VII. AIRCRAFT CONTROL & FLIGHT CONTROLS

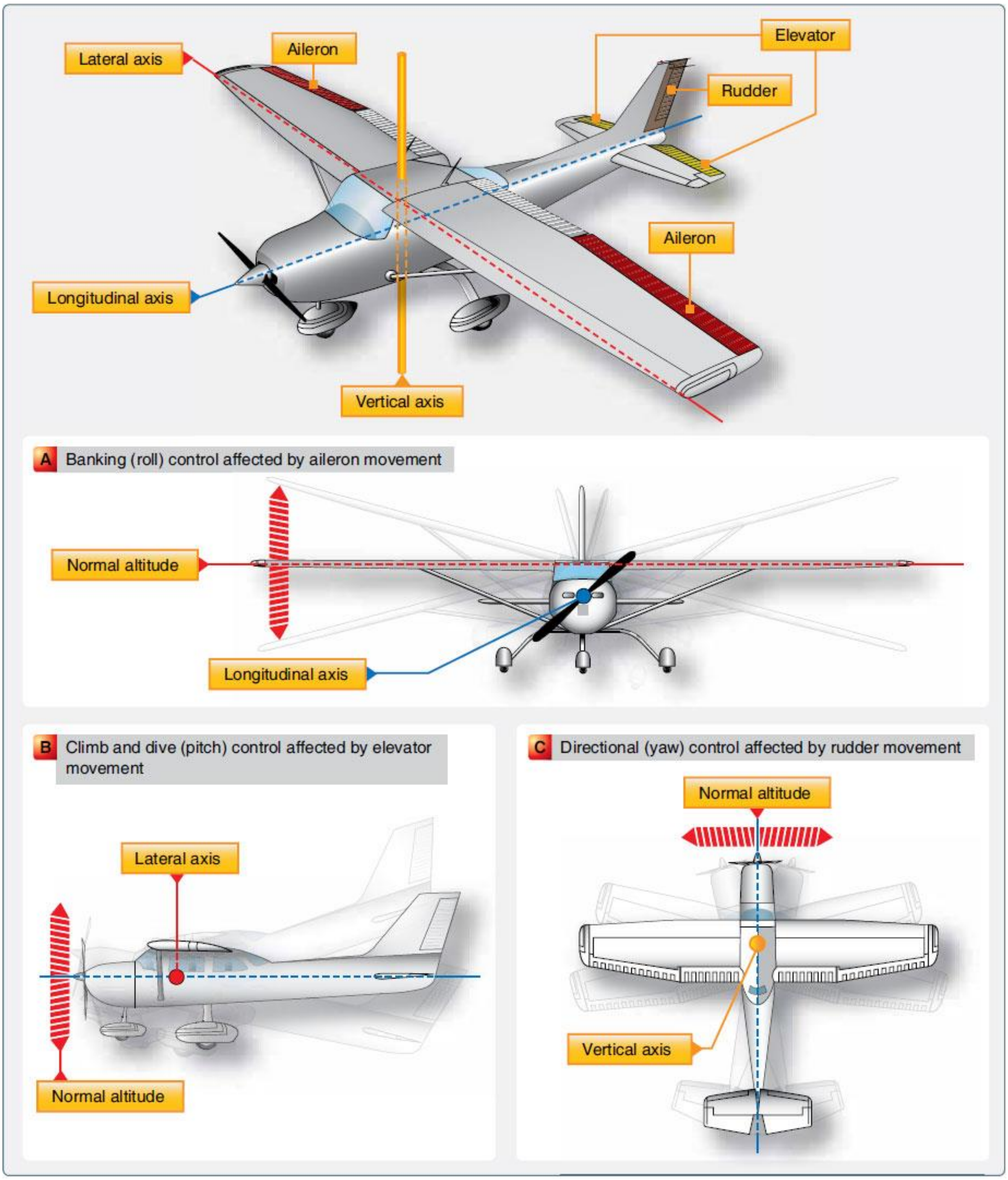
1) Main motions & Primary Flight Controls

An aircraft has three axis of rotation. The aircraft

ROLL around its **LONGITUDINAL AXIS**

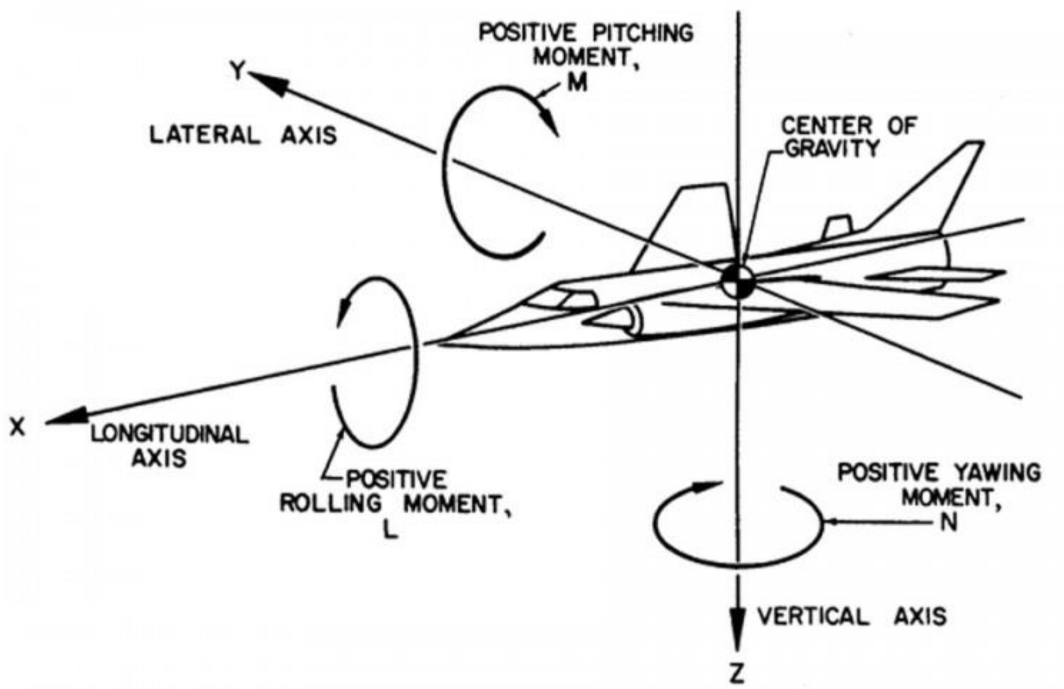
PITCH around its **LATERAL AXIS**

YAW around its **NORMAL/VERICAL AXIS**



Those motions are the primary motions of the aircraft, and they are generated from the ELEVATOR, AILERONS, and RUDDER, which are are called the PRIMARY CONTROL surfaces connected to the yawk/stick/side-stick and the pedals

The three axis meet at the Centre of Gravity (CG) of the aircraft. In other words, the aircraft rotates around its CG.



When the rotation are calculated or measured in a graph

Pitch UP is a POSITIVE (+) PITCH / Pitch DOWN is a NEGATIVE (-) PITCH

Roll RIGHT is a POSITIVE (+) ROLL / Roll LEFT is a NEGATIVE (-) ROLL

Yaw RIGHT is a POSITIVE (+) YAW / Yaw LEFT is a NEGATIVE (-) YAW

Basic Physics:

A rotation is caused by a rotational force called MOMENT

MOMENT = arm x Force

2) PITCH

Deflection of the primary surface control located on the horizontal stabiliser (or tailplane) called ELEVATOR by pulling/pushing on the flight control (column control).

This surface control is an aerofoil and it will create an aerodynamic force.

When the pilot pulls on the flight control, the elevator is deflected up, which will increase the negative camber of the tailplane and generate a downward force, forcing the aircraft to pitch up around its CG, and when the pilot pushes on the flight control, the elevator is deflected down, which will increase the positive camber of the tailplane and generate a upward force, forcing the aircraft to pitch down around its CG.

During take-off, when the aircraft reaches the correct speed (V_R), the pilot will pull on the flight control and rotate the aircraft. The tailplane forces the nose to go up and the wings AoA increases which will increase the lift until it becomes higher than the weight for the aircraft to lift off from the ground.

The pitch will depend on the position of the CG from the elevator (arm) and of the F generated from the elevator

$$F = \frac{1}{2}\rho V^2 \, S \, C_F$$

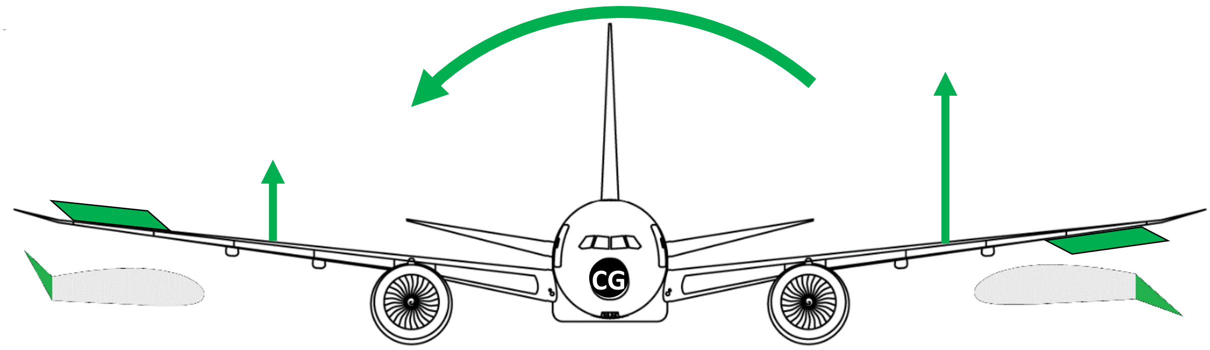
C_F will depend on the input from the pilot, more deflection of the flight control will result in a higher F generated from the flight control surface. <u>This applicable to the other aircraft motions and their respective flight control and control surfaces.</u>
C_F is limited since the input (deflection) is limited, so at a very low speed, the output will be less as required or inefficient

- ➔ For the same input (deflection), at lower/higher speed the moment (output) will be smaller/higher
- ➔ For the same speed, for a lower/higher input (deflection) the moment (output) will be smaller/higher
- ➔ The control surface is more efficient at high speed and with a high input (deflection). However, a high input (deflection) at high speed will stress the airframe and can cause permanent deformation and/or structural failure of the airframe

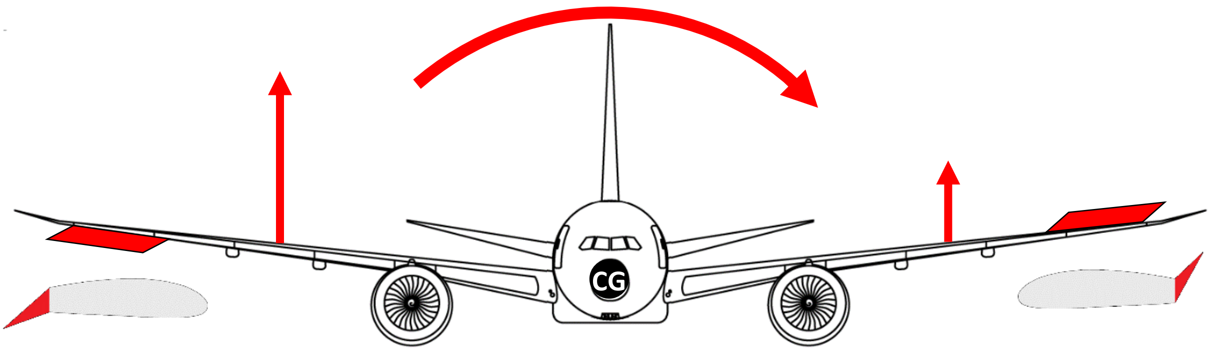
3) ROLL

Deflection oppositely the primary control surfaces located outboard of the wing called AILERONS, by deflection the flight control LEFT/RIGHT

When the pilot deflect the flight control to the right, the right ailerons is deflected up and increases the negative camber of the aerofoil which result in a reduced total lift of the right wing, although the left ailerons is deflected down and increases the positive camber of the aerofoil which result in an increased total lift of the left wing. The difference in lift between the two wings will force the aircraft to roll right around it CG.



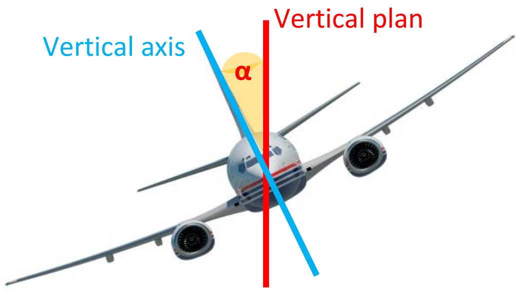
When the pilot deflect the flight control to the left, the left ailerons is deflected up and increases the negative camber of the aerofoil which result in a reduced total lift of the left wing, although the right ailerons is deflected down and increases the positive camber of the aerofoil which result in an increased total lift of the right wing. The difference in lift between the two wings will force the aircraft to roll left around it CG.



Note: The ailerons of the upgoing wing is deflected down and the ailerons of the downgoing wing is deflected up.

<u>Angle of bank</u>

When the aircraft is rolled, the angle between the vertical axis of the aircraft and the vertical plan is called the **BANK** or **ANGLE OF BANK**. Indeed the aircraft is **banking**.



Roll assistance

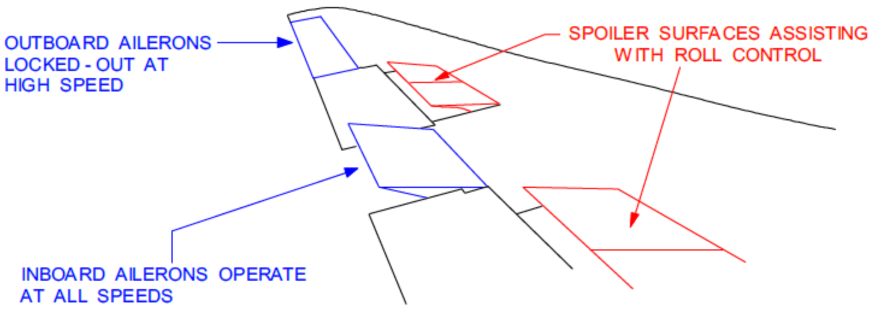
Inboard and Outboard Ailerons: Some aircrafts require additional assistance to roll, and will be equipped with inboard ailerons which are operative at all speeds, and outboard ailerons which are operative only at low speeds.

Spoilers: Spoilers are devices mounted over the wings used:

- As SECONDARY FLIGHT CONTROL to assist the roll at LOW SPEED, by extending further on the downgoing wing.
- As Speedbrakes in flight
- To damp the LIFT on the ground after landing and reduce the landing distance

Secondary flight control

Spoilers may be used to give lateral control, in addition to, or instead of ailerons. Spoilers consist of movable panels on the upper wing surface, hinged at their forward edge, which can be raised hydraulically, as illustrated below. A raised spoiler will disturb the airflow over the wing and reduce lift.



To function as a lateral control, the spoilers rise on the wing with the up going aileron (down going wing), proportional to aileron input. On the wing with the down going aileron, they remain flush. Unlike ailerons, spoilers cannot give an increase of lift, so a roll manoeuvre controlled by spoilers will always give a net loss of lift. However the spoiler has several advantages compared to the aileron:

- There is no adverse yaw (covered later): The raised spoiler increases drag on that wing, so the yaw is in the same direction as the roll.

- Wing twisting is reduced**:** The aerodynamic force on the spoilers acts further forward than is the case with ailerons, reducing the moment which tends to twist the wing.

- It cannot develop flutter.

- Spoilers do not occupy the trailing edge, which can then be utilised for flaps.

- At transonic speed its effectiveness is not reduced by shock induced separation (covered later).

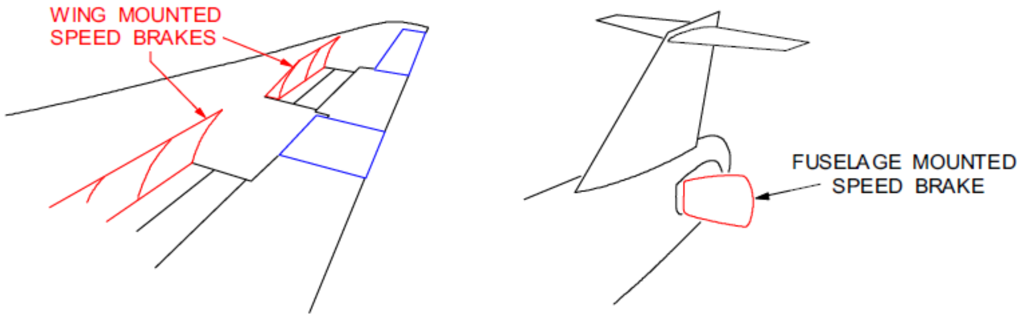
Combined ailerons and spoilers controls: On a few aircraft, lateral control is entirely by spoilers, but in the majority of applications the spoilers work in conjunction with the ailerons. Ailerons alone may be inadequate to achieve the required rate of roll at low speeds when the dynamic pressure is low, and at high speeds they may cause excessive wing twist and begin to lose effectiveness if there is shock induced separation. Spoilers can be used to augment the rate of roll, but may not be required to operate over the whole speed range. On some aircraft the spoilers are only required at low speed, and this can be achieved by making them inoperative when the flaps are retracted.

Movement of the cockpit control for lateral control is transmitted to a mixer unit which causes the spoiler to move up when the aileron moves up, but to remain retracted when the aileron moves down.

Speed Brakes: Speed brakes are devices to increase the drag of an aircraft when it is required to decelerate quickly or to descend rapidly. Rapid deceleration is required if turbulence is encountered at high speed, to slow down to the Rough Air Speed as quickly as possible. A high rate of descent may be required to conform to Air Traffic Control requirements, and particularly if an emergency descent is required.

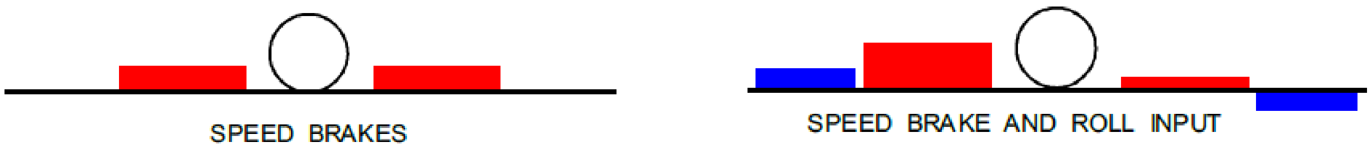
Type of Speed Brakes

Ideally the speed brake should produce an increase in drag with no loss of lift or change in pitching moment. The fuselage mounted speed brake is best suited to meet these requirements



However, as the wing mounted spoiler gives an increase in drag, it is convenient to use the spoiler surfaces as speed brakes in addition to their lateral control function. To operate as speed brakes they are controlled by a separate lever in the cockpit and activate symmetrically. Speed brakes are normally cleared for operation up to V_{MO} / M_{MO} but may “blow back” from the fully extended position at high speeds. Spoilers will still function as a roll control whilst being used as speed brakes, by moving asymmetrically from the selected speed brake position.

An example below (aircraft seen from the rear) Speed brakes have been selected and then a turn to the left is initiated. The spoiler surfaces on the wing with the up going aileron will stay deployed, or modulate upwards, depending on the speed brake selection and the roll input. The spoiler surfaces on the wing with the down going aileron will modulate towards the stowed position. The spoiler surfaces on the wing with the down going aileron may partially or fully stow, again depending on the speed brake selection and the roll input.



Effect of Speed Brakes on the Drag curve

The drag resulting from the operation of speed brakes is profile drag, so will not only increase the total drag but will also decrease V_{MD} . This is an advantage at low speeds as the speed stability will be better than with the aircraft in the clean configuration.

Ground Spoilers (Lift dampers)

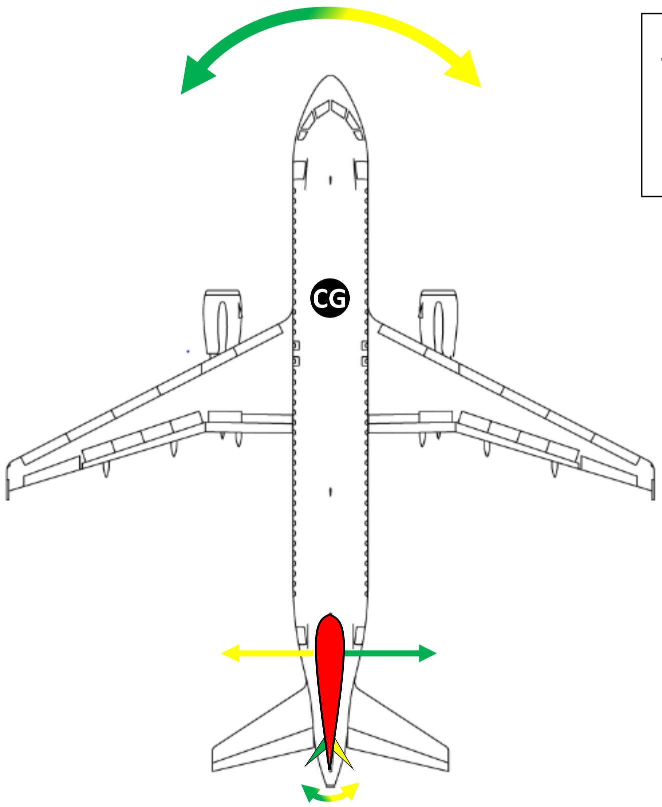
During the landing run the decelerating force is given by aerodynamic drag, reverse thrust and the wheel brakes. Wheel brake efficiency depends on the weight on the wheels, but this will be reduced by any lift that the wing is producing. Lift can be reduced by operating the speed brake lever to the lift dump position. Both the wheel brake drag and the aerodynamic drag are increased, and the landing run reduced. On many aircraft types, additional spoiler surfaces are activated in the lift dumping selection than when airborne. These ground spoilers are made inoperative in flight by a switch on the undercarriage leg which is operated by the extension of the leg after take-off.

Flaperons: Devices used as ailerons and flaps.

4) YAW

Deflection of the primary control surface on the vertical stabiliser (or fin) called RUDDER by pushing LEFT/RIGHT the foot pedal.

When the pilot pushes on the right rudder pedal, the rudder is deflected to the right, cambering the fin to the right which generate a left side aerodynamic force, forcing the aircraft to yaw to the right, and when the pilot pushes on the left rudder pedal, the rudder is deflected to the left, cambering the fin to the right which generate a right side aerodynamic force, forcing the aircraft to yaw to the left.



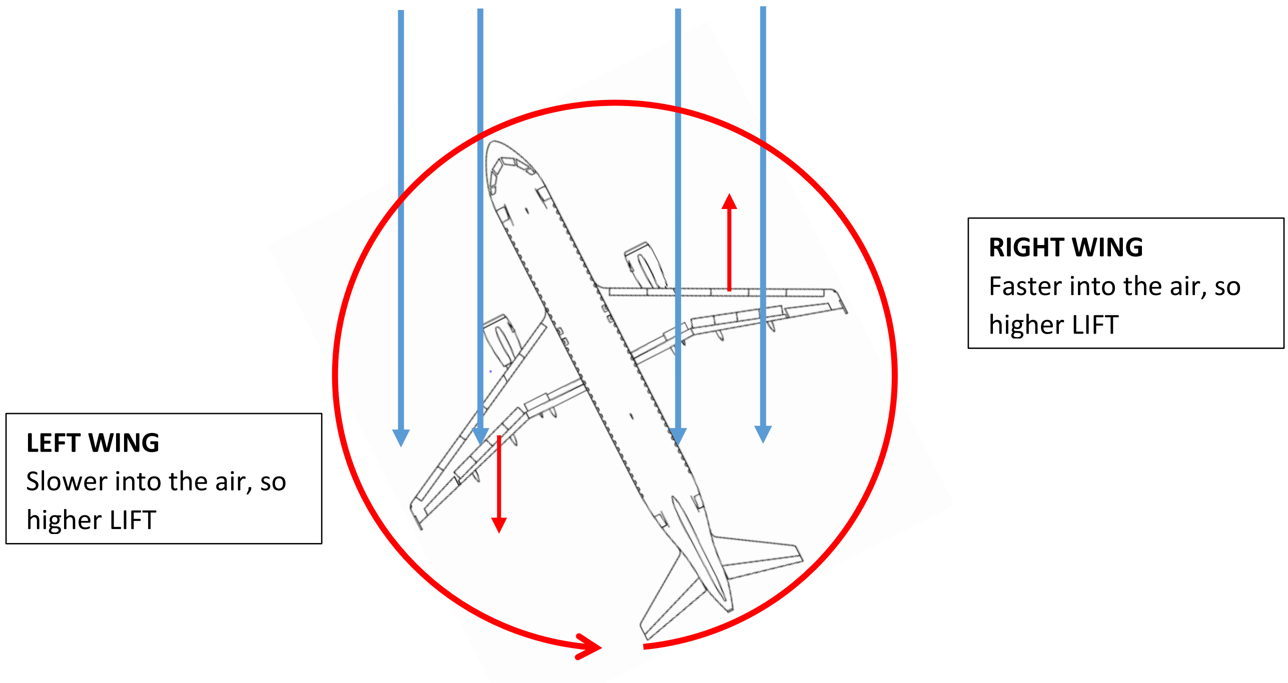
NOTE: The pedals will deflect the nose wheel to control (turn) the aircraft on the ground.

5) ROLL/YAW COORDINATION

A) SECONDARY EFFECT

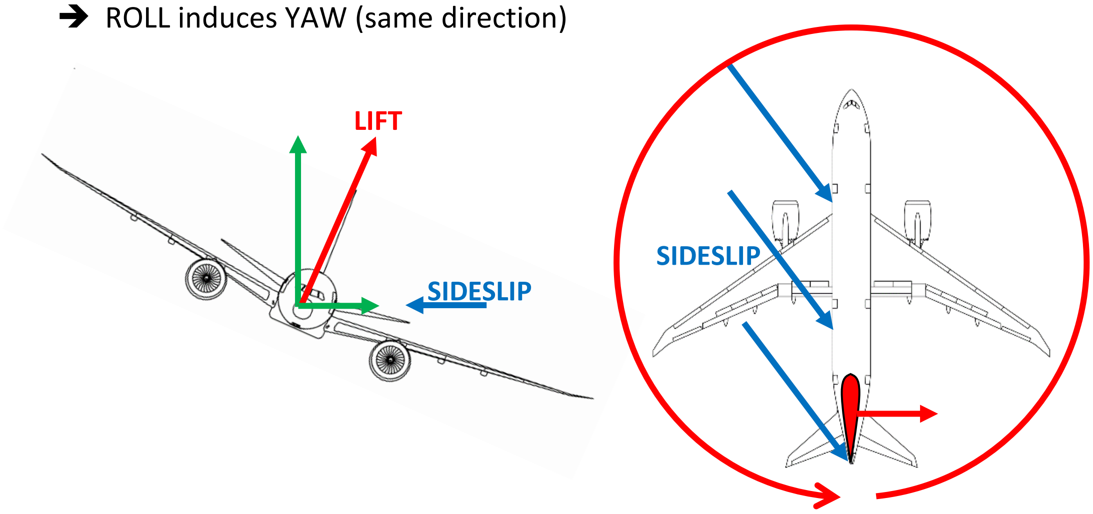
When the aircraft is yawed, the outer wing (outside of the turn) will travel at faster speed in the air than the inner wing due to its forward motion. Resulting in more LIFT on the outer wing than the inner wing, and this will induce a ROLL in the direction of the yaw

➔ YAW induces ROLL (same direction)



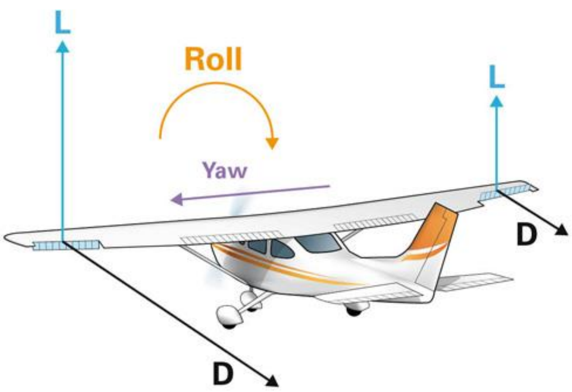
When the aircraft is rolled, a sideslip (side flow) will appear from the direction of the roll, which will form a different AoA of the vertical stabiliser (or fin), and this will induce a YAW in the direction of the roll

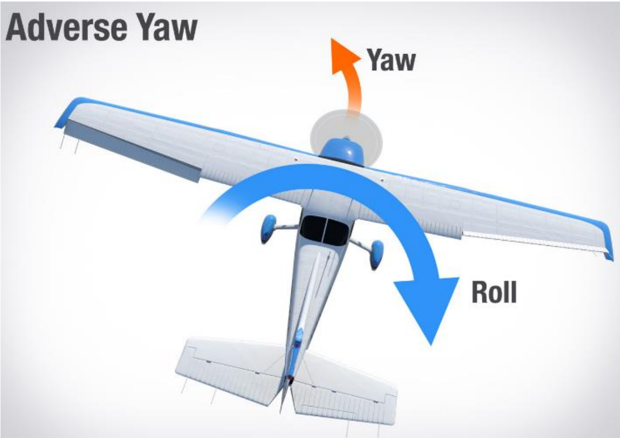
➔ ROLL induces YAW (same direction)



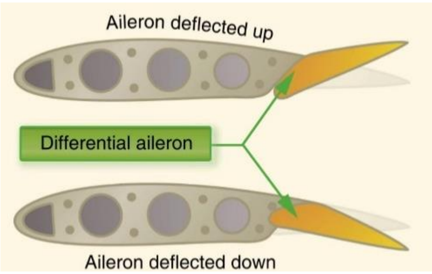
B) ADVERSE YAW

When the aircraft is rolled, the upgoing wing has a higher AoA than the downgoing wing, and so it generates more LIFT than the downgoing wing, however at a higher AoA, it generates as well more DRAG. This difference in DRAG between the wings, will yaw the aircraft in the opposite direction of the roll.





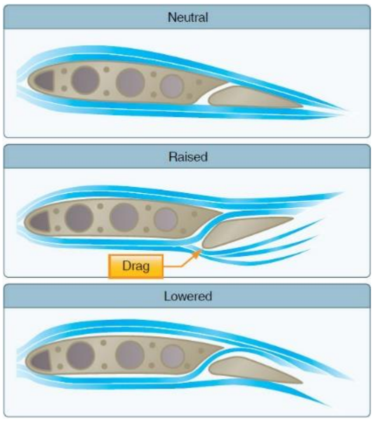
Technics to reduce the ADVERSE YAW.



Differential Ailerons: The upward ailerons is deflected more (at higher angle) than the downward ailerons, causing an increase in the form drag, and equalising the total drag between the two wings, reducing the adverse yaw.

Frise Ailerons: The hinge of the ailerons is shift in such a way that the upgoing ailerons will have a part exceeding the surface of the wings, to increase the form drag of the downgoing wing, and so to equalise the total drag between the two wings, reducing the adverse yaw.

Spoilers: The raised spoiler increases drag on the doinggoing wing, so the drag is equalized between the two wings and the yaw is in the same direction as the roll



FRISE AILERONS

C) TURN COORDINATION

Since the ROLL and the YAW are "coupled", it is important that during a turn, the aircraft is coordinated in order to keep the nose in the path of turn for minimise drag and avoid dangerous flight characteristics.

A turn is coordinated when there's no sideslip and the nose remains aligned with the relative airflow.

To coordinate a turn, the pilot must rely on the instrument called **TURN & SLIP COORDINATOR**, and must keep the ball in the centre by applying the appropriate correction

On the instrument, the aircraft or the needle represent the rate of turn and direction of the bank.

The ball shows the position of the tail

The first graduation (left or right) shows the **standard rate of turn**, **which is 360°/2min or 3°/second**, also known as **RATE 1**

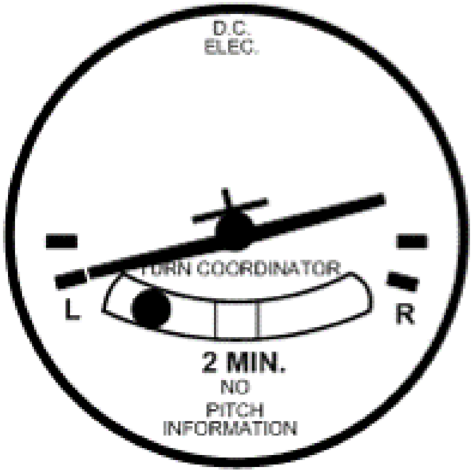
Some Turn & Slip coordinator show a **second graduation** of **360°/min or 6°/second**, also known as **RATE 2**

In any case, apply rudder where the ball is (ball on the left -> apply left pedal)
→ STEP ON THE BALL

Unbalanced turn: When the turn is not coordinated, it will cause more drag, loss of aircraft speed and performance, discomfort, fuel unbalance, and could lead to dangerous flight characteristics.

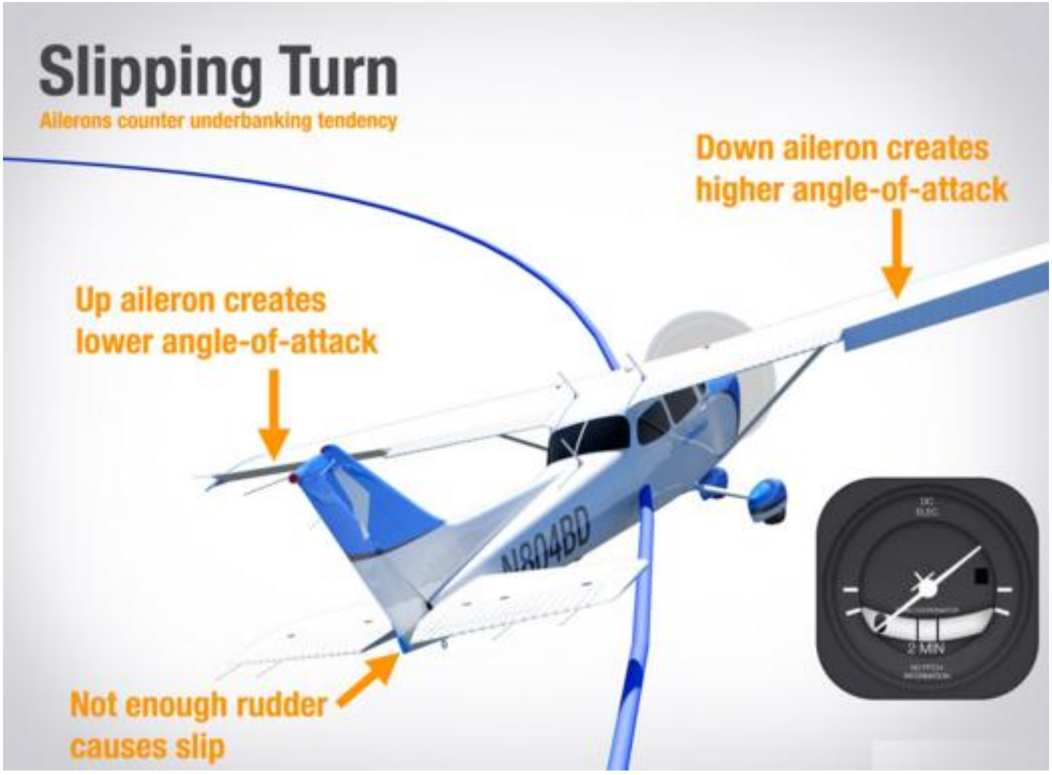
SLIPPING TURN

Instrument description: The ball is in the same side of the aircraft bank



Aircraft description: The aircraft's tail is into the turn and the nose in outside of the turn

This occur when the bank angle is too high for the rate of turn, or when the pilot is not applying enough pedal in the direction of the turn, or when the pilot applies too much rudder when correcting for a skidding turn.

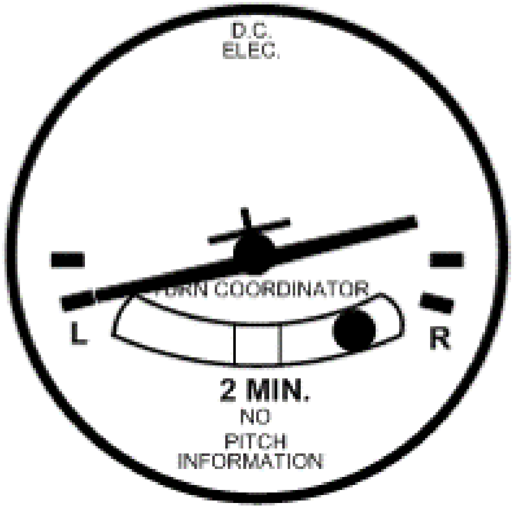


Corrective action:

- Apply more rudder on the same side of the ball (if ball on the left, push left pedal)
- or reduce rudder on the opposite side of the ball
- or decrease bank angle

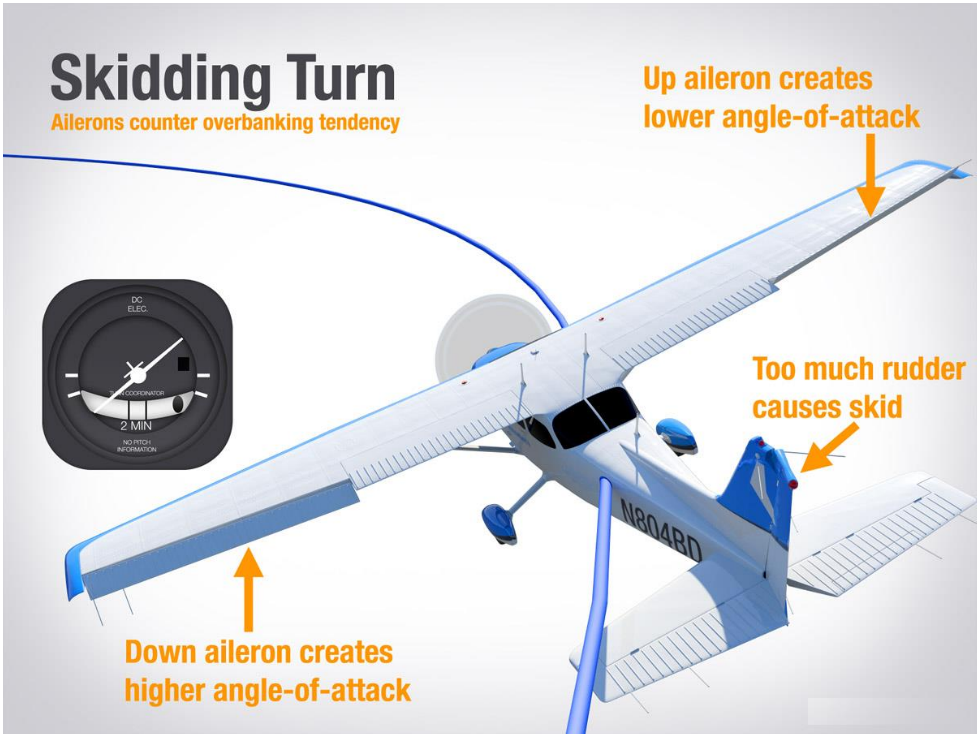
SKIDDING TURN

Instrument description: The ball is in the opposite side of the aircraft bank



Aircraft description: The aircraft's nose is into the turn and the tail in outside of the turn

This occur when the rate of turn is too high for the bank angle, or when the pilot is applying too much pedal in the direction of the turn when correcting for a slipping turn, or not enough opposite pedal to coordinate the turn.



Corrective action:

- Apply more rudder on the same side of the ball (if ball on the left push left pedal)
- or reduce rudder on the opposite side of the ball
- or increase bank angle

6) Other induced motions

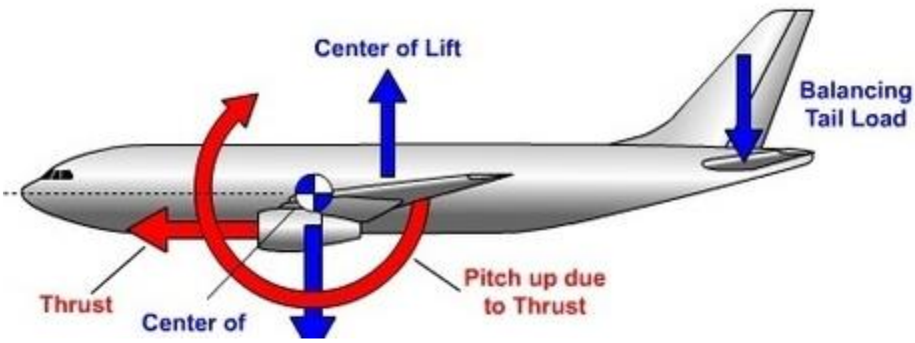
THRUST/DRAG LINE

<u>THRUST</u>

The aircraft will also pitch if there's a change in the THRUST since the CG and the THRUST LINE are not some plan.

For an aircraft whose engines are mounted below the wings, the THRUST line is below the CG

- Increase in THURST, produces a NOSE UP moment
- Decrease in THRUST, produces a NOSE DOWN moment



For an aircraft whose engines are mounted on the tail, the THURST line is above the CG

- Increase in THURST, produces a NOSE DOWN moment
- Decrease in THRUST, produces a NOSE UP moment

<u>DRAG</u>

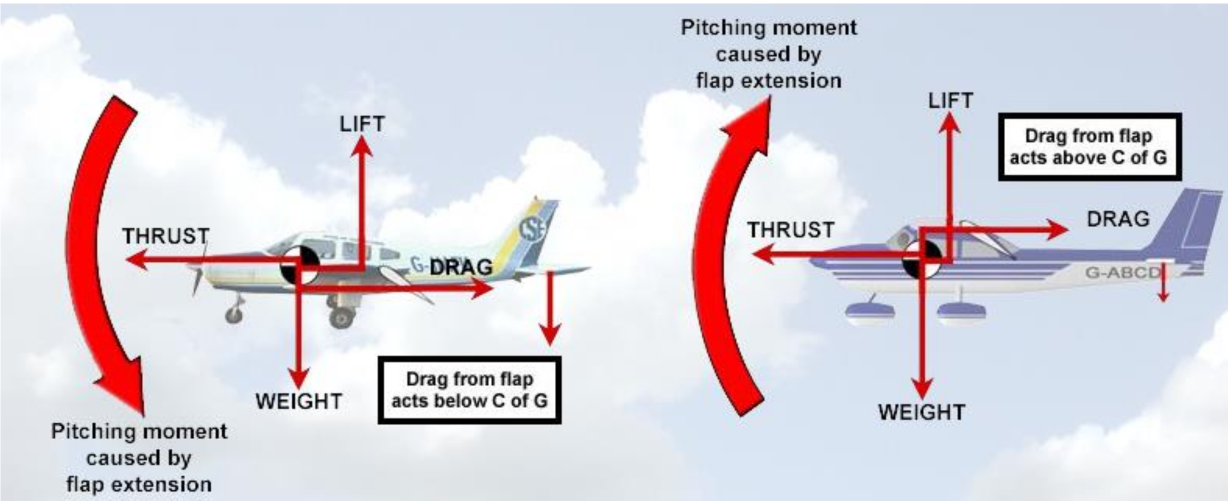
When the flaps are extended or retracted, the change of drag will generate a pitching moment.

For an aircraft with low wings:

- Flaps extension, produces NOSE DOWN moment
- Flaps retraction, produces NOSE UP moment

For an aircraft with high wings:

- Flaps extension, produces NOSE UP moment
- Flaps retraction, produces NOSE DOWN moment

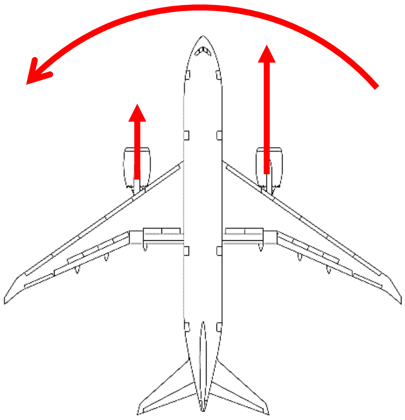


ASSYMETRIC THRUST

For a multiengine aircraft, when the THRUST generated from the LEFT engine(s) and the RIGHT engine(s) are not the same, the aircraft will initially YAW toward the side where less THURST in generated, and this YAW will induce a ROLL.

This can occur in flight following an engine failure, where the pilot must maintain the heading by yawing and rolling toward the alive engine (dead leg -> dead engine) and reducing the THRUST from the alive engine if necessary.

On the ground, the asymmetric thrust can be used as a technic to turn through acute angle where the nose wheel steering is not enough.



A change is the amount of lift or position of the CP or CG, a new pitch moment will exist.

DO NOT CONFUSE **CG** and **AC**
CG (Centre of Gravity) is the pivot point of the aircraft

AC (Aerodynamic Centre) is the pivot point of an aerofoil and it's usually at 25% of the chord in subsonic incompressible fluid (M<0,4)

FLAPS ASSYMETRY

In an event of flaps failure on one side (wing), the differential lift will roll the plane toward failed side, and the differential drag will yaw the aircraft opposite of the failed side.

The pilot can recover from this upset attitude, but it could be critical when the flaps are extended in turn and this event occur.

In the advanced systems, the flaps positions are continuously compared by the system, and in the event of one flap failure, the other flaps will stop extending or retracting.

7) Hinge moment & Control Balancing

A) Hinge Moment

When the pilot deflects the flight control, the flight control surface will generate an aerodynamic force which will try to rotate the control surface around its hinge in the direction of the force.

This moment is called the HINGE MOMENT and it will tend to bring back the control surface to its initial position.

Hinge Moment (feel) = d x F

d: arm between the hinge and the centre of the Force (F)

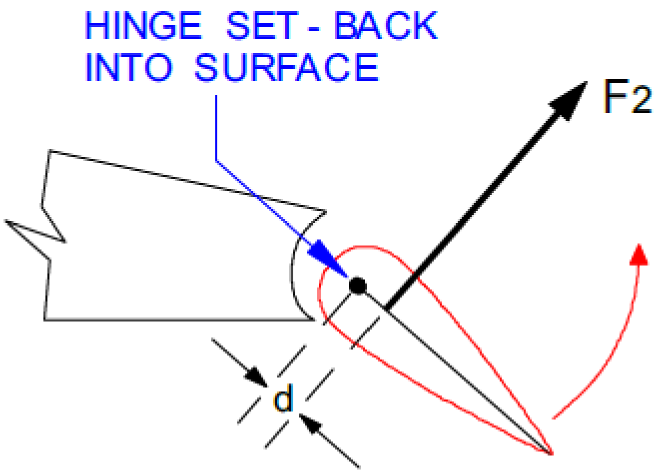
The pilot must overcome to the hinge moment, and at a higher speed, the Hinge Moment will be higher (F 🡅)

B) Control Balancing

The control balancing is to <u>assist</u> the pilot to deflect the flight controls.

➔ **<u>Aerodynamic Balance</u>**
Aerodynamic balance involves the use of the aerodynamic forces on the control surfaces to reduce the hinge moment/stick force and may be done in several ways

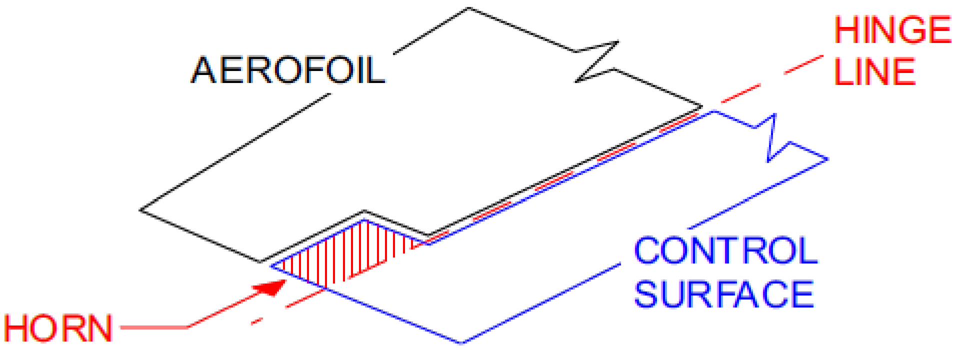
- **Inset Hinge:** Consist of shifting the hinge line in order to reduce the arm "d" which will reduce the hinge moment without reduction of the effectiveness.



Caution!: If F moves forward of the hinge, a condition known has "overbalance" would exist. Reversal stick force would occur. The manufacturer must ensure this doesn't exist.

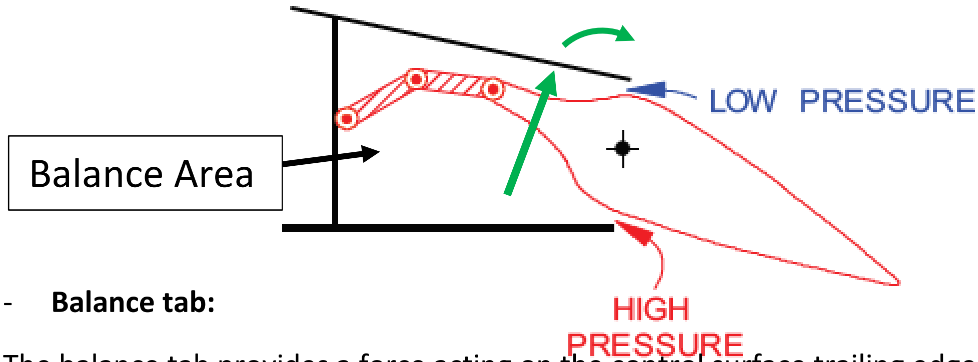
- **Horn Balance:**

Part of the control surface is located forward of the hinge line, which will give an opposite moment to the hinge moment and so assist the pilot to deflect the control surface, without reduction of the its effectiveness.



- **Internal Balance:**

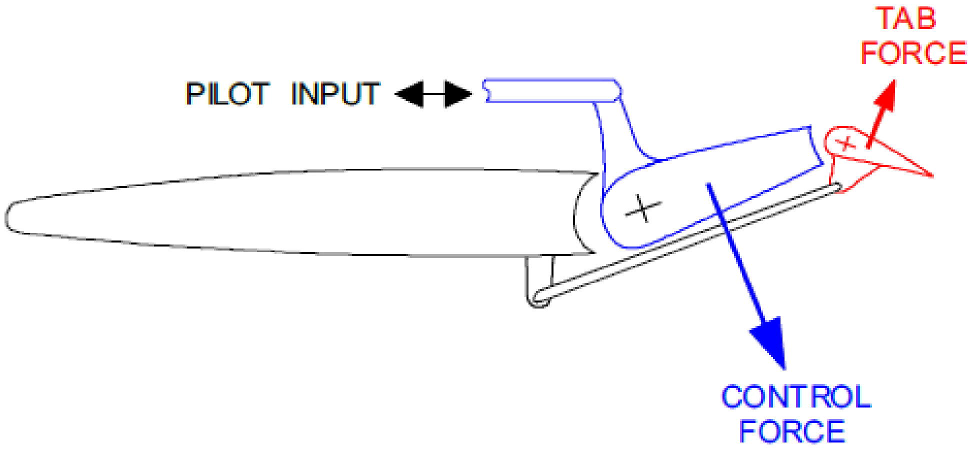
Movement of the surface control causes pressure change on the aerofoil, and this pressure change is felt in the balance area which will generate an opposite hinge moment.



- **Balance tab:**

The balance tab provides a force acting on the control surface trailing edge opposite to the force on the main control surface.

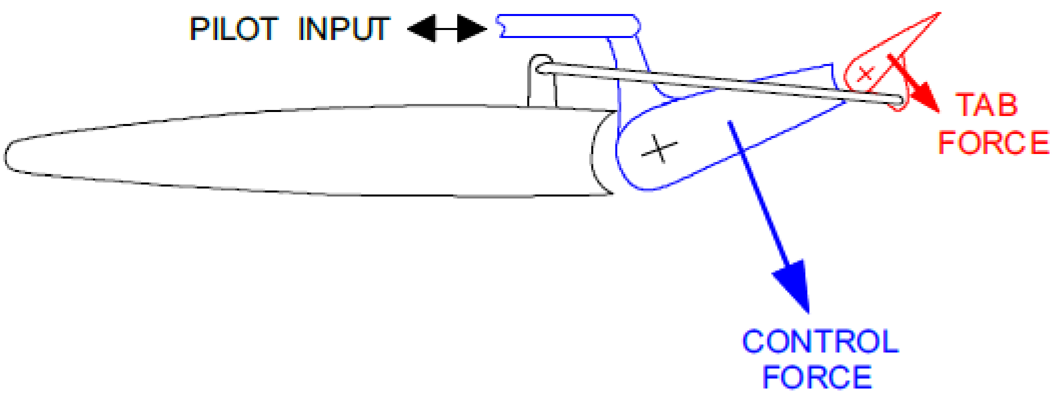
When pilot deflects the main control surface, the balance tab deflects in the opposite direction. This will reduce the hinge moment, however it also reduces the control surface effectiveness.



- **Anti-balance tab:**

The anti-balance tab provides a force acting on the control surface trailing edge in the same direction to the force on the main control surface.

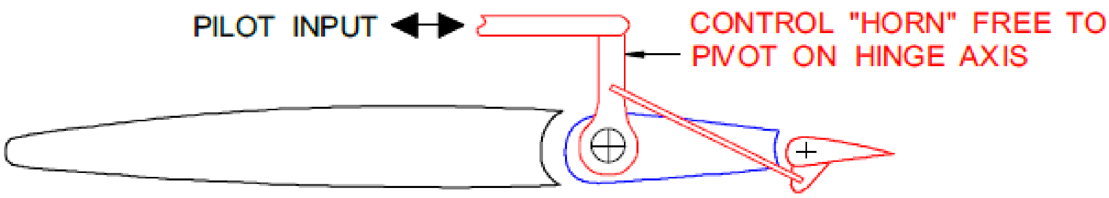
When pilot deflects the main control surface, the anti-balance tab deflects in the same direction. This will increase the hinge moment and so provide a higher "feel"/stick force, in addition it also increase the control surface effectiveness.



- **Servo tab:**

It works as a balance tab, however at a high speed, the dynamic pressure around the control surface will not permit the pilot to deflect the control surface, so in this system, the pilot deflects directly the balance tab on the trailing which is easier due to its smaller surface, which will deflect the control surface oppositely.

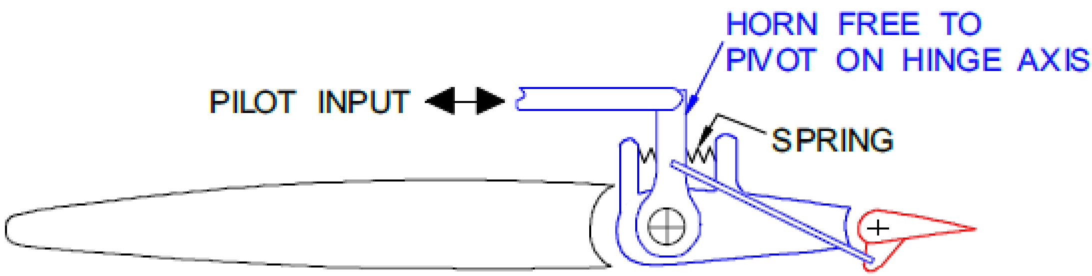
This will reduce the stick force at high speeds, however it will reduce the control surface effectiveness at low speeds.



- **Spring tab:**

It's a modification of the Servo Tab. It works as a balance tab at high speed, the high dynamic pressure will prevent the control surface to move, and the pilot compress the spring and move the tab.

At low speeds, the low dynamic pressure will not prevent the pilot from moving the control surface and so the spring is not compressed, therefore the pilot will deflect the control surface AND the tab in the same direction, proving more "feel/stick force and effectiveness at low speed.



➔ **<u>(Hydraulic) Powered Flying Control</u>**

If the required assistance for the pilot to move the control isn't enough with the aerodynamic balance, then the **power assisted** or **fully power control** have to be used.

- **Power Assisted Control**

With the Power Assisted Control, only a certain proportion of the force required to oppose to the hinge moment is provided by the pilot. The hydraulic system provides most of the force. The pilot will only have a small portion of the force in order to have a natural "feel".

- **Fully Powered Control**

For bigger or faster aircraft, the hinge moment are so large that a fully powered controls must be used. In a fully powered control system, none of the force to move the control surface is supplied by the pilot. All the necessary power to move the control surface is supplied by the aircraft's hydraulic system.

The aerodynamic loads on the control surface are unable to move the cockpit flight controls. So fully powered controls are known as **“irreversible” controls.**

Artificial “Q” Feel

With a fully powered flying control, the pilot is unaware of the aerodynamic force on the control surface, so it’s necessary to incorporate an “artificial” feel to prevent the aircraft from being overstressed. This system used the dynamic pressure (Q).

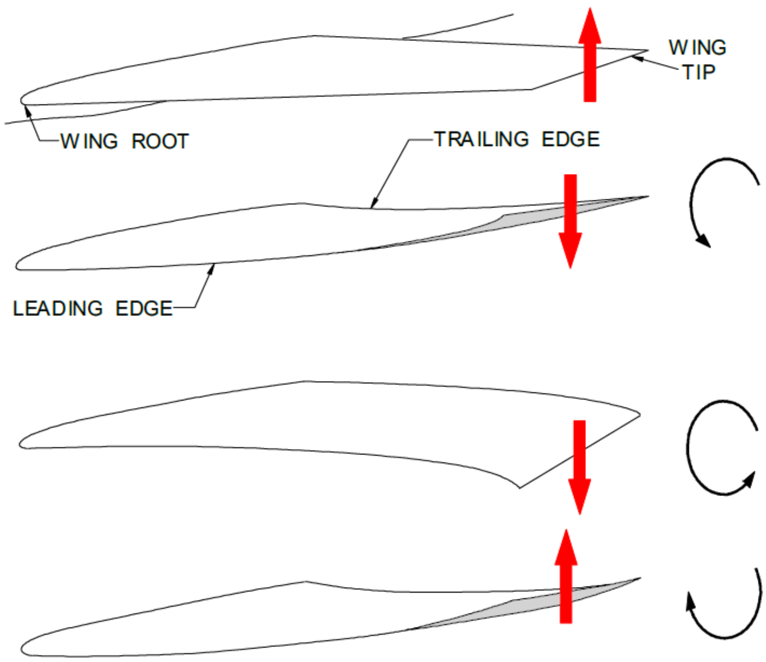
So in fully powered controls, an Artificial “Q” Feel is incorporated to provide (an artificial) feel to the pilot.

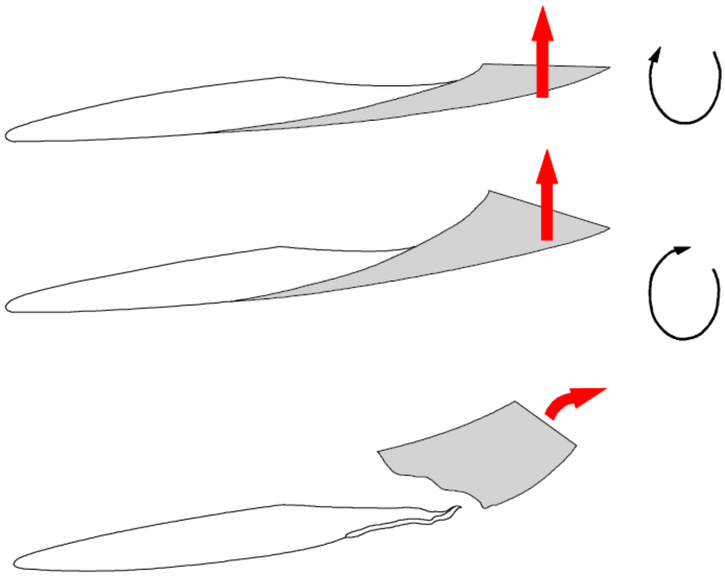
C) Mass Balance

Mass balance is a WEIGHT attached to the control surface forward of the hinge. Most control surfaces are mass balanced. The purpose to do so is to prevent control surface **flutter**.

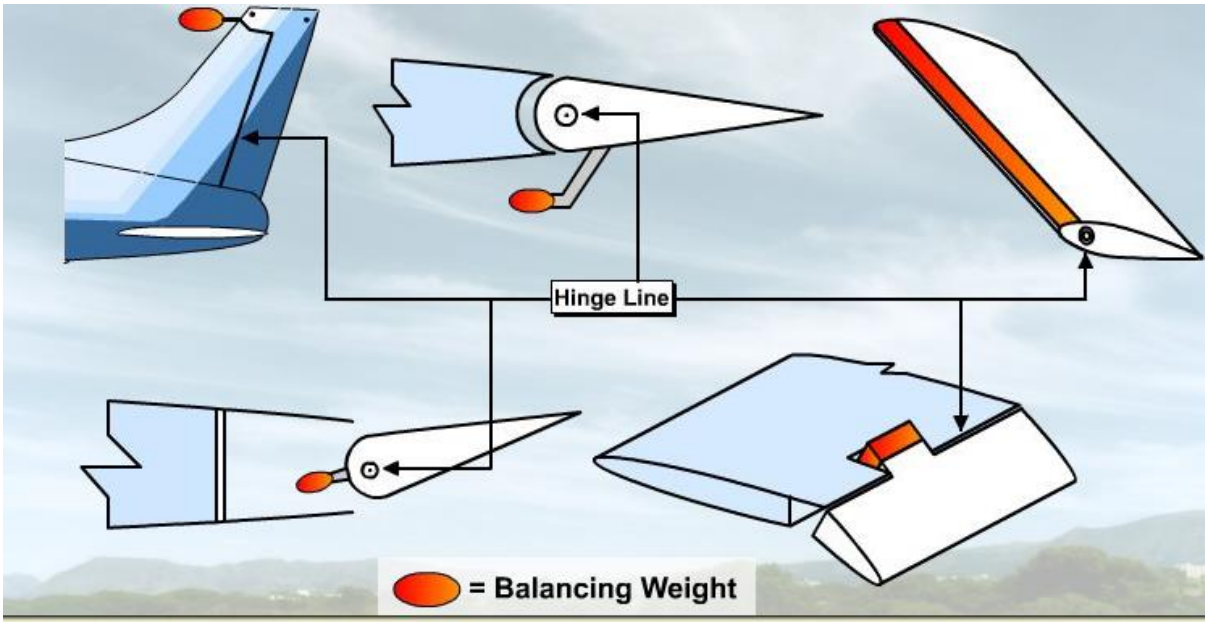
Flutter is an oscillation of the control surface which can occur due to the bending and twisting of the structure under loads.

If the control surface CG is behind the hinge line, the inertia will cause the surface to oscillate about its hinge line. The oscillations can be divergent, and cause structural failure.





Flutter may be prevented by adding weight to the control surface in front of the hinge line to shift the CG.



D) <u>Trimming</u>

An aeroplane is trimmed when it will maintain its attitude and speed without the pilot having to apply any load in cockpit flight controls.

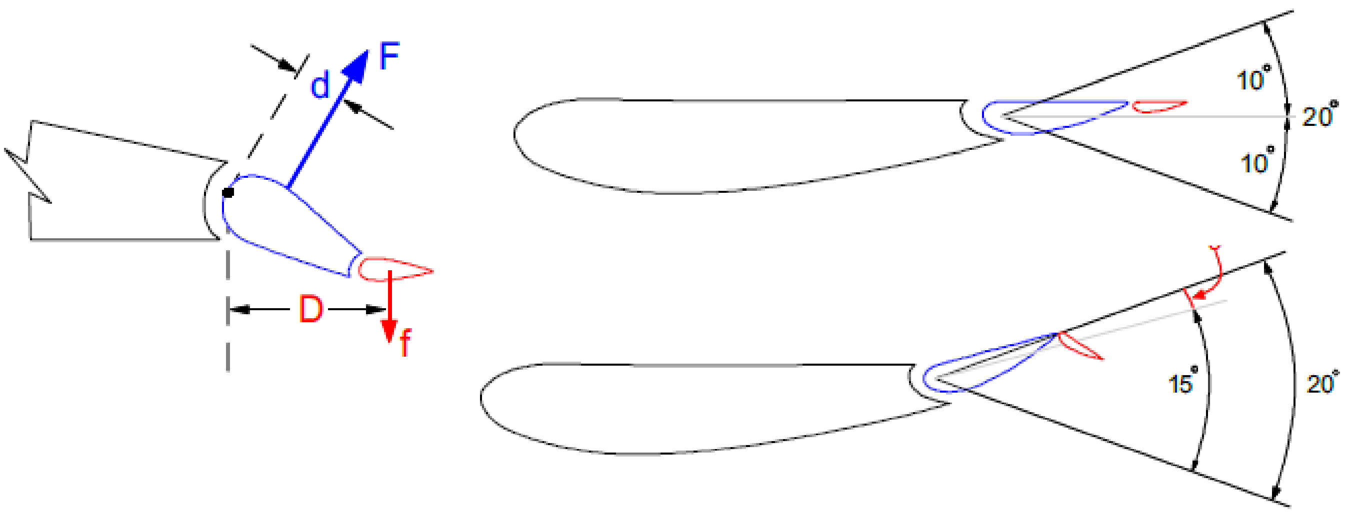
If it necessarily for a control surface to be deflected to maintain balance of the aircraft, the pilot will need to apply a force to the cockpit flight control to hold the surface in its deflected position.

This force may be reduced to zero by operation of the trim controls.

A trim control is a secondary flight control to maintain the primary flight control in the desired position.

➔ **Trim Tab**

A trim tab is a small adjustable surface set into the trailing edge of a main control surface. Its deflection is controlled by a trim wheel or electrical switch in the cockpit, usually arranged to operate in an instinctive sense.
To maintain the primary flight control surface in its required position, the tab is moved in the opposite direction to the control surface, until the tab moment balances the control surface hinge moment.



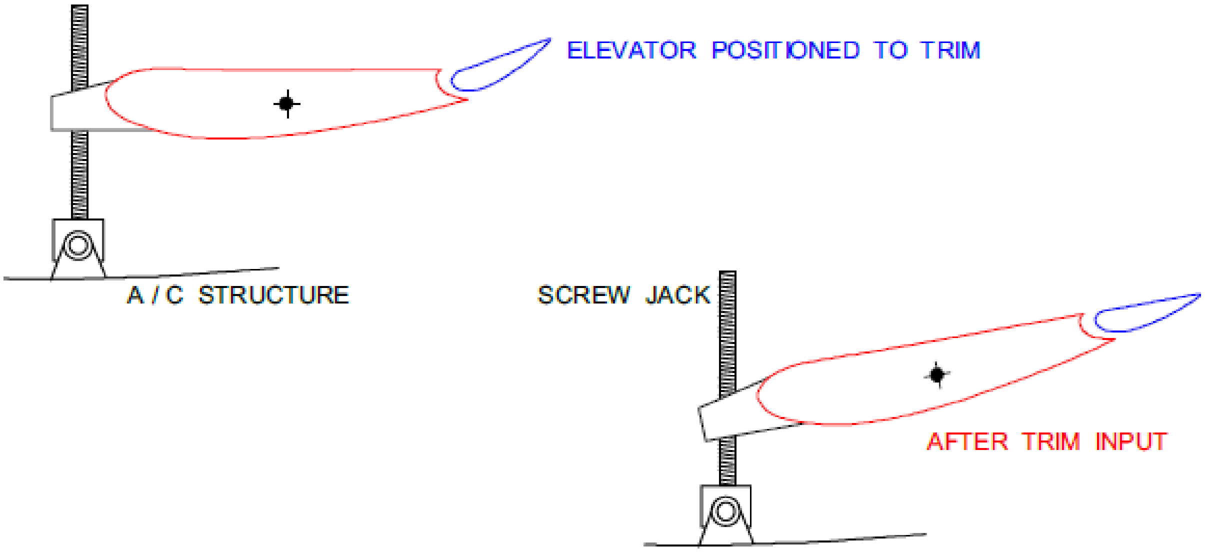
- A trim tab will reduce the effectiveness of the flight control and the pitch authority for the direction where the primary flight control is held.
- Since it's not streamlined into the airflow, the trim tab generates additional drag
- In the event of a trim tab jamming or runaway, the pilot will still be able to control the aircraft.
- A trim tab is easy to manufacture and set.

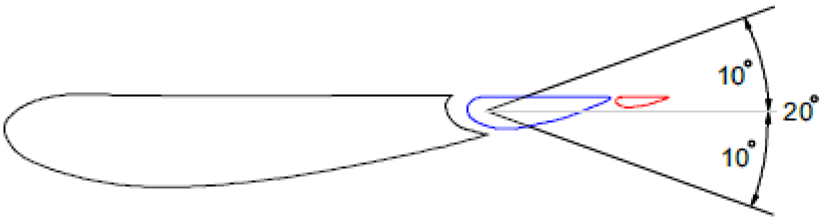
➔ Fixed Tab

Some trim tab are not adjustable in flight, but can be adjusted on the ground.

➔ Adjustable stabiliser / Trimmable stabiliser / Variable Incidence tailplane

This system of trimming may be used on manually operated and power operated controls. To trim, the tailplane or stabiliser incidence is adjusted by the trim wheel until the tailplane/stabiliser load is equal to the previous balancing load required.

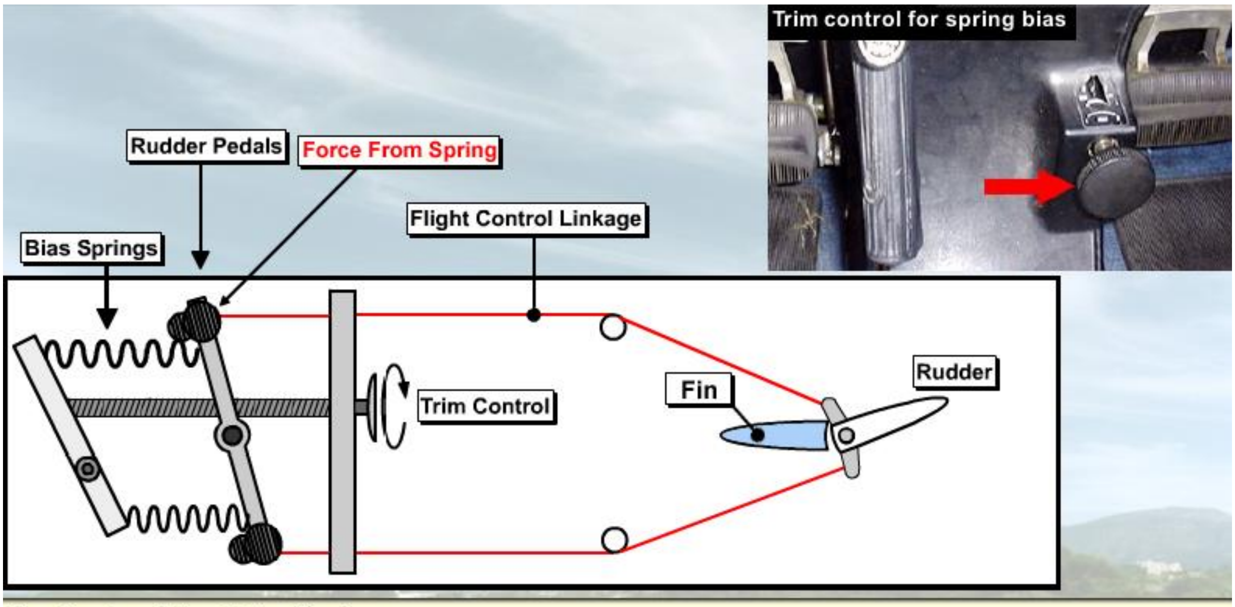




- The adjustable stabiliser will create less drag than the trim tab since it will remain streamlined into the airflow
- The adjustable stabiliser maintain the efficiency and authority of the control surface for a wider speed range.
- In the event of the adjustable stabiliser jamming or runaway, the pilot will not be able to control the aircraft.
- The adjustable stabiliser is more complex to make than the trim tab

➔ Spring Bias

In the spring bias trim system, an adjustable spring force is used to decrease the stick force. No tab is required for this system.



The Spring Bias Trim System.

➔ Artificial Feel Trim

If the flying controls are powered operated, there is no feedback of the load on the control surface to the cockpit flight control.

The feel on the controls has to be created artificially. When a control surface is moved, the artificial feel unit provides a force to resist the movement of the cockpit flight control. To remove this force, the datum of the feel unit can be adjusted so that it no longer gives any load on the flight deck control.

TABS – QUICK REFENRENCE GUIDE				
TYPE OF TAB	**OPERATED BY**	**MOVEMENT RELATIVE TO CONTROL SURFACE**	**STICK FORCE**	**CONTROL EFFECTIVENESS**
Balance	Control surface	Opposite	Less	Reduced
Anti-Balance	Control surface	Same	More	Increased
Servo	Pilot	Opposite	Less	Reduced
Spring	Pilot at high speed	Opposite at high speed	Less at high speed	Reduced at high speed
Trim	Trim control only	Opposite	Zero “deflection”	Reduced