SNS COLLEGE OF TECHNOLOGY

(An Autonomous Institution)

DEPARTMENT OF AERONAUTICAL ENGINEERING

Subject Code & Name**: 16AE309 Airplane Stability and Control** Date: **27.01.20**

DAY: **01** TOPIC: ***GENERAL ABOUT AIRCRAFT AND AIRPLANE***

A fixed-wing aircraft is an aircraft, such as an aeroplane, which is capable of flight using wings that generate lift caused by the vehicle's forward airspeed and the shape of the wings. An airplane or aeroplane (informally plane) is a powered, fixed-wing aircraft that is propelled forward by thrust from a jet engine or propeller. An aircraft is a machine that is able to fly by gaining support from the air. It counters the force of gravity by using either static lift or by using the dynamic lift of an airfoils, or in a few cases the downward thrust from jet engines.

He human activity that surrounds aircraft is called *aviation*. Crewed aircraft are flown by an on-board pilot, but unmanned aerial vehicles may be remotely controlled or self-controlled by on-board computers. Aircraft may be classified by different criteria, such as lift type, aircraft propulsion, usage and others.

The forerunner of the fixed-wing aircraft is the kite. Whereas a fixed-wing aircraft relies on its forward speed to create airflow over the wings, a kite is tethered to the ground and relies on the wind blowing over its wings to provide lift. Kites were the first kind of aircraft to fly, and were invented in China around 500 BC. Much aerodynamic research was done with kites before test aircraft, wind tunnels, and computer modelling programs became available.

The first heavier-than-air craft capable of controlled free-flight were gliders. A glider designed by Cayley carried out the first true manned, controlled flight in 1853.

Practical, powered, fixed-wing aircraft (the aeroplane or airplane) were invented by Wilbur and Orville Wright. Besides the method of propulsion, fixed-wing aircraft are in general characterized by their wing configuration. The most important wing characteristics are:

- Number of wings – Monoplane, biplane, etc.
- Wing support – Braced or cantilever, rigid, or flexible.
- Wing plan form – including aspect ratio, angle of sweep, and any variations along the span (including the important class of delta wings).
- Location of the horizontal stabilizer, if any.
- Dihedral angle – positive, zero, or negative (Anhedral).

A variable geometry aircraft can change its wing configuration during flight.

A *flying wing* has no fuselage, though it may have small blisters or pods. The opposite of this is a *lifting body*, which has no wings, though it may have small stabilizing and control surfaces.

Wing-in-ground-effect vehicles are not considered aircraft. They "fly" efficiently close to the surface of the ground or water, like conventional aircraft during take-off. An example is the Russian ekranoplan (nicknamed the "Caspian Sea Monster"). Man-powered aircraft also rely on ground effect to remain airborne with a minimal pilot power, but this is only because they are so underpowered—in fact, the airframe is capable of flying higher.

Subject Code & Name **16AE309 Airplane Stability and Control** Date: **27.01.20**

DAY: **02** TOPIC: ***DEGREES OF FREEDOM OF A SYSTEM***

1.1 INTRODUCTION

1.1.1 Aircraft:

An Aeroplane, helicopter or other machine capable of flight.

1.1.2 Stability:

The state of being stable.

1.1.3 Aircraft stability:

Stability is the tendency of an airplane in flight to remain in straight, level, upright flight and to return to this attitude, if displaced, without corrective action by the pilot.

1.1.4 Control:

Controls are a very reliable way to control worker exposures as long as the controls are designed, used and maintained properly.

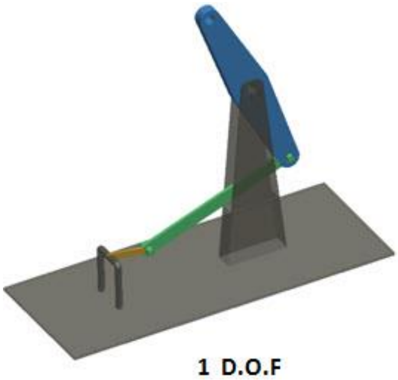
1.1.5 Aircraft control:

A conventional fixed-wing aircraft flight control system consists of flight control surfaces, the respective cockpit controls, connecting linkages, and the necessary operating mechanisms to control an aircraft's direction in flight. Aircraft engine controls are also considered as flight controls as they change speed.

1.1.6 Aircraft stability and control:

Aircraft stability and control is a fundamental result of dynamics: for rigid bodies motion consists of translations and rotations about the centre of gravity.

1.2 DEGREES OF FREEDOM



1 D.O.F

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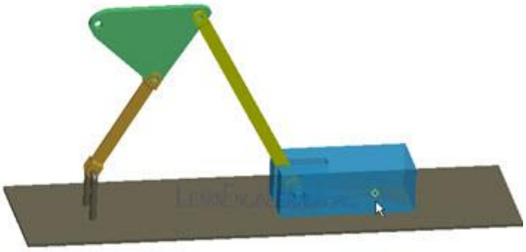


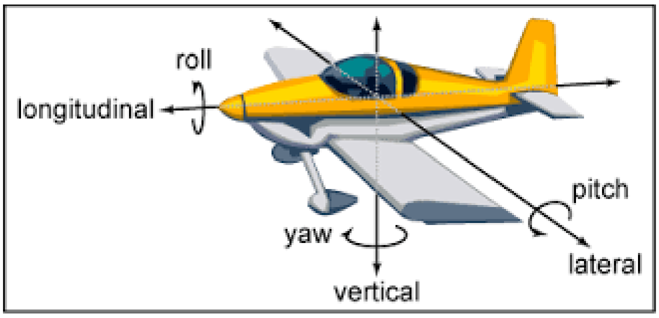
2 D.O.F

In physics, the degree of freedom (DOF) of a mechanical system is the number of independent parameters that define its configuration. ... The position and orientation of a rigid body in space is defined by three components of translation and three components of rotation, which means that it has six degrees of freedom

Degrees of freedom (mechanics), independent displacements and/or rotations that specify the orientation of the body or system.

Degrees of freedom (statistics), the number of values in the final calculation of a statistic that is free to vary.

1.2.1 Six Degrees of Freedom



Refers to motion of a rigid body in three-dimensional space, namely the ability to move forward/backward, up/down, left/right combined with rotation about three perpendicular axes (pitch, yaw, roll). As the movement along each of the three axes is independent of each other and independent of the rotation about any of these axes, the motion indeed has six degrees of freedom. Notice that the initial conditions for a rigid body include also the derivatives of these variables (velocity and angular velocity), being therefore a 12-DOF system.

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1.2.2 Translation and Rotation:

The trajectory of an airplane in flight has three degrees of freedom and its attitude along the trajectory has three degrees of freedom, for a total of six degrees of freedom.

The motion of a ship/aircraft at sea has the six degrees of freedom of a rigid body, and is described as:

1. Moving up and down (elevating/heaving)
2. Moving left and right (strafing/swaying)
3. Moving forward and backward (walking/surging)
4. Swivels left and right (yawing)
5. Tilts forward and backward (pitching)
6. Pivots side to side (rolling).

EXAMPLE: 1

1. What are degrees of freedom in robotics?

Part of the Robotics glossary: Degrees of freedom, in a mechanics context, are specific, defined modes in which a mechanical device or system can move. The number of degrees of freedom is equal to the total number of independent displacements or aspects of motion.

2. How many degrees of freedom are there in a human arm?

Elbow motion can occur only as pitch. Wrist motion can occur as pitch or yaw. Rotation (roll) may also be possible for wrist and shoulder. Such a robot arm has five to seven degrees of freedom.

3. How many degrees of freedom does a robot need to reach any point in space?

To access any point in space (within reach) from any angle, a robot needs six degrees of freedom: three arm movements and three wrist movements. Some robots have more than six degrees of freedom, some less, depending on the kind of work they do.

4. What are the six degrees of freedom?

Six degrees of freedom (6DoF) refers to the freedom of movement of a rigid body in three-dimensional space. Specifically, the body is free to move forward/backward, up/down, left/right (translation in three perpendicular axes) combined with rotation about three perpendicular axes, often termed pitch, yaw, and roll.

5. How many Degrees Of Freedom do the car having?

2 Degrees of Freedom, although it is restrained to One degree at a moment while traversing, but it can move into another degree perpendicular to the previous at will whenever required.

6. How many degrees of freedom are in the human body?

The human body has 244 degrees of freedom. There are around 230 joints in the body, most of which have one degree of freedom (DoF). Some joints have multiple degrees of freedom (DoF) - for example, the hip and the shoulder joints have atleast 3 DoF.

Subject Code & Name**: 16AE309 Airplane Stability and Control** Date: **27.01.20**

DAY: **03** TOPIC: **Static stability of an Airplane**

STABILITY

How stable is your aircraft? It depends on what you're flying. Let's take a look at why that's the case.

Two Types of Stability

Stability is the ability of an aircraft to correct for conditions that act on it, like turbulence or flight control inputs. For aircraft, there are two general types of stability:

1. **Static**
2. **Dynamic.**

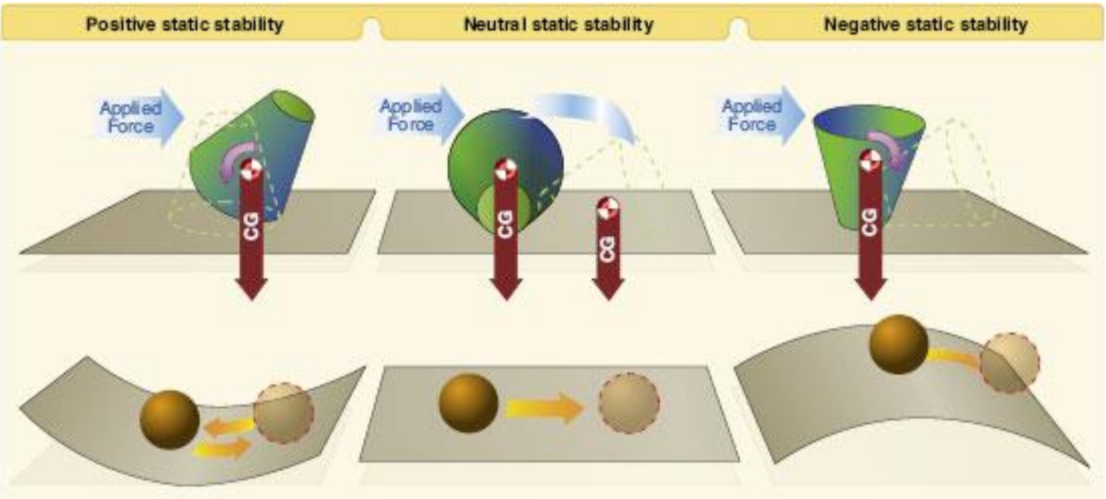
Most aircraft are built with stability in mind, but that's not always the case. Some aircraft, like training airplanes, are built to be very stable. But others, like fighter jets, tend to be very unstable, and can even be un-flyable without the help of computer controlled fly-by-wire systems.

Static Stability

Let's start with static stability. Static stability is the initial tendency of an aircraft to return to its original position when it's disturbed.

There are three kinds of static stability:

- Positive
- Neutral
- Negative



Positive Static Stability

An aircraft that has positive static stability tends to return to its original attitude when it's disturbed. Let's say you're flying an aircraft, you hit some turbulence, and the nose pitches up. Immediately after that happens, the nose lowers and returns to its original attitude. That's an example positive static stability, and it's something you'd see flying an airplane like a Cessna 172.

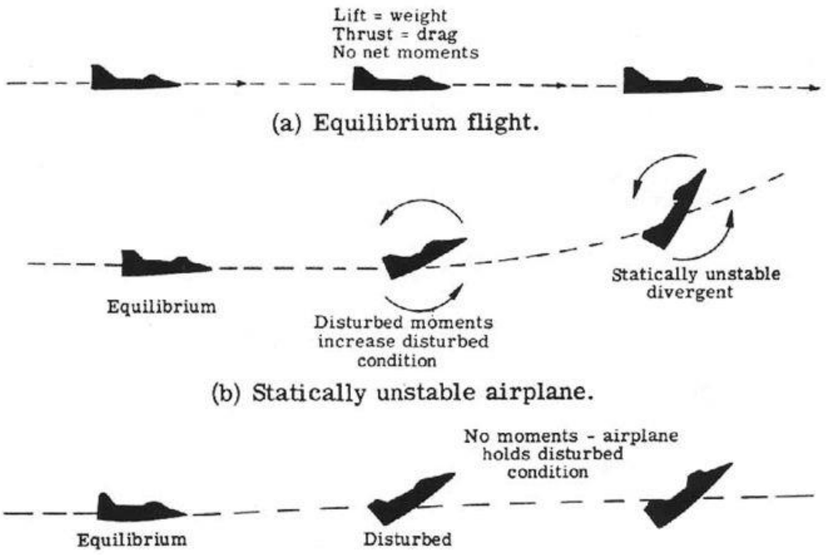
Neutral static stability

An aircraft that has neutral static stability tends to stay in its new attitude when it's disturbed. For example, if you hit turbulence and your nose pitches up 5 degrees, and then immediately after that it stays at 5 degrees nose up, your airplane has neutral static stability.

Negative static stability

Finally, an aircraft that has negative static stability tends to continue moving away from its original attitude when it's disturbed. For example, if you hit turbulence and your nose pitches up, and then immediately continues pitching up, you're airplane has negative static stability. For most aircraft, this is a very undesirable thing.

Static Stability



(a) Equilibrium flight.

(b) Statically unstable airplane.

(c) Neutral static stability.

Subject Code & Name: **16AE309 Airplane Stability and Control** Date: **27.01.20**

DAY: **04** TOPIC: ***DYNAMIC STABILITY***

USAF

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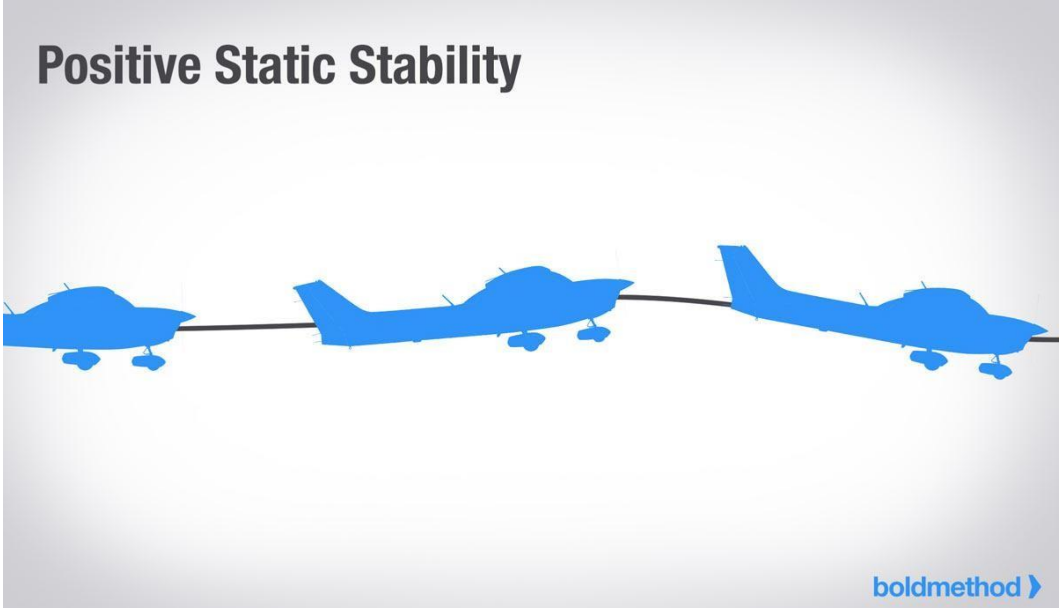

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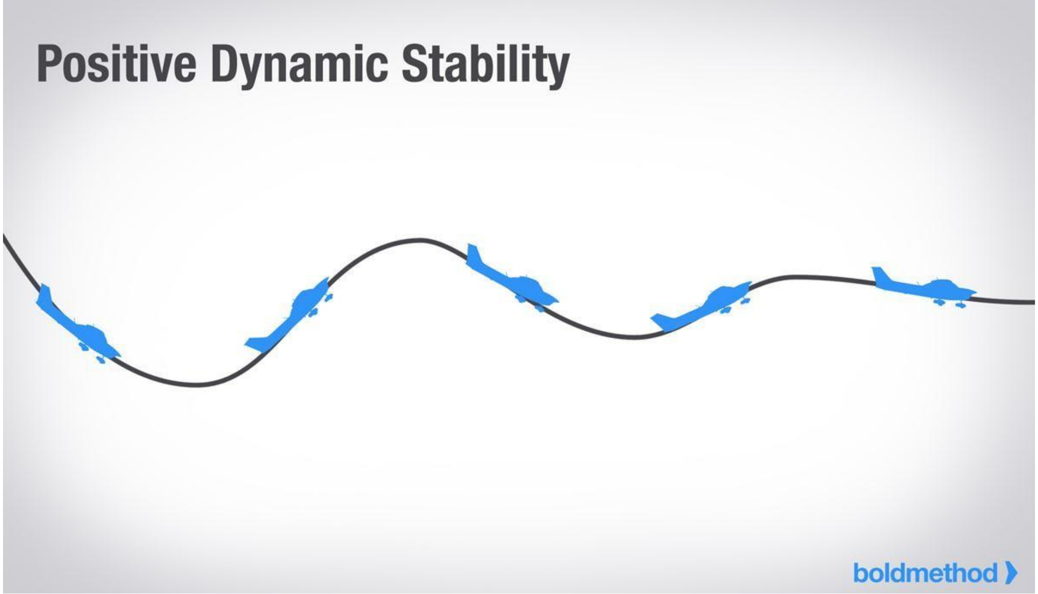
Dynamic Stability

Now that you have static stability down, let's go over the really fun one: dynamic stability. Dynamic stability is how an airplane responds over time to a disturbance. And it's probably no surprise that there are three kinds of dynamic stability as well:

- Positive
- Neutral
- Negative

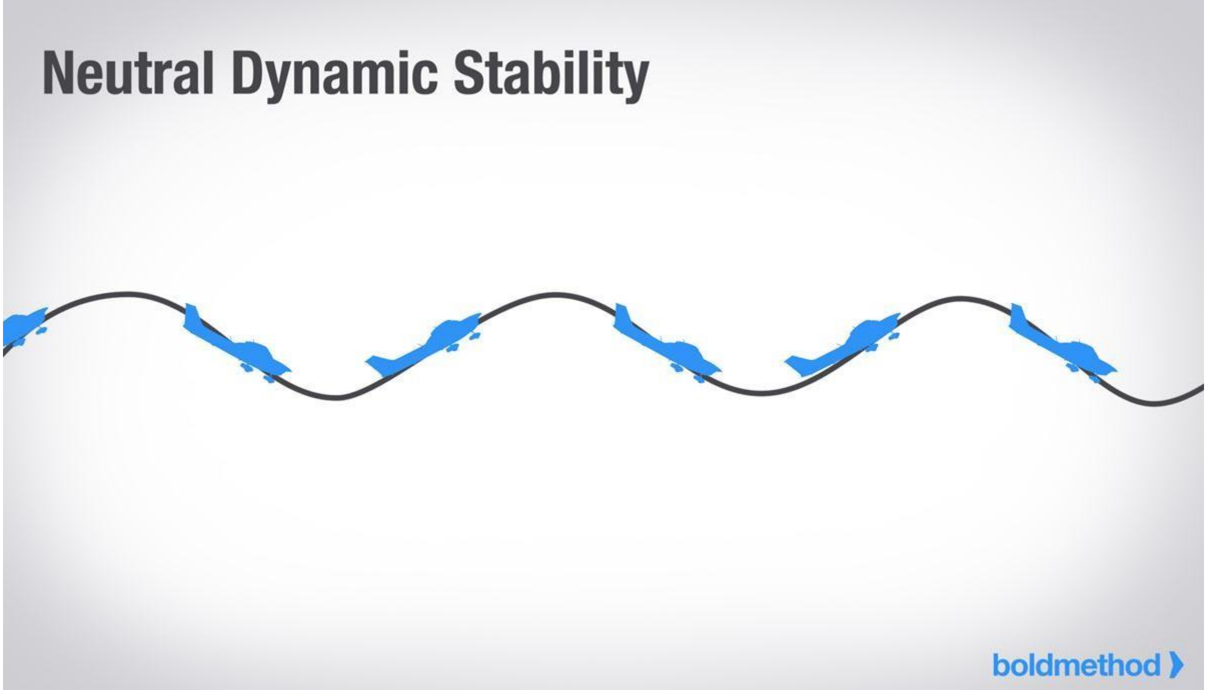
Positive Dynamic Stability

Aircraft with positive dynamic stability have oscillations that dampen out over time. The Cessna 172 is a great example. If your 172 is trimmed for level flight, and you pull back on the yoke and then let go, the nose will immediately start pitching down. Depending on how much you pitched up initially, the nose will pitch down slightly nose low, and then, over time, pitch nose up again, but less than your initial control input. Over time, the pitching will stop, and your 172 will be back to its original attitude.



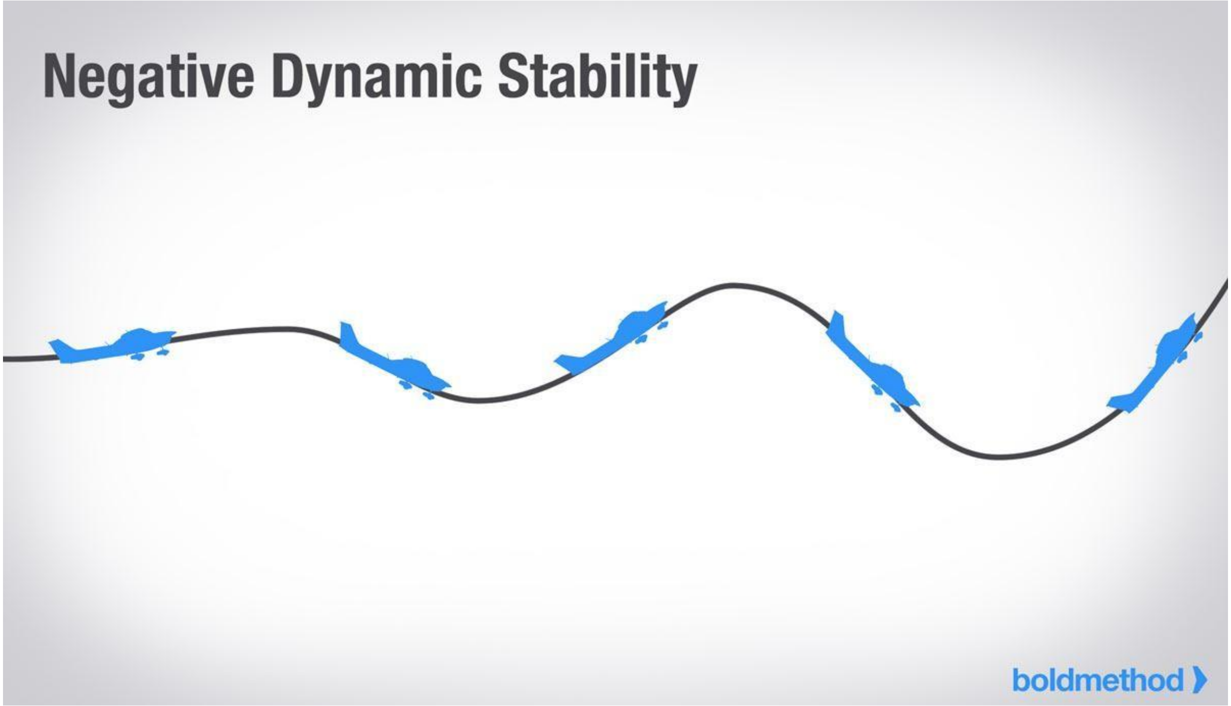
Neutral dynamic stability

Aircraft with neutral dynamic stability have oscillations that never dampen out. As you can see in the diagram below, if you pitch up a trimmed, neutrally dynamic stable aircraft, it will pitch nose low, then nose high again, and the oscillations will continue, in theory, forever.



Negative dynamic stability

Aircraft with negative dynamic stability have oscillations that get worse over time. The diagram below pretty much sums it up. Over time, the pitch oscillations get



more and more amplified.

Why Aren't All Aircraft Stable?

It really comes down to what your aircraft is built for. Stable aircraft, like Cessna and Piper training aircraft, are built to be statically and dynamically stable, making them easy to trim and fly 'hands off'.

However, jets like the F-16, are built to be unstable, making them highly manoeuvrable and easy to pitch, roll and yaw aggressively.

In a future post, we'll talk about the designs features that make those aircraft stable or unstable. Until then, enjoy the fact that your aircraft (most likely) doesn't have negative static stability.

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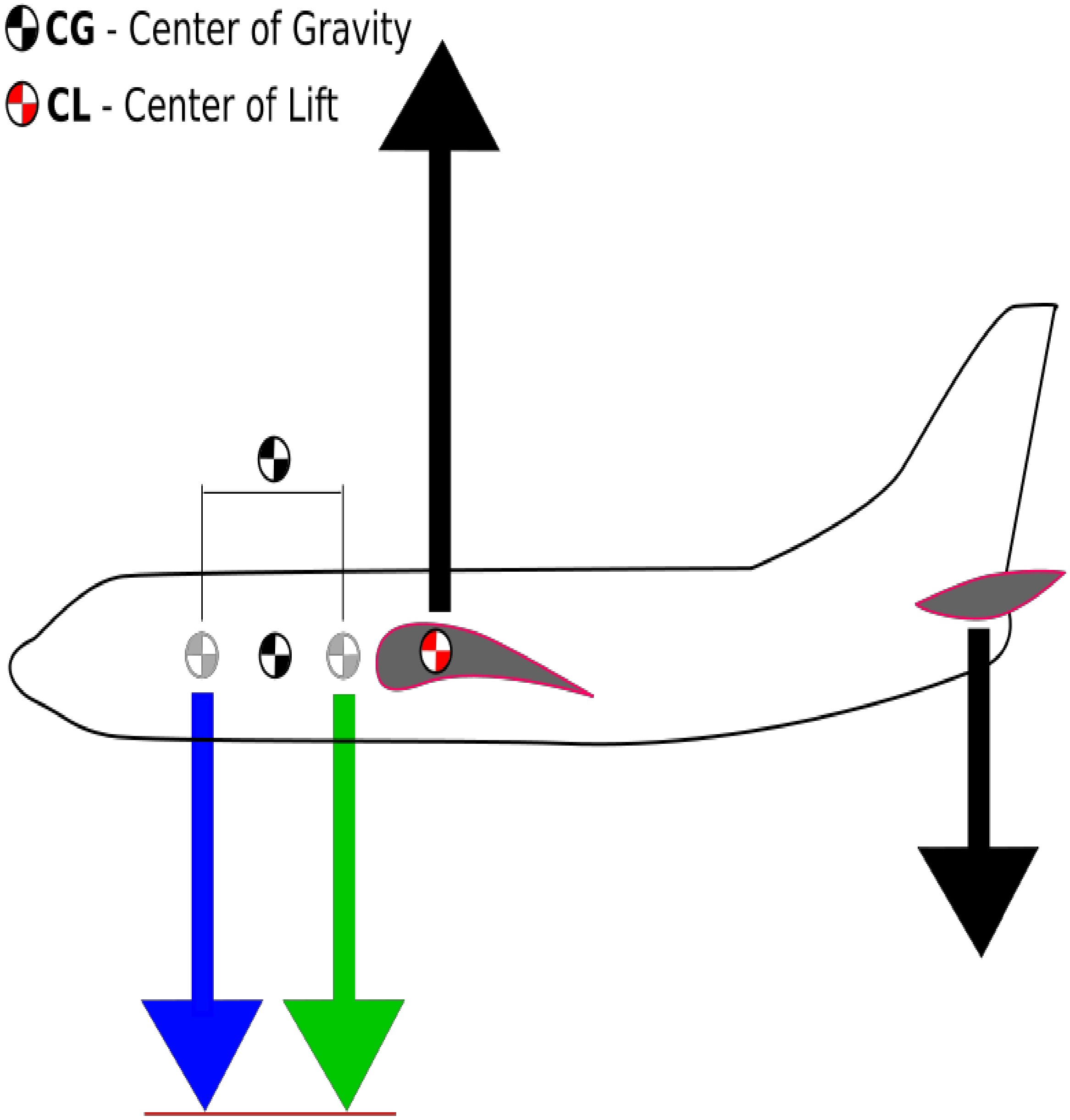
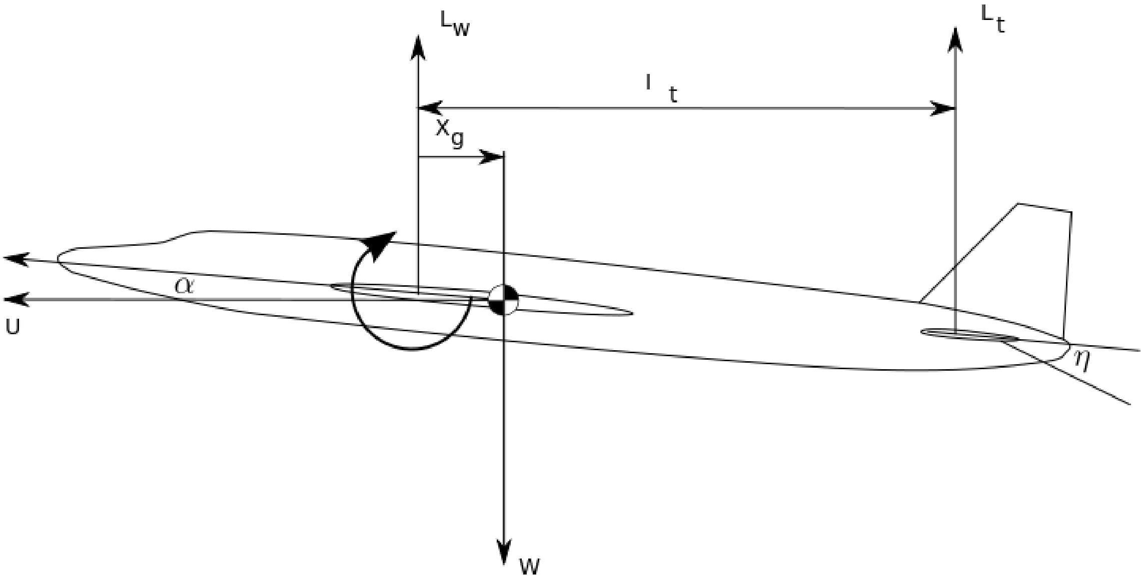
DAY:**5** TOPIC:***<u>Need for stability in an Airplane & Purpose of controls</u>***

Longitudinal **stability** is pitch **stability**, or **stability** around the lateral axis of the **airplane**. It is because of this nose heavy characteristic that the **airplane** requires a tailplane. Its **function** is to resist this diving tendency.





Aircraft in Level Flight

Roll, Pitch, and Yaw

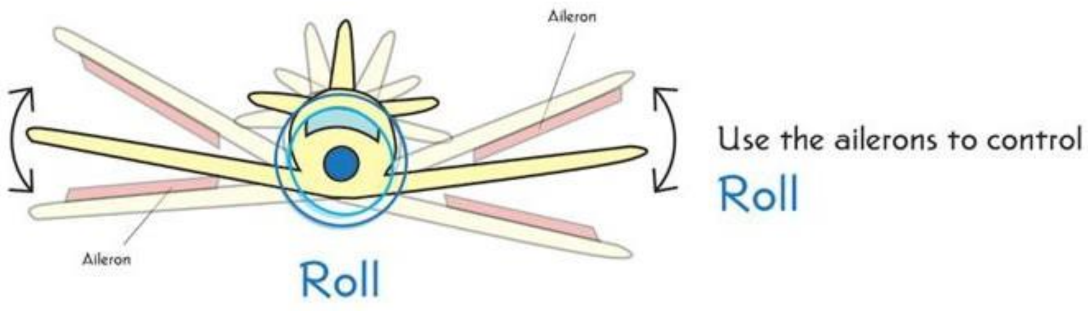
HOW IS CONTROLLING AN AIRPLANE DIFFERENT THAN CONTROLLING A CAR OR BOAT?

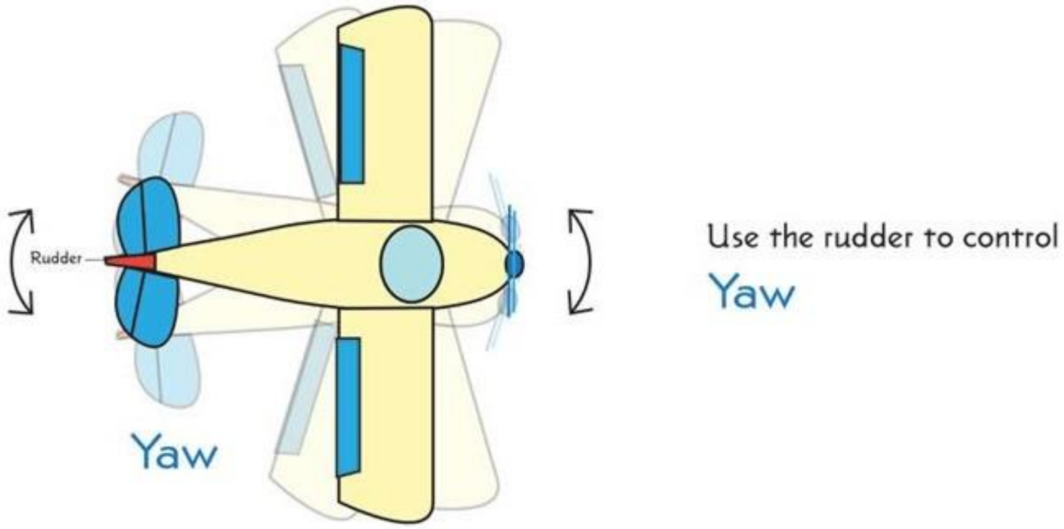
Stability and control are much more complex for an airplane, which can move freely in three dimensions, than for cars or boats, which only move in two. A change in any one of the three types of motion affects the other two.

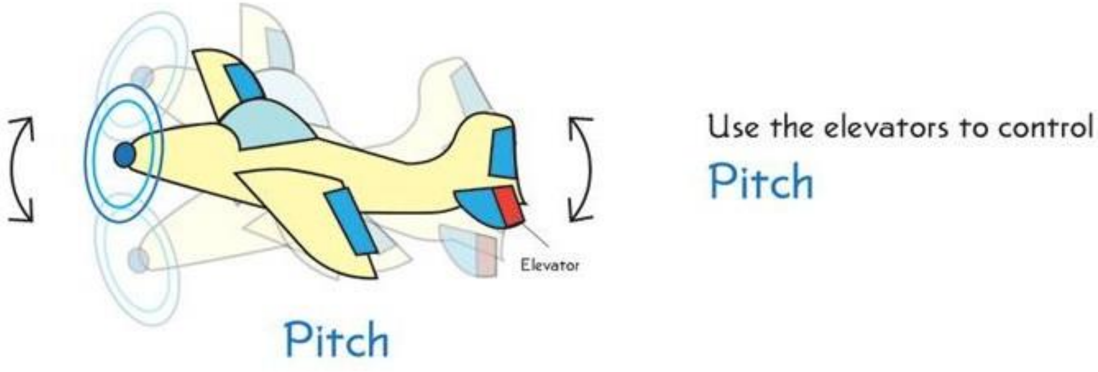
WHAT ARE ROLL, PITCH, AND YAW?

Imagine three lines running through an airplane and intersecting at right angles at the airplane's center of gravity.

- Rotation around the front-to-back axis is called **roll**.
- Rotation around the side-to-side axis is called **pitch**.
- Rotation around the vertical axis is called **yaw**.







The longitudinal axis of an aircraft is more or less a straight line through the aircraft's nose cone or prop hub and the endpoint of the fuselage (the aircraft's center of gravity will usually lie along or just slightly above/below this line as well). It is the axis around which the aircraft rolls, controlled by the ailerons. The lateral axis is parallel to the wings and passes through the aircraft's center of gravity. It is the axis around which the aircraft pitches, as controlled by the elevators. Finally, the vertical axis is "normal" (perpendicular in all directions to) the geometric plane formed by the longitudinal and lateral axes, parallel to the aircraft's primary lift vector and (in level flight) its weight vector. It is the axis around which the aircraft yaws, controlled by the rudder.

Rotation about any one axis is the job of one linked set of control surfaces as mentioned above. Stability in that same axis, roughly defined as keeping that line passing through your aircraft pointing in the same direction, is the job of the other two surfaces in concert, but primarily the one that would move the endpoints of that axis up or down relative to the aircraft. So, elevators provide lateral rotation to achieve longitudinal stability, and vice versa for ailerons.

It differs slightly for the vertical axis, as if your plane is both longitudinally and laterally stable, it's also "vertically stable", however the plane is longitudinally and laterally stable, but completely out of control, in a "flat spin". Stability in the vertical axis therefore is secondary to "directional stability", which keeps the longitudinal axis pointing in a particular direction along the geometric plane formed by the lateral and longitudinal axes. In this case the rudder both controls yaw and provides directional stability.

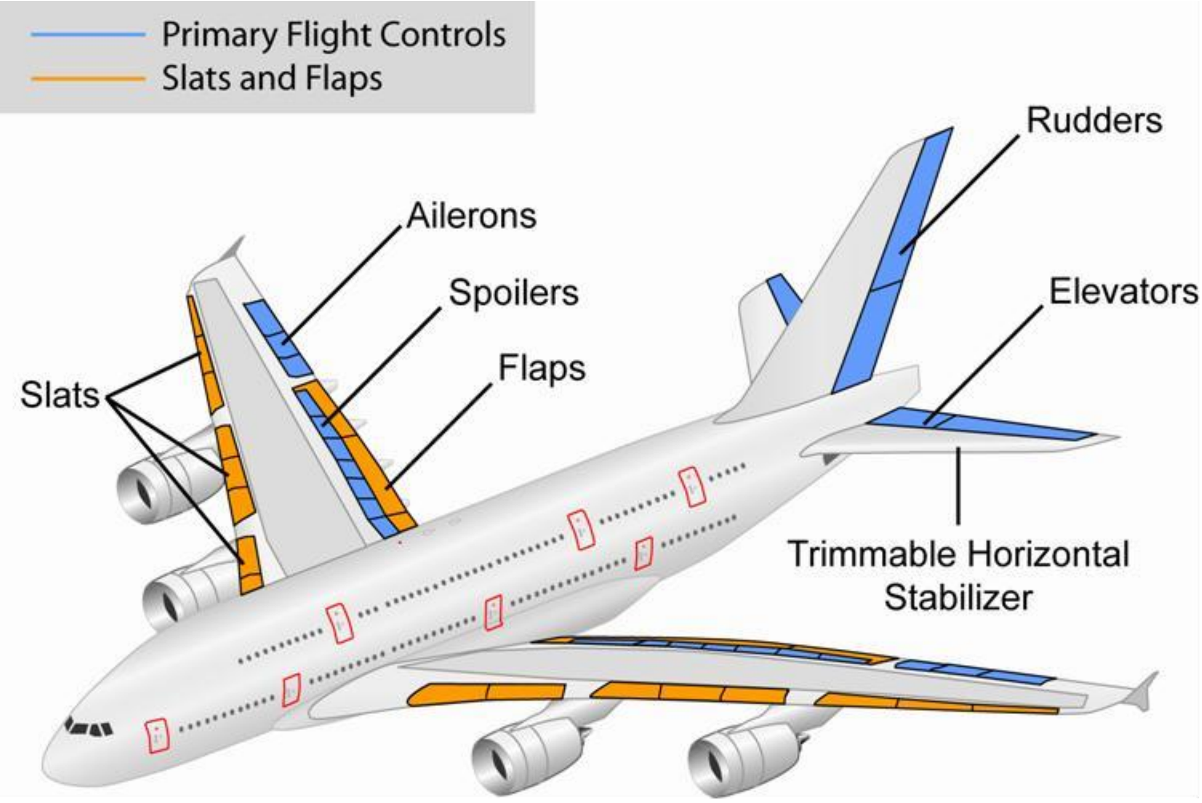
In addition to control surfaces, weight and especially the aircraft's center of gravity is important in stability. Ideally, most small planes are most stable in level flight when the CG of the aircraft is exactly on the centerline of the aircraft (between the tip of the nose and the tip of the tail) and slightly forward of the aircraft's center of lift (which depends on the wing's angle of attack but is usually close to the thickest point in the wing's cross-section). In this configuration, while the aircraft is travelling forward normally, downwash from the wings flow over the top of the horizontal stabilizer, keeping the nose level. In a stall, the slight nose-heavy configuration along with the stabilizers in the rear will cause the nose to point downward gently, restoring normal airflow and allowing the pilot to recover.

If the CG is too far forward, the pilot will need to apply upward pitch or trim to keep the nose level. This will reduce the amount of travel he will have available to pitch up, and in a stall, the plane will nose down sharply and the elevator may provide insufficient force for the pilot to pull out of the dive.

If the CG is too far aft, the plane will want to nose up constantly, and the pilot will have to apply downward elevator or trim. In a stall, a plane with an aft CG won't nose down, preventing the pilot being able to restore normal airflow over the wings. This is especially dangerous in an uncoordinated stall aka a spin; the aft center of gravity in combination with the forward thrust of the engine will "stabilize" the plane in the spin and make it impossible to recover.

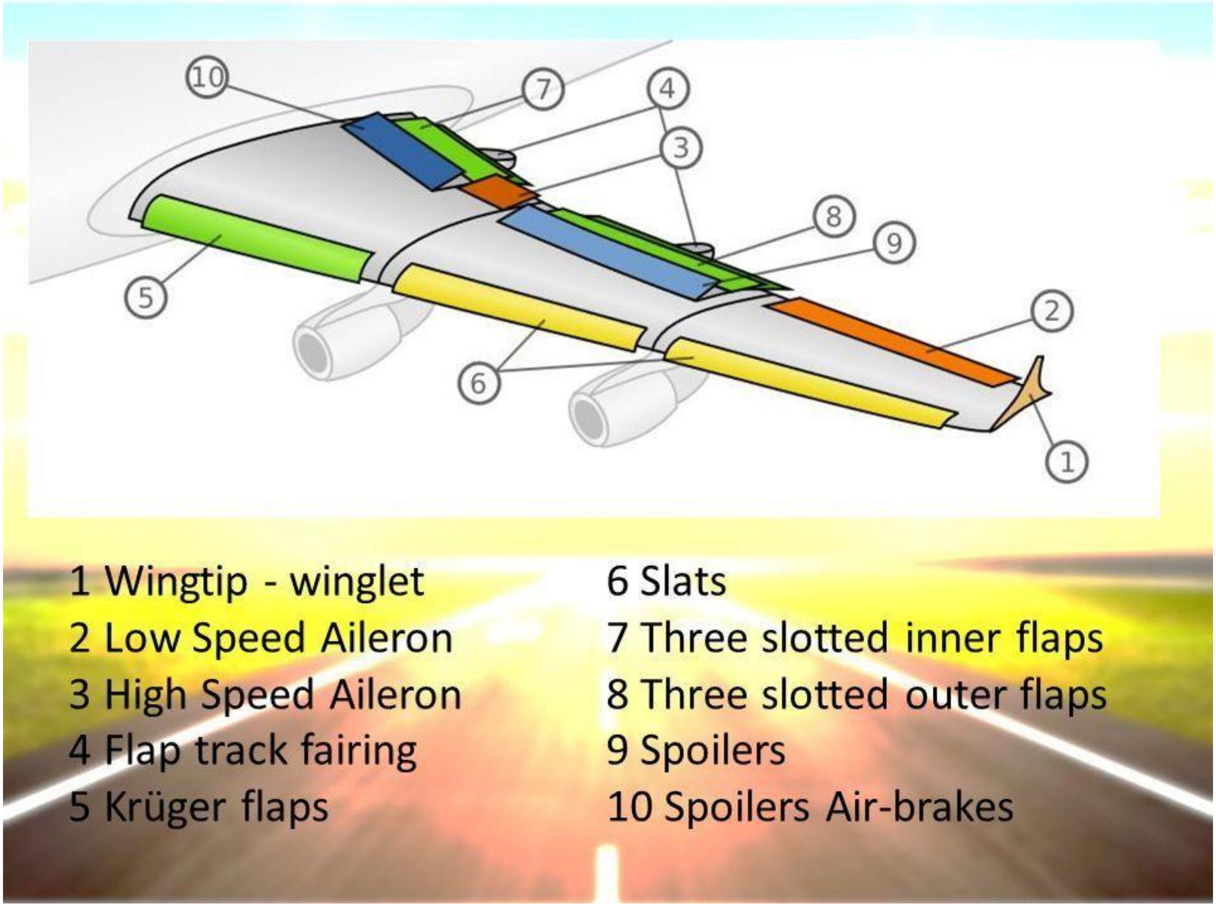
If the CG is off the aircraft's centerline, the plane will tend to roll towards its heavier side. This is compensated for with ailerons or aileron trim, and for most everyday flight it's the easiest to compensate for, but it can cause unfamiliar roll behavior and a tendency to spiral down, which the pilot must be aware of and correct for.

Purpose of controls



1. **Ailerons**
2. **Elevator**
3. **Rudder**
4. **Spoilers**

Flaps are mounted on the trailing edge on the inboard section of each wing (near the wing roots). They are deflected down to increase the effective curvature of the wing. Flaps raise the Maximum Lift Coefficient of the aircraft and therefore reduce its stalling speed.[5] They are used during low speed, high angle of attack flight including take-off and descent for landing. Some aircraft are equipped with "flaperons", which are more commonly called "inboard ailerons" These devices function primarily as ailerons, but on some aircraft, will "droop" when the flaps are deployed, thus acting as both a flap and a roll-control inboard aileron.



SLATS

Slats, also known as *leading edge devices*, are extensions to the front of a wing for lift augmentation, and are intended to reduce the stalling speed by altering the airflow over the wing. Slats may be fixed or retractable - fixed slats give excellent slow speed and STOL capabilities, but compromise higher speed performance. Retractable slats, as seen on most airliners, provide reduced stalling speed for take-off and landing, but are retracted for cruising.

AIR BRAKES

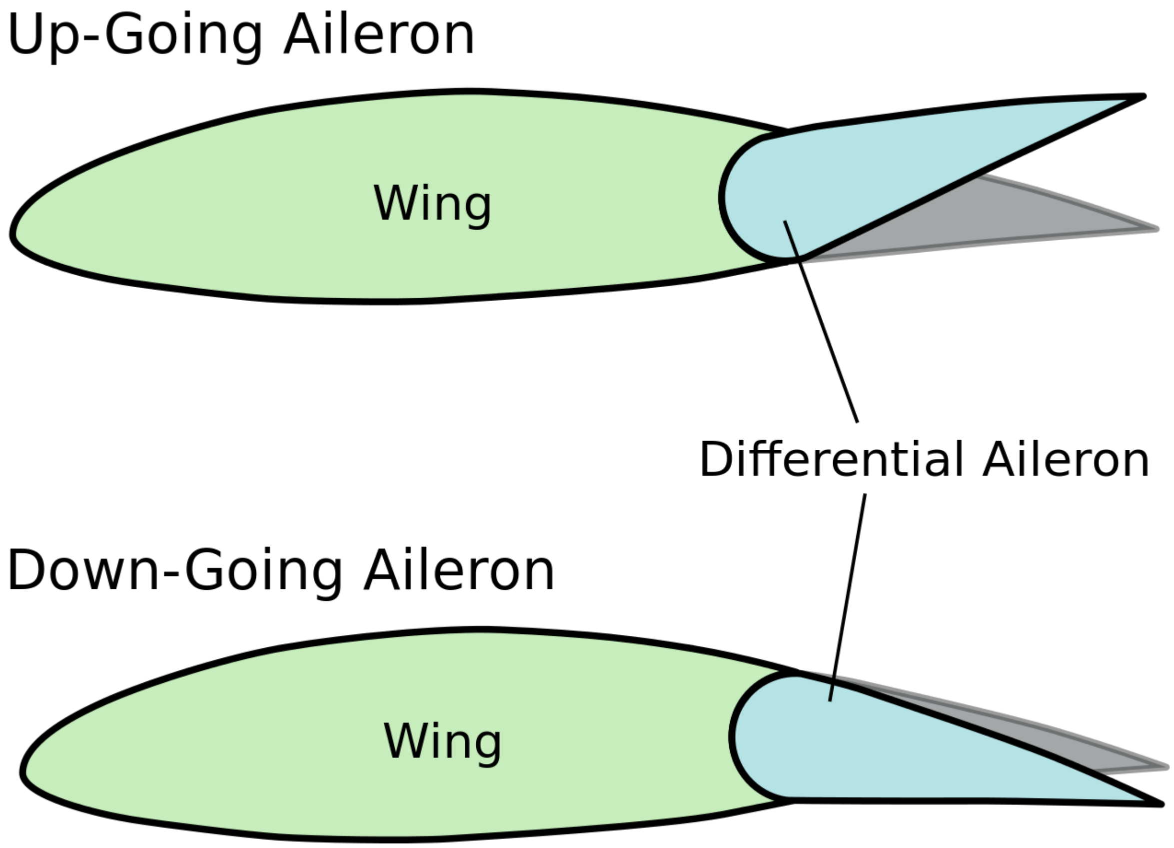
Air brakes are used to increase drag. Spoilers might act as air brakes, but are not pure air brakes as they also function as lift-dumpers or in some cases as roll control surfaces. Air brakes are usually surfaces that deflect outwards from the fuselage (in most cases symmetrically on opposing sides) into the airstream in order to increase form-drag. As they are in most cases located elsewhere on the aircraft, they do not directly affect the lift generated by the wing. Their purpose is to slow down the aircraft. They are particularly useful when a high rate of descent is required or the aircraft velocity needs to be retarded.

They are common on high performance military aircraft as well as civilian aircraft, especially those lacking reverse thrust capability.

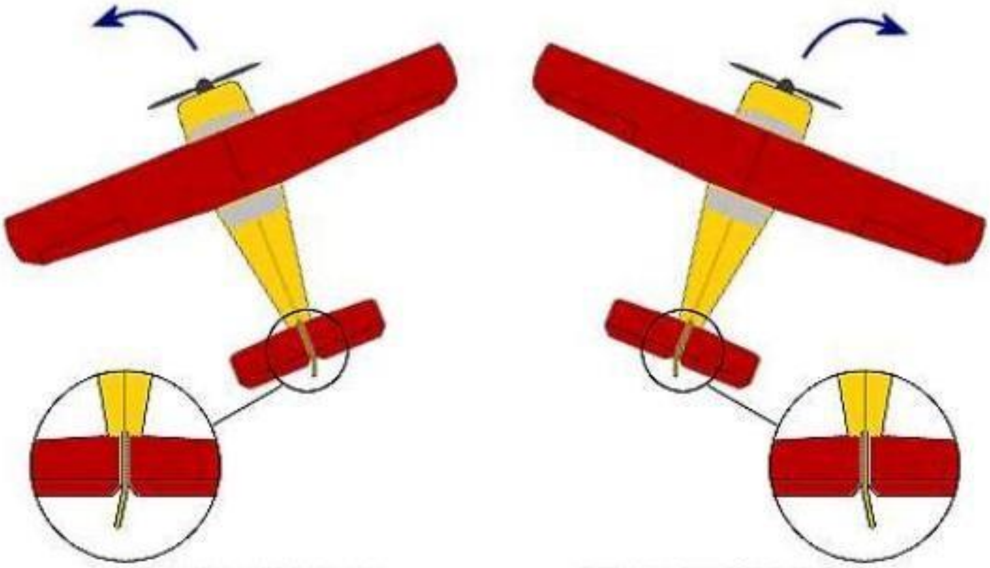
Elevator trim

Elevator trim balances the control force necessary to maintain the correct aerodynamic force on the tail to balance the aircraft. Whilst carrying out certain flight exercises, a lot of trim could be required to maintain the desired angle of attack. This mainly applies to slow flight, where a nose-up attitude is required, in turn requiring a lot of trim causing the tailplane to exert a strong downforce. Elevator trim is correlated with the speed of the airflow over the tail, thus airspeed changes to the aircraft require re-trimming. An important design parameter for aircraft is the stability of the aircraft when trimmed for level flight. Any disturbances such as gusts or turbulence will be damped over a short period of time and the aircraft will return to its level flight trimmed airspeed.

- Flaperon (flaps + aileron in one part)
- **Frieze Ailerons**



- When rudder is pushed left the air pushes aircraft to move left and similarly in the right direction.
- Thus a turn is the result of the combined inputs of the ailerons, rudder, and elevator.



Left rudder cause left yaw

Right rudder cause right yaw

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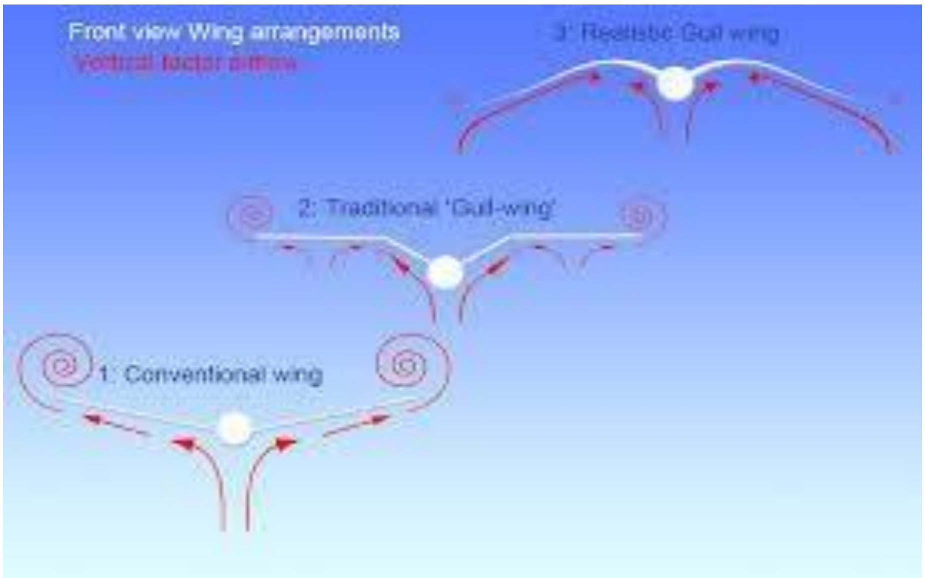
Subject Code & Name: **16AE309 Airplane Stability and Control** Date: **27.01.20**

DAY: **06** TOPIC: ***Inherently & Marginally stable Airplanes***

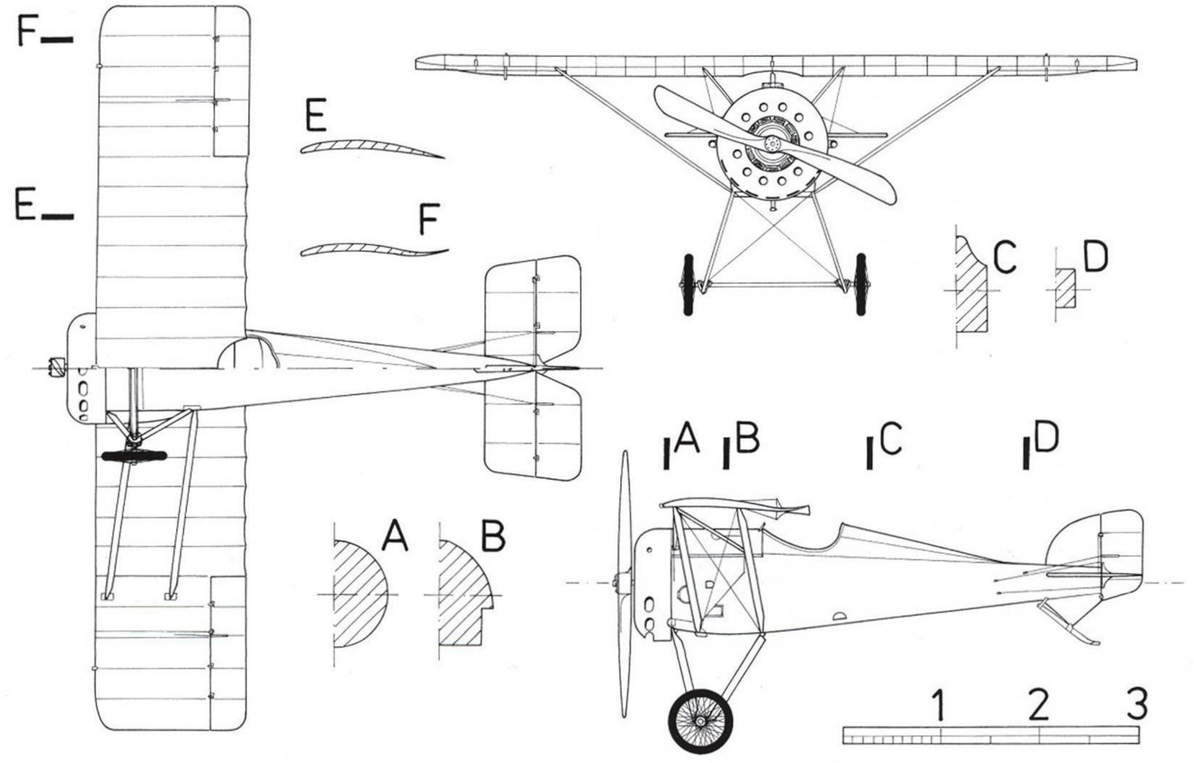
INHERENT INSTABILITY

What is inherent instability?

Inherent stability is the tendency of an aircraft to return to straight and level flight, when the controls are released by the pilot. Most aircraft are designed with this in mind and are said to be "**inherently stable**."

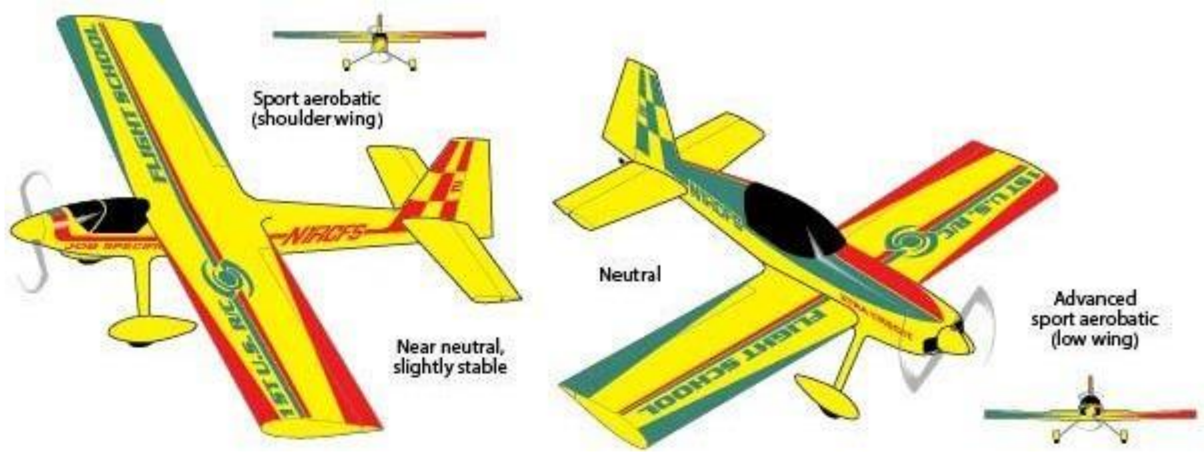


High-performance aircraft, such as fighter planes and aerobatic aircraft, often have little or no inherent stability and when the pilot releases the controls, the aircraft may bank or pitch in one direction or another. These aircraft take much more skill and concentration to fly safely, while the most sophisticated aircraft are computer controlled. Most civilian aircraft are designed to provide a high amount of inherent stability.

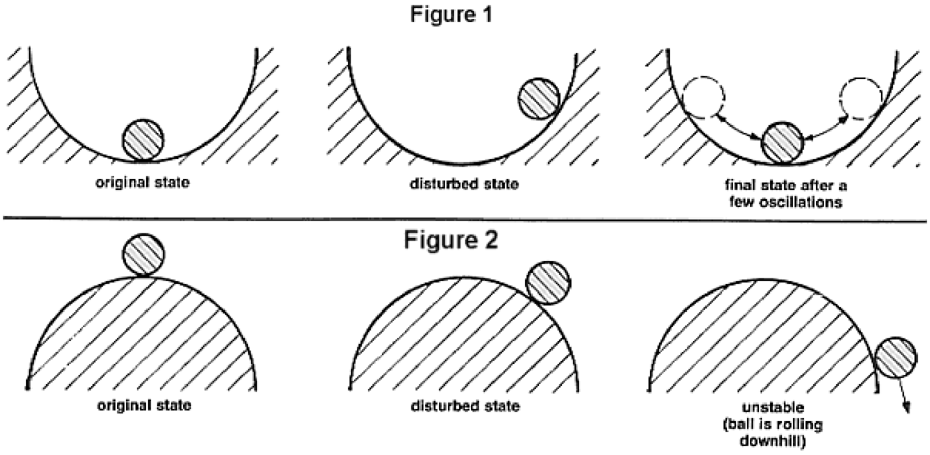


Inherent stability vs inherent instability

One of the Wright Brothers' breakthroughs was the realization that an inherently stable airplane is difficult to control in that it wants to keep following its original path. Therefore they designed their planes to be inherently Unstable. The resulting aircraft were easier to turn but when banked for a turn lift was lost, the aircraft stalled, and at the altitudes they flew at there was no room to recover. This, along with spins and the aircraft breaking up in mid-air became a leading cause of death for early flyers.

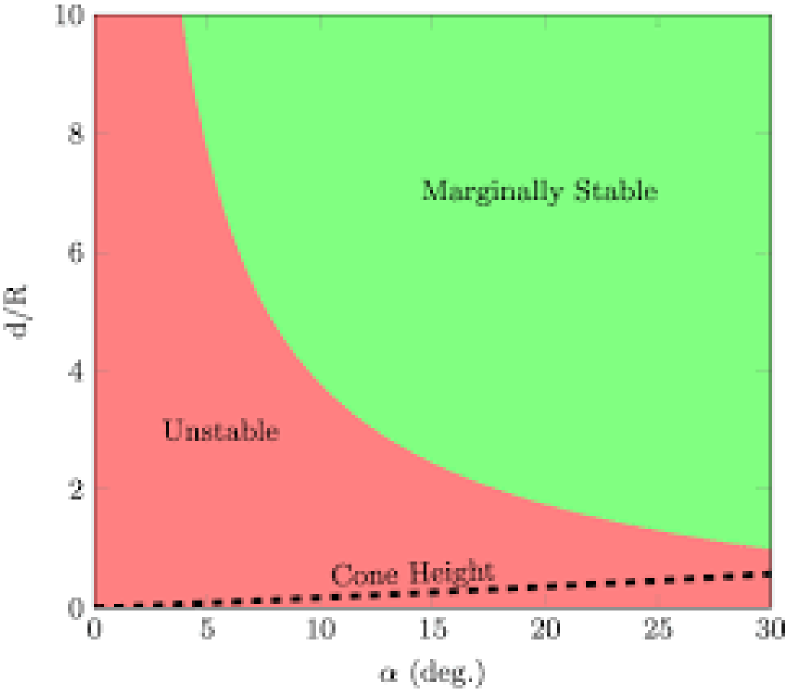


Free flight model airplanes are designed for inherent stability and any builder from Langley to the present can take one look at a Wright Flyer and say, "That could use more (some) dihedral." Why didn't the Wrights make this correction to their design, which used knowledge available to them, rather than burying so many pilots? Providing SOME inherent stability would not prove their theories wrong.



MARGINALLY STABLE AIRPLANE

In the theory of dynamical systems, and control theory, a linear time-invariant system is marginally stable if it is neither asymptotically stable nor unstable. Marginal stability is sometimes referred to as neutral stability.



A homogeneous continuous linear time- invariant system is marginally stable if and only if the real part of every pole in the system's transfer-function is non-positive, one or more poles have zero real part, and all poles with zero real part are simple roots (i.e. the poles on the imaginary axis are all distinct from one another). In contrast, all the poles have strictly negative real parts, the system is instead asymptotically stable. If one or more poles have positive real parts, the system is unstable.

If the system is in state space representation, marginal stability can be analysed by deriving the Jordan normal form:[2] if and only if the Jordan blocks corresponding to poles with zero real part are scalar is the system marginally stable.

A homogeneous discrete time linear time-invariant system is marginally stable if and only if the greatest magnitude of any of the poles of the transfer function is 1, and the poles with magnitude equal to one are all distinct. That is, the transfer function's spectral radius is If the spectral radius is less than the system is instead asymptotically stable. A marginally stable system is one that, if given an impulse of finite magnitude as input, will not "blow up" and give an unbounded output, but neither will the output return to zero. A bounded offset or oscillations in the output will persist indefinitely, and so there will in general be no final steady-state output. If a continuous system is given an input at a frequency equal to the frequency of a pole with zero real part, the system's output will increase indefinitely (this is known as pure resonance)This explains why for a system to be BIBO stable, the real parts of the poles have to be strictly negative (and not just non positive).

A continuous system having imaginary poles, i.e. having zero real part in the pole(s), will produce sustained oscillations in the output. For example, an undamped second-order system such as the suspension system in an automobile (a mass–spring–damper system), from which the damper has been removed and spring is ideal, i.e. no friction is there, will in theory oscillate forever once disturbed. Another example is a frictionless pendulum. A system with a pole at the origin is also marginally stable but in this case there will be no oscillation in the response as the imaginary part is also zero ($jw = 0$ means $w = 0$ rad/sec). An example of such a system is a mass on a surface with friction. When a sidewards impulse is applied, the mass will move and never returns to zero. The mass will come to rest due to friction however, and the sidewards movement will remain bounded.

Since the location of the poles must be *exactly* on the imaginary axis or unit circle (for continuous time and discrete time systems respectively) for a system to be marginally stable, this situation is unlikely to occur in practice.