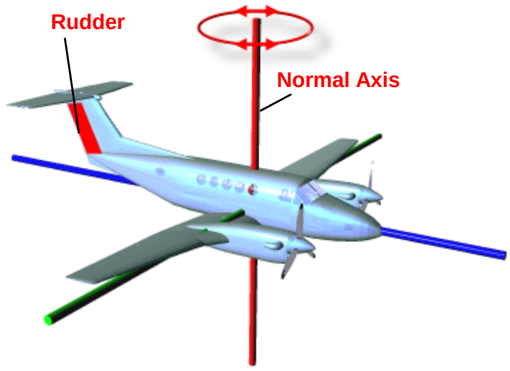
SUFFICIENT PITCH ON LANDING

If the elevators can produce a large enough tail-down pitching moment during take-off, there is usually no problem with insufficient elevator response during landing *(even when ground effect is taken into account)*.

With some tailless delta aircraft the forward movement of the CG can present problems. However, the forward movement of the CG is countered by transferring fuel aft and so ensuring sufficient elevator moment during landing.

RUDDERS

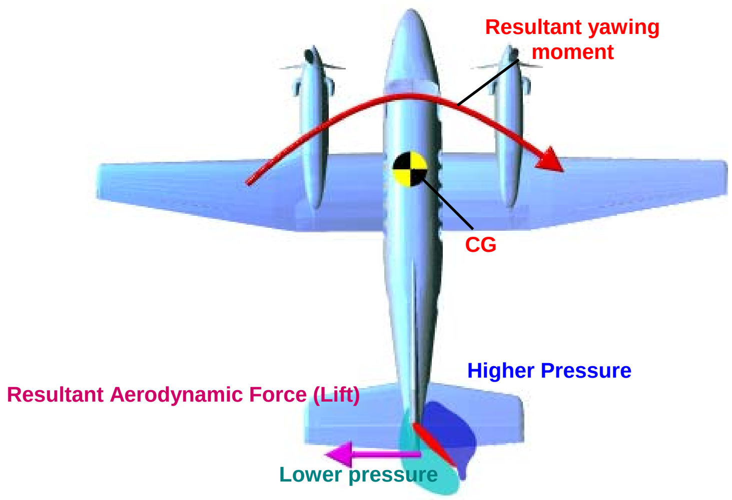
INTRODUCTION



The rudder control surface controls the yawing moment of an aircraft around the normal axis and is controlled by the rudder pedals. Because the rudder deflection produces a steady change of direction about the normal axis it is known as a displacement control.

The rudder is part of the vertical stabilizer and when not deflected, helps to keep the aircraft directionally stable.

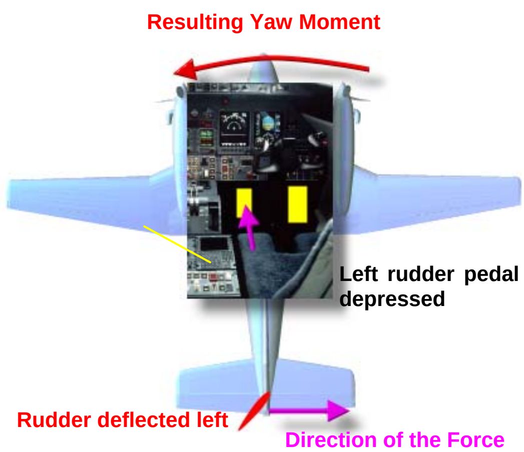
The rudder causes a lower pressure to form on the one side and a higher pressure to form on the other side of the vertical stabilizer when deflected.



This lift produced on the one side of the vertical stabilizer will in turn cause the aircraft to yaw about its normal axis, which runs through the C of G.

The rudder does not necessarily have to be a symmetrical aerofoil section. The slipstream from a single-engine, propeller driven aircraft causes the whole aircraft to yaw to one side. If the rudder is then designed as a cambered aerofoil section, the lift produced will cancel out the slipstream and the aircraft will be in equilibrium.

PRINCIPLE OF OPERATION



The rudder is essentially an aerofoil that is hinged at the rear of the vertical stabilizer and connected to a rudder bar.

If the left pedal is depressed, the rudder will be deflected to the left.

Due to the aerodynamic force on the vertical stabiliser of the aircraft, it will move to the right, but the pilot sees a yaw to the left.

As with the other primary controls, rudder effectiveness increases with an increase in speed, with large rudder deflections being required at low speed.

<u>The rudder has the following functions</u>:

- Cancellation of unwanted yaw effects.
- Directional control during take-off.
- As an aid to directional control in flight.

FACTORS MODIFYING RUDDER RESPONSE

The response to rudder deflections is modified by the following factors:

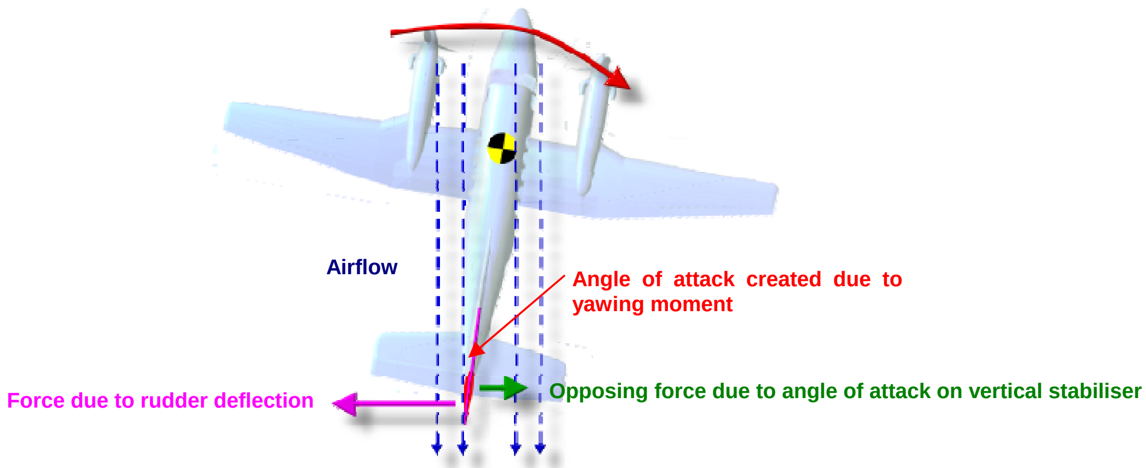
- Damping in yaw.
- Position of the Centre of Gravity.
- Yaw induced roll.
- Effect of EAS.

AERODYNAMIC DAMPING IN YAW

Opposing of the yawing moment is known as ***damping in yaw*** and only takes place while the aircraft is yawing.

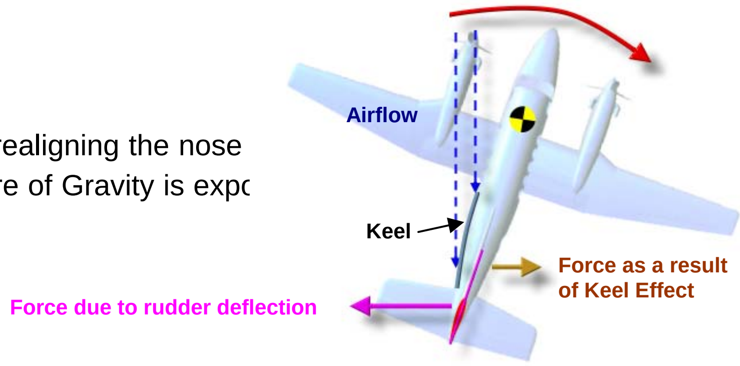
ANGLE OF ATTACK ON THE VERTICAL STABILISER

As the aircraft yaws about its vertical axis, the vertical stabilizer now has an angle of attack, which previously did not exist ***(or if there was one, it was smaller).*** This angle of attack on the vertical stabiliser causes a force in the opposite direction to the force created by the rudder deflection.

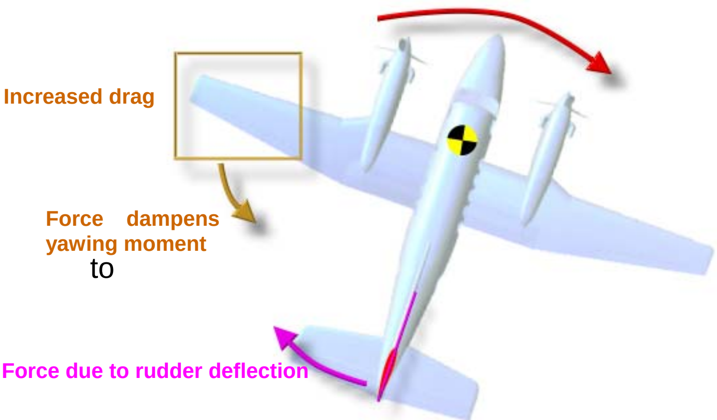


KEEL EFFECT

The keel of the aircraft also assists in realigning the nose the part of the aircraft behind the Centre of Gravity is expo is "pushed" in the opposite direction.



INCREASED DRAG

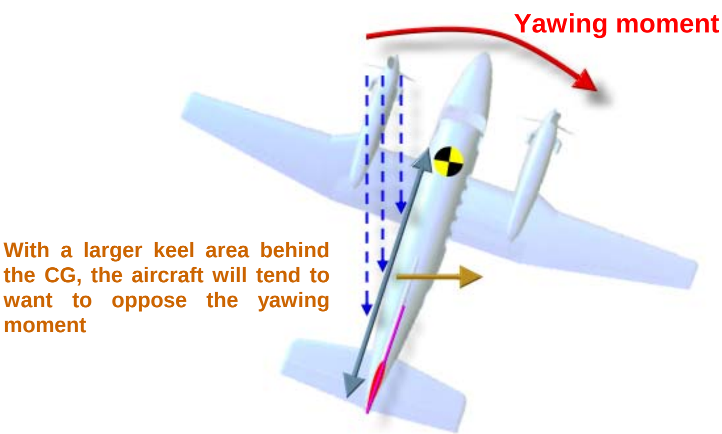


to

As the outside wing is moving faster, it develops more lift and therefore more drag. This increase in drag will also tend damp the yaw of the aircraft.

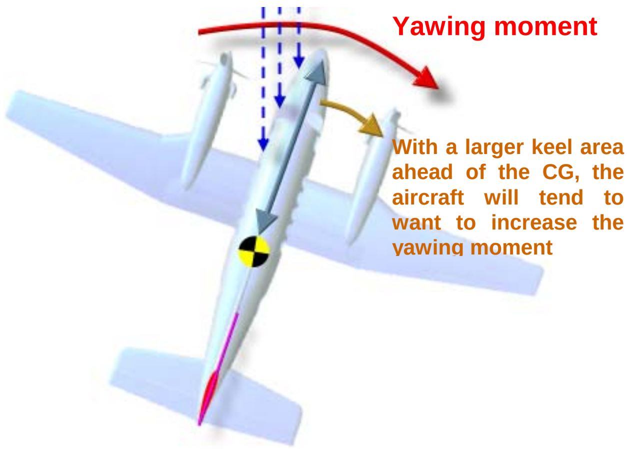
POSITION OF THE CENTRE OF GRAVITY –

The position of the CG plays an important role with the application of rudders. The amount of keel surface of the aircraft ahead or behind the CG causes either a stabilizing or destabilizing moment.



As the CG moves forward, the keel surface aft of the CG increases. This will tend to produce a stabilizing moment further aft that will want to reduce the yaw angle. **(As the CG moves forward, the stabilizing moment will necessitate a large rudder deflection to maintain the yaw.)**

With a rearward movement of the CG, the keel surface in front of the CG increases. The slightest rudder deflection causes the lift developed by the fuselage to produce the destabilizing moment that will automatically increase the yaw angle. **(With a rearward movement of the CG, the destabilizing moment will necessitate a large opposite rudder deflection to prevent any further yawing moment).**



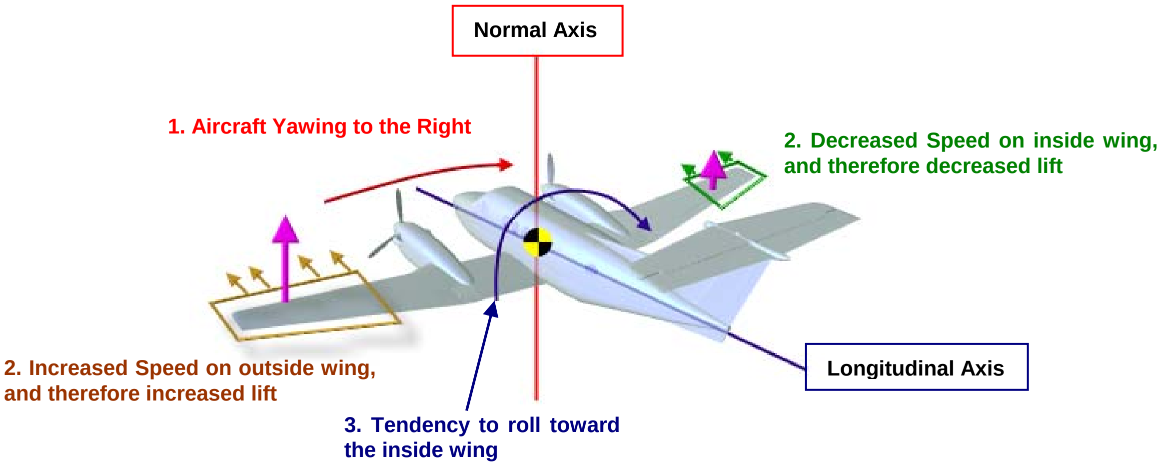
Excessive Increase in yaw angle

When the yaw angle is increased excessively ***(as with a rearward positioned CG),*** the sideways lift force produced by the fuselage will increase even more. If this continues the aircraft will be presented broadside into the flow. This is termed "side swapping" by the Americans and such a situation is obviously very dangerous.

YAW INDUCED ROLL

Yaw induced roll, is simply the tendency of the aircraft to want to roll as a direct result of the yawing moment of the aircraft. This roll with yaw has greatest effect at low speeds/high angles of attack.

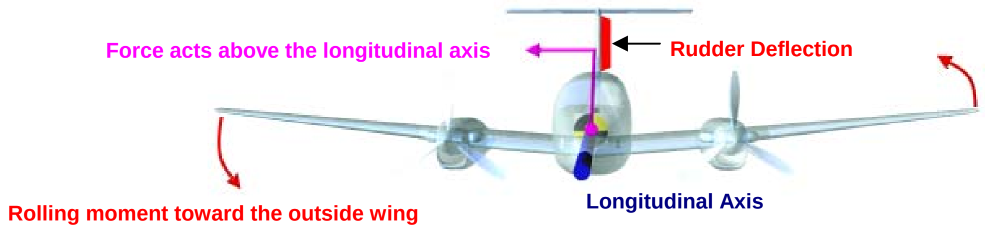
When rudder is applied and the aircraft yaws, the EAS of the outer wing increases while the EAS of the inner wing decreases. The EAS differential causes a lift differential and the outer wing produces more lift than the inner wing due to the difference in speed. This lift differential produces a rolling moment in the direction of the yaw.



Rudder is often used to pick up a dropped wing at low speeds. When the inside wing stalls and opposite rudder is applied, the yawing moment accelerates the inside wing, increases lift and raises the wing.

Rudder Induced Roll

Rudder induced roll is normally found on aircraft with a tall fin and rudder or on T-tail configured aircraft. When a rudder deflection is made, it invariably produces a rolling moment due to the resultant control force acting above the longitudinal axis of the aircraft.



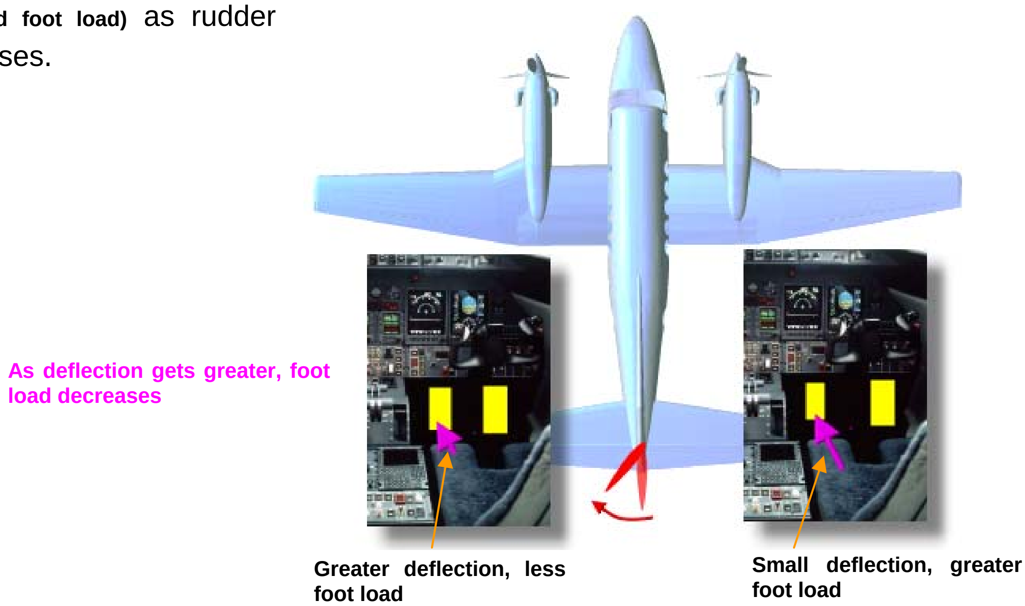
Although the effect is small it does play an important role on aircraft with tall fins and rudders. Rudder induced roll can be eliminated by cross-linking the rudder and aileron circuits.

EAS EFFECTS

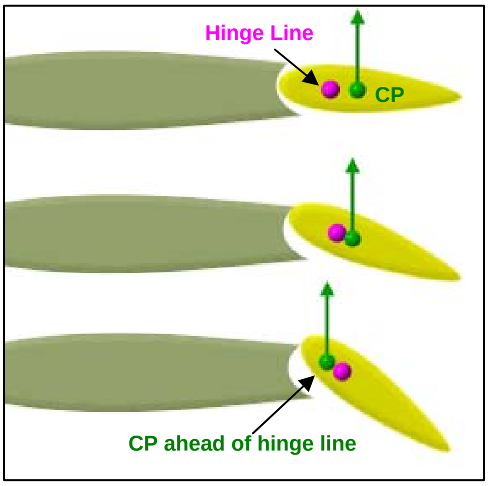
One of the factors which effect control effectiveness is speed. An increase in speed increases control effectiveness. This means that, for a constant control deflection, an increase in speed will produce an increased aerodynamic force.

RUDDER OVERBALANCE

Rudder overbalance is indicated by a progressive lessening of the force required to deflect the rudder **(decreased foot load)** as rudder displacement increases.



On some aircraft the onset of rudder overbalance is associated with a fluctuation of the rudder foot loads ***(forces required to deflect the rudder vary).*** This is known as ***"rudder tramping"*** and if the yaw is increased any further, overbalance may



If the aerodynamic balance is too great when the rudder is deflected, the effectiveness of the balance will increase at larger deflection angles. As the rudder deflection angle increases, the CP also moves and if the CP moves forward of the hinge line, the rudder may lock hard over to the full deflection position.

LARGE RUDDER DEFLECTIONS

On multi-engined aircraft slight overbalance may be experienced under asymmetric power conditions when large amounts of rudder trim are used to reduce the foot load of the pilot. To prevent any further overbalance, trim should be reduced.

At large yaw angles ***(such as when performing a sideslip),*** the fin may stall and rudder control and directional stability will deteriorate suddenly. The only recovery action is to reduce the sideslip by banking into the yaw. By converting the sideslip into a turn, the fin will un-stall and rudder control and directional stability will be regained.

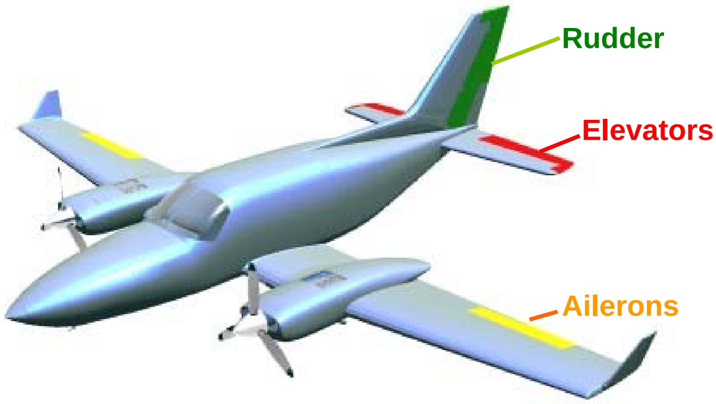
Control effectiveness varies, as EAS^2 and therefore the rudder will give a greater yaw rate for a given deflection at a higher speed. However, the higher the speeds, the greater the force required to obtain the same deflection from the rudder ***(only with conventional systems).***

Most aircraft are under-balanced at higher speeds. The optimum yaw rates will probably be found in the medium EAS range due to the balancing of the controls.

SECONDARY CONTROL SURFACES

INTRODUCTION

An aircraft has three main control surfaces to fly with; rudders, elevators and ailerons.



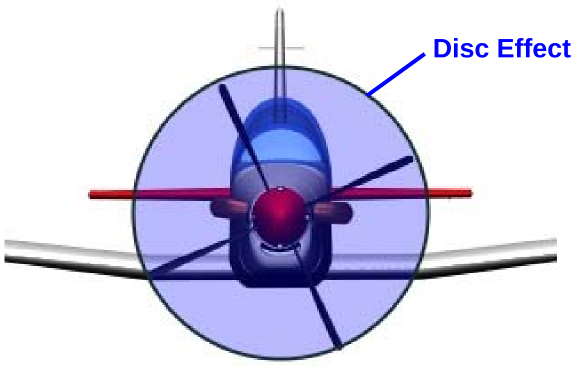
Aerodynamic forces exert heavy forces on these control surfaces and an aircraft can not be flown with these controls alone for a long period of time without leading to exhaustion.

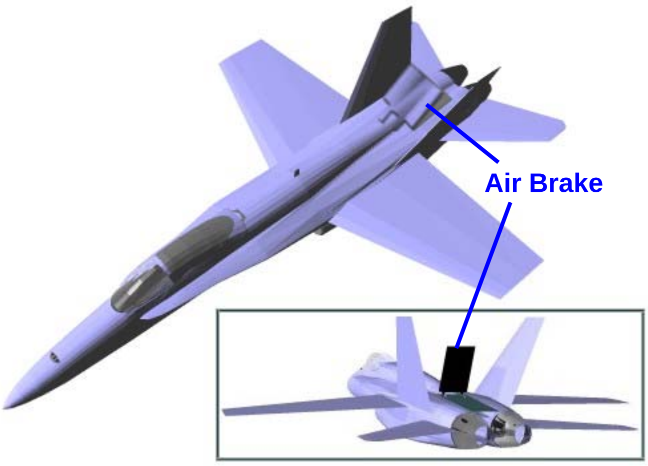
Secondary Control Surfaces provide assistance to help cope with these forces. These controls usually form part of the primary control surfaces, but can also be in the form of extra controls that will assists in manoeuvring the aircraft in certain ways.

AIR BRAKES

The two aircraft featured below, one driven by a jet engine and the other driven by a propeller, have very smooth design lines that produce as little drag as possible.

If both these aircraft should decrease the power to reduce the speed, the propeller aircraft has the advantage in that the propeller produces a **disk effect** that increases the drag and thereby decreases the speed at a high rate.



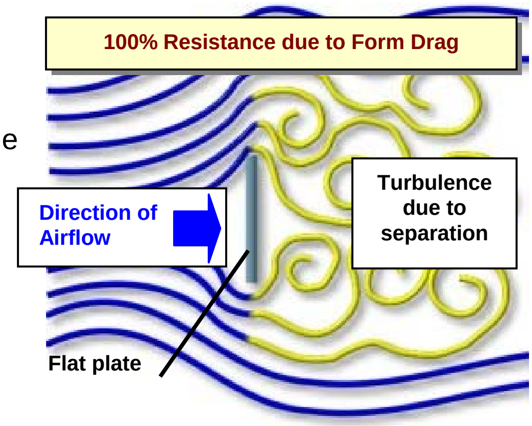


The jet aircraft on the other hand, with no propeller drag, will take much longer to reduce speed. If it eventually reaches the desired lower speed, any slight downward flight path will again increase the speed immediately.

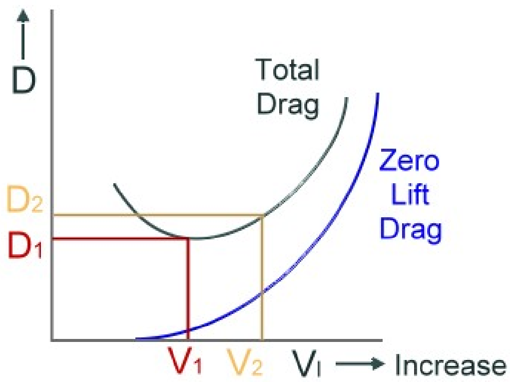
Because jet aircraft have no propeller drag, a device called an **Air Brake** is used to increase the drag on the aircraft at will, thereby decreasing the speed more rapidly or regulating the speed in a descent.

An air brake forms an integral part of the airframe or wings and cannot be seen on the aircraft when it is not extended. Some aircraft lower the undercarriage partially or fully to increase drag and in so doing obtain the same effect.

An air brake, when extended, will have the same effect as a flat plate standing 90º into the airflow. The flat plate and also the air brake produce form drag.



Form drag is a part of Zero Lift Drag and from the zero lift drag and total drag curves we can make the following conclusion:



If an air brake should be extended at speed V1 it will produce a total drag value of D1.

If the air brake should be extended at speed V2 it will produce a total drag value of D2.

With D2 greater than D1 it can therefore be seen that an air brake produces more drag at higher speeds at a given altitude.

In general air brakes are small, but produce considerable drag at high speeds. Refer to the following example of an aircraft flying at sea level with the air brake extended. The air brake has a drag coefficient of 1.2 and a total area of 2.5 sq ft.

With the aircraft flying at a 120 kts, the air brake produces 330 lb of drag.

If the aircraft however flies at 500 kts, the air brake will produce 5700 lb of drag.

Speed = 120 kts

Air Brake Drag = 330 lb

Speed = 500 kts

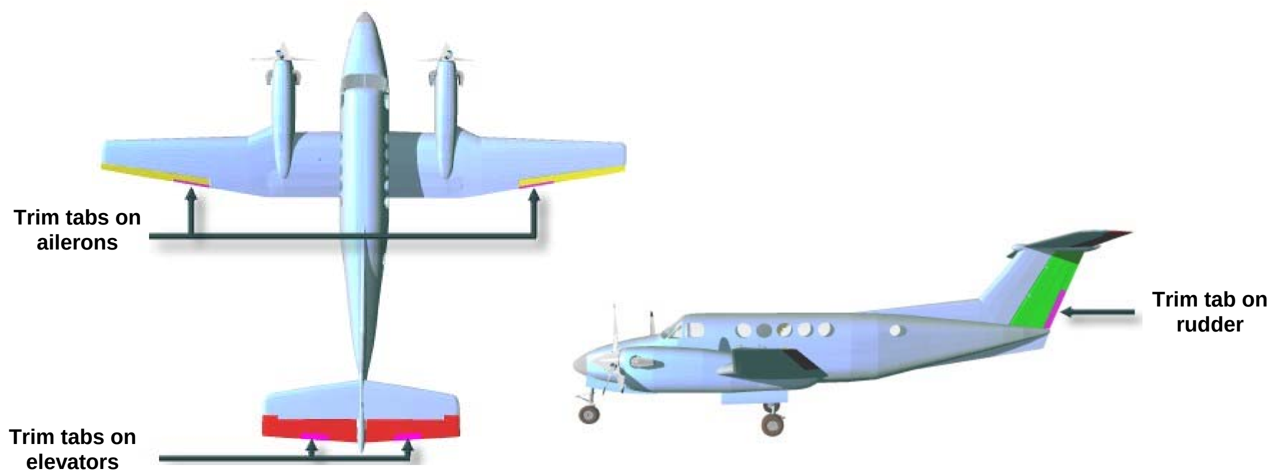
Air Brake Drag = 5700 lb

Looking at decelerating time, an aircraft at low altitude will take 2 min 58 sec to decelerate from 400 kts to 150 kts without the air brake extended, but power off. With the air brake extended, the same aircraft will take 1 min 27 sec to decelerate from 400 kts to 150 kts.

Air brakes are supposed to produce drag alone, but the opening of most air brakes are accompanied by a buffet and/or pitching moment *(either nose-up or nose-down)*.

TRIM TABS

Trim tabs are small-hinged surfaces and are normally situated at the trailing edges of the primary control surfaces.



Trim tabs can be fixed or adjustable in flight. The cross section and characteristics of a trim tab are similar to that of a wing, but trim tabs are just physically smaller.

FIXED TRIM TABS

A fixed trim tab can only be adjusted on the ground and the correct position can be determined by executing one or two test flights.

When there is no stick force, the trailing edge of the main control surface will be controlled by the tab.

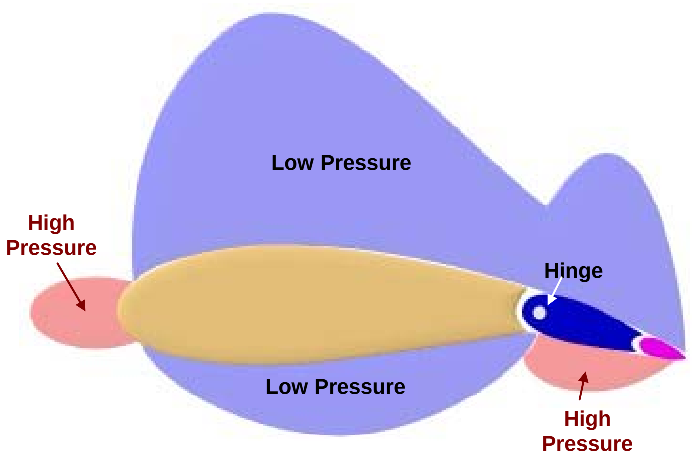
ADJUSTABLE TRIM TABS

Adjustable trim tabs are used to get rid of unwanted forces on the controls, such as those occurring with a power change or a change in the CG position.

The pilot can adjust these trim tabs electrically or by means of a trim wheel from the cockpit. A **rod** or a system of cables and pulleys control the actual movement of the trim tabs.

PRINCIPLE OF OPERATION

In order to effectively demonstrate the principle of operation of trim tabs refer to the following simple scenario: an aircraft is tail heavy and in order to maintain straight and level flight, the pilot needs to push forward on the control column thus deflecting the elevator down.

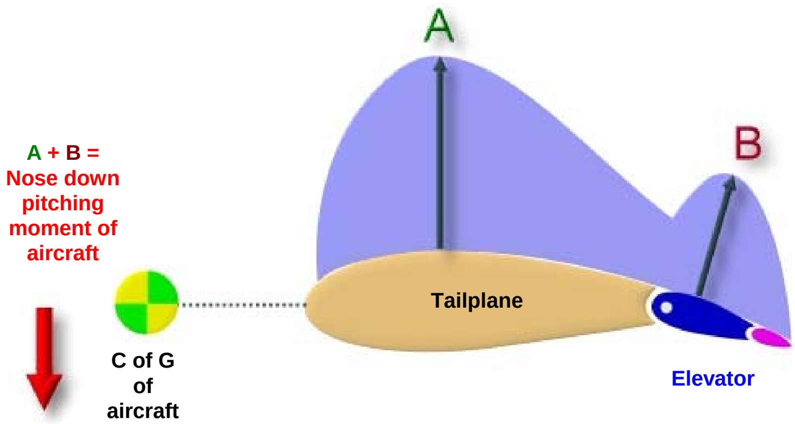


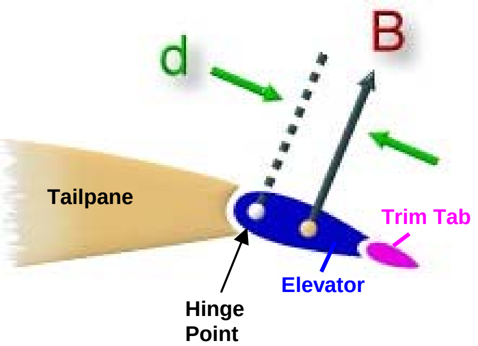
As the control surface is deflected downwards, it changes the camber of the tailplane.

When the camber of the tailplane increases, the value of the C_L also increases and therefore the lift over the elevator.

The elevator can be seen as an aerofoil on its own and therefore it produces its own low-pressure area and lift.

The lift force produced by the elevator down deflection (**B**) is added to the lift force produced by the tailplane (**A**). This total lift force (**A + B**) will cause an anti-clockwise pitching moment about the CG of the aircraft. It will cancel out the tail-heavy tendency and the aircraft will now maintain straight and level flight.





The elevator, like any other control surface, pivots around a point called the hinge point.

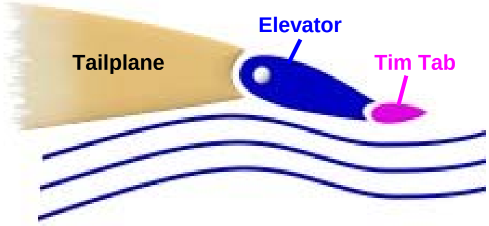
It therefore follows that the force applied on the control column by the pilot to maintain straight and level flight, will be force (**B**) multiplied by the moment arm (**d**).

Force = B x d

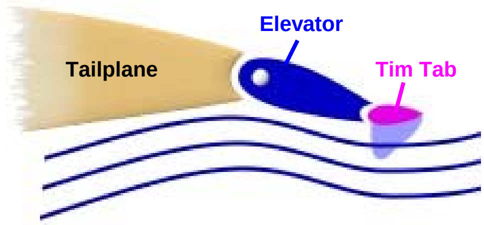
It's exhausting and impractical for a pilot to maintain a force (**B x d**) on the control column to keep the aircraft straight and level. It also affects his/her concentration and ability to take care of the other tasks in the cockpit.

To get rid of this force, the pilot has to trim the aircraft by deflecting the trim tab upwards.

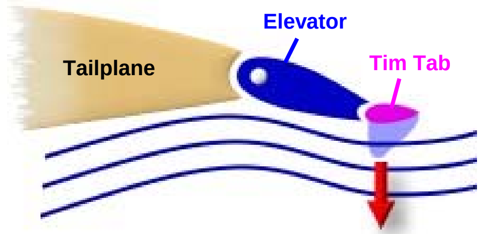
As with the elevator, the trim tab can also be seen as an aerofoil section on its own.



As the airflow follows the surface of the trim tab, its speed increases and that is accompanied by a decrease in pressure.



A **low-pressure area** forms under the trim tab with a relative high-pressure area above the trim tab.



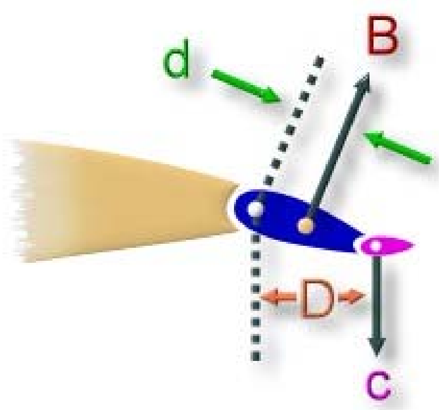
Air flow from a high-pressure area to a low-pressure area and this will cause a downwards **lifting force** on the trim tab.

The trim tab therefore exerts a force downwards about the **hinge point of the elevator** and the value of this force will be the product of force **c** and moment arm **D**:

Force = c x D

Elevator hinge point:

The reason the hinge point of the elevator is used for both the elevator moment arm and the trim tab moment arm, is because the force felt by the pilot on the control column, acts about the hinge point of the elevator. Any input by the pilot on the elevator will only act about the elevator hinge point and not the trim tab hinge point.



If the value of force (**B**) is bigger than force (**c**) and the moment arm (**D**) of the trim tab is longer than the moment arm (**d**) of the elevator, the following equation applies: **B x d = c x D**

At this point, where **B x d = c x D**, the downward force of the trim tab is holding the elevator in the deflected position and the pilot can therefore release the pressure on the control column. The trimmed aircraft will now maintain straight and level flight.

The effectiveness of trim tabs also varies with speed as with the primary control surfaces. This means that at low speeds a large deflection on the trim tab is needed to trim the aircraft and at high speeds a much smaller deflection of the trim tab is needed to trim the aircraft.

OTHER METHODS OF TRIMMING AIRCRAFT

- Spring-Bias Trimmers
- Variable-incidence and all flying tailplanes
- Variable-incidence wings

SPRING - BIAS TRIMMERS

In some light aircraft where there are no trim tabs, trimming is done by means of springs. These springs are connected to the control column / control stick.

Whenever the pilot has to exert a force on the control stick in a direction to maintain a certain attitude, he/ she can trim the aircraft by increasing the tension on one of the springs to keep the stick in the desired position.

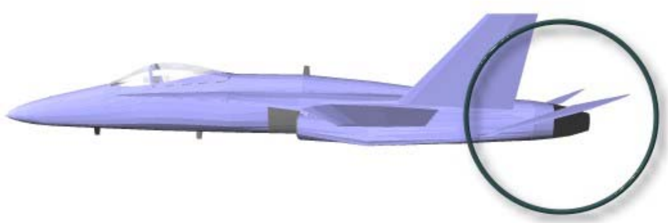
TAILPLANES

- **Variable - Incidence Tailplane**

With this concept the aircraft is equipped with a tailplane and elevator, but no trim tabs. When the pilot trims the aircraft, the whole tailplane will move. An example of an aircraft with a variable-incidence tailplane is the F4 Phantom.

- **All Flying Tailplanes**

A good example to look at is the **F - 18** where the whole tailplane acts as a control surface. When the pilot trims the aircraft, the whole tailplane will move. This reduces trim drag at high speeds.



VARIABLE - INCIDENCE WINGS

Pilots of swept-wing aircraft usually have the problem that their forward vision is limited during landing and take-off. The Vought F-8 Crusader ***(1960's vintage carrier-borne fighter aircraft)*** used variable-incidence wings to overcome this problem. With this concept the pilot could increase the angle of incidence of the wings during an approach for landing; which had the effect of lowering the fuselage and therefore the nose attitude of the aircraft.

Strictly speaking this is not a trimming device at all, but a means of altering the attitude of the aircraft during an approach in order to increase forward visibility for the pilot.

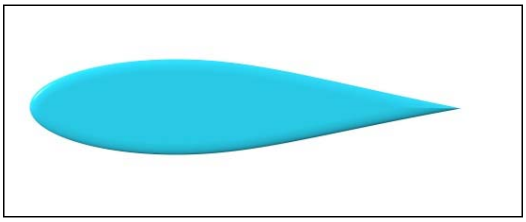
BALANCE TABS

Another method that is used to counter the aerodynamic forces on the control column is Balance Tabs. These tabs do what their names say i.e. they balance aerodynamic loads on the control surfaces.

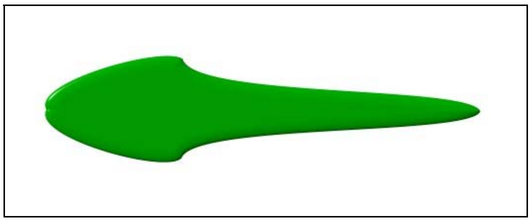
Balance tabs are not under the control of the pilot. The angles are changed automatically when the main control surface is moved.

Although the cross-sectional shape of the balance tab is the same as that of an aerofoil, the shape of the tab can have an important effect on aerodynamic balance.

A **convex** shape tab can tend towards overbalance.



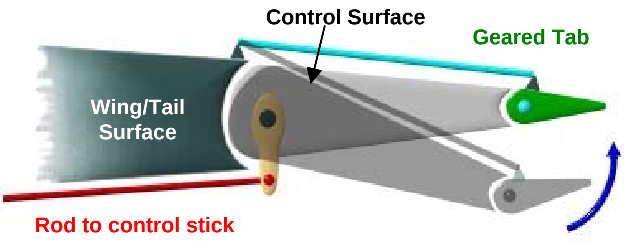
A **concave** shape tab can tend towards underbalance.



GEARED TABS

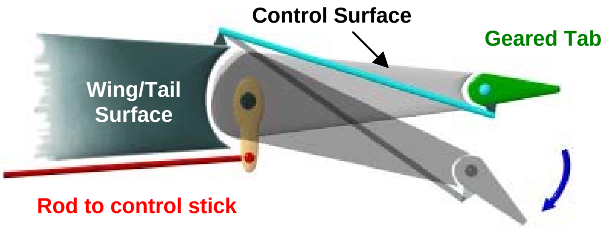
For balance, the **geared tab** is attached directly to the wing or tail surface with a **rod**. A balance tab will assist the pilot to move the flight controls by creating a localised lift force in the direction of movement. Used when stick forces become uncomfortably high on large or fast aircraft

When the control surface is deflected, the tab is geared to move at a set ratio.



The tab will therefore **deflect** in the opposite direction to the movement of the **control** surface.

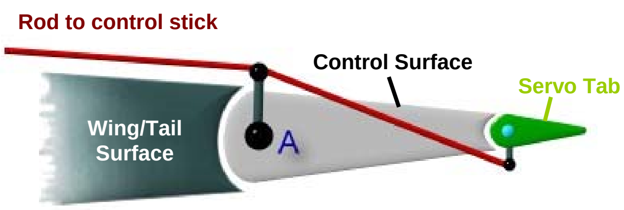
In order to have stick-free stability, it might mean that a large horn balance is required. In this case an anti-balance tab is needed to increase stick forces and overcome overbalancing.

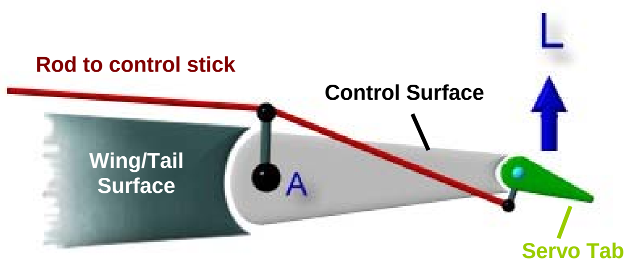


In this example the bottom of the **geared tab** is attached to the top of the wing or tail surface. A down deflection of the control surface will cause a **down deflection** of the tab as well. The tab shown is an Anti Balance Tabs are used to stiffen controls up when stick forces are too light. This gives more "feel" to the system.

SERVO TABS

Servo tabs are connected directly to the control stick with linkages.

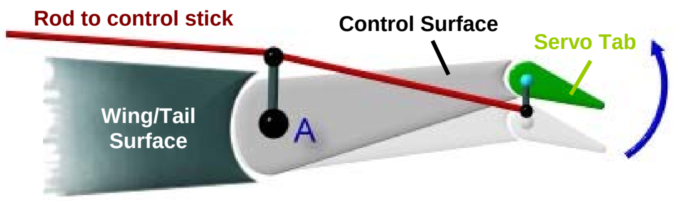




If the pilot pulls back on the stick to climb, the tab downward deflected. (By applying the same aerodynamic principles as with trim tabs, the servo tab will now exert a **lift force** upwards.)

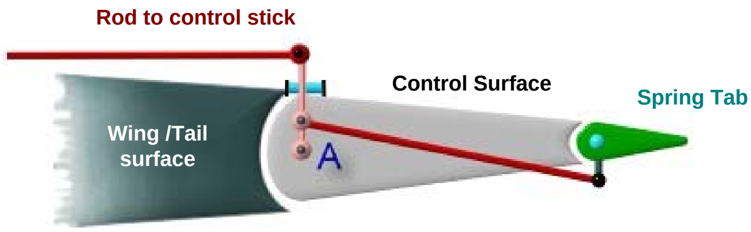
With the control surface free to **pivot** about point A, the force produced by the servo tab will pick it up.

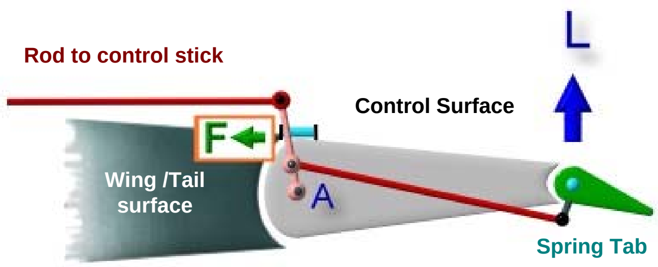
The stick forces involved are those acting on the tab, which are much less than those on the main control surface.



SPRING TABS

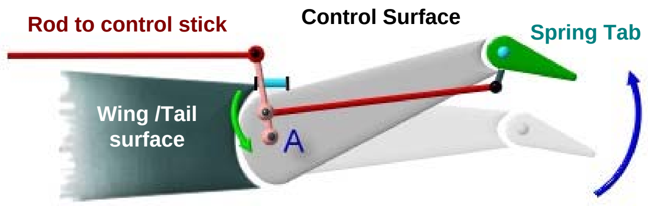
The spring tab looks similar to the servo - tab. The control surface is free to pivot about point **A**. The main difference is that two **springs** are added both sides of the **rod** connected to pivot point **A**.





As with the servo-tab, when the pilot pulls back on the stick to climb, the tab will be deflected downwards, but provide a **lift force** upwards. The vertical connecting rod exerts a force **F** (by spring tension) in the direction of the leading edge of the control surface.

With force **F** providing a **moment** anti-clockwise about point A, it assists the **moment** produced by the lift force and this moment will move the control surface upwards. Again the stick forces will be much less as they are not from the control surface.



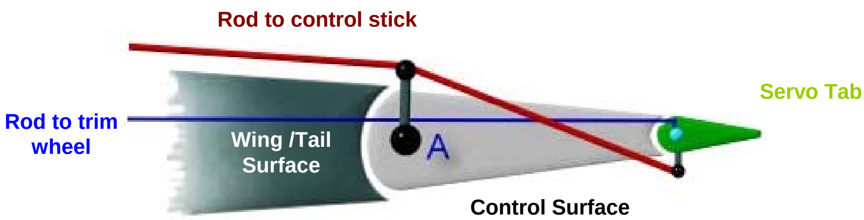
Spring tabs can be set to first start operating once the stick or rudder forces exceed a predetermined value. This is done mainly to keep the spring tab out of action at low speeds and so avoid excessive lightening and lack of feel on the control stick.

Spring tabs are used widely on modern aircraft with success, but on large surfaces the spring tab or servo-tab may produce a "spongy" feel in the controls to which a pilot might object.

DUAL PURPOSE TABS

In some aircraft the features of two or more of the tabs can be combined.

For example: A servo-, geared- or spring tab can be connected to the pilot-operated trim wheel. This means that the pilot can change the position of the tab.

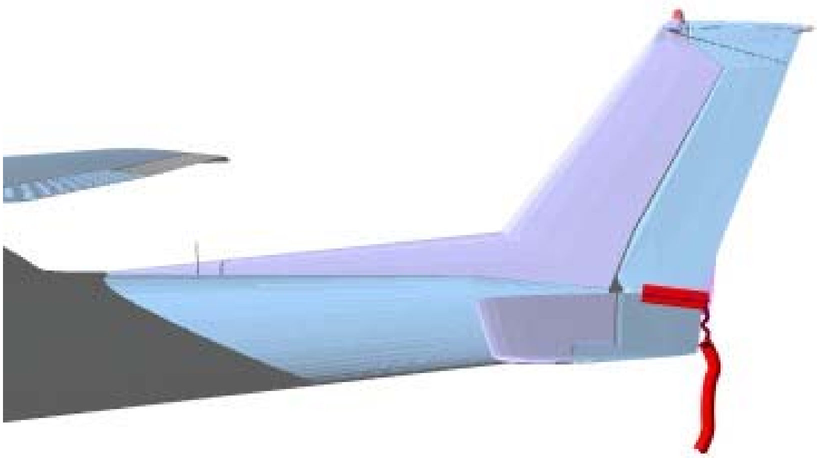


The tab will therefore function as a trim tab and as a pure servo-, geared- or spring tab.

CONTROL LOCKS

Usually control surfaces are locked by locking the control column or rudder bar. With servo- and spring tabs this method will not prevent high winds from moving the control surfaces due to the fact that these control surfaces are free to pivot and they are not directly connected to the control column.

External control surface clamps are needed to stop them from moving around in strong winds and possibly causing damage.



The **red wooden blocks** lock the rudder and elevators of this aircraft.

On certain spring tab installations you still have partial or full control column movement when the external locks are in position. For this reason it is vital that a thorough before flight check is done to make sure that the locks are out and so prevent

NON-CONVENTIONAL FLIGHT CONTROLS

INTRODUCTION

The types of non-conventional flight controls used are varied, but the most common types in use are:

- All-moving (slab) or flying tail.
- Elevons and Tailerons
- Ruddervators or elerudders
- Canard configurations

ALL MOVING (SLAB) OR FLYING TAIL

At high Mach numbers a shock wave forms in front of all control surfaces which reduces the control effectiveness of conventionally hinged control surfaces and leads to a serious decrease in accuracy with which the aircraft can be controlled.

To overcome this problem, high-speed aircraft make use of *all-moving control surfaces*. With these types of control surfaces, full and accurate control of the aircraft is maintained at all Mach numbers.

ELEVONS AND TAILERONS

Some aircraft combine the function of the elevator and aileron in one control that is situated at the wing tips. This control is known as an elevon.

RUDDERVATORS OR ELERUDDERS

These odd terms are used to describe the "V"-tail arrangement found on some aircraft. Two surfaces are mounted at a high dihedral angle on the empennage and they perform both the functions of the elevator and rudder. Certain advantages are claimed for the "V"-tail:

- Weight saving due to less tail surface required.
- Performance gain due to less drag.
- Tail surfaces are removed from downwash and wing wake.
- Better spin recovery.

CANARD CONFIGURATIONS

An aircraft with a canard-type configuration has a fore-plane located forward of the wing instead of the more conventional aft position. This configuration is somewhat unstable, but has the advantage of being out of the downwash or shock wave region.

The Rockwell/MBB X-31 is used by NASA for the researching of manoeuvres at high angle of attack and is fully controllable at angles of attack of around 70º nose-up.