Stability and Control

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Now that you know what goes into making sure that an aircraft stays in the air, you might be wondering how exactly aircraft are designed to be stable and easily controllable. For that matter, how are aircraft controlled at all? How do you decide where to place the wings and engines and fuel tanks? How do you ensure that it is as easy as possible for a pilot to fly the aircraft? In this module, we're going to be looking at the answers to these questions and more.

Center of Lift (COL) and Center of Mass (COM): Definition

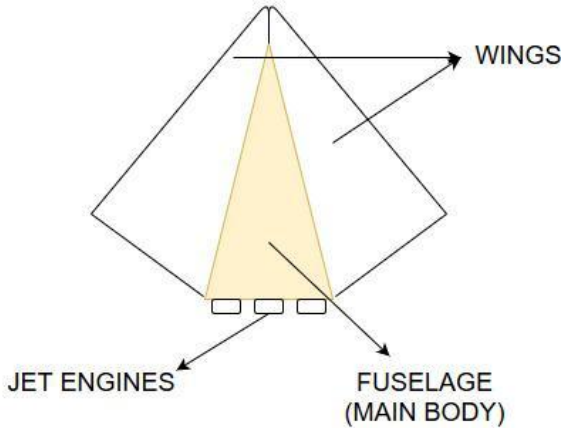
We have already studied how the lift force is generated. And we also know that it is generated by wings. However, later on we'll also learn how control surfaces and other aerodynamic fuselage parts play their part in this.

COL is a hypothetical point where the sum of all lift forces produced by wings, control surfaces etc. balance out. It may also be called the point where we can assume the net lift force is acting. Since it is quite difficult to analyse the lift forces from each part of the aircraft individually, we use this hypothetical point, where all the net effect of all the lift forces can be assumed to be acting.

COM is similar to the COL, it is just that it's a hypothetical point where we assume all the mass of a particular body to be concentrated. If the gravitational field is uniform across an object (which is true for almost all practical purposes in the scope of this course), this is the same point where the net effect of all the gravitational forces acting on all parts (wings, fuselage, control surfaces etc.) is acting. If you do not much knowledge about COM I recommend you to read this article (and do the problems given in this article, otherwise it'll become difficult to visualise the location of COM. Once, you get what COM is, you can easily make out what COL is from the name itself.

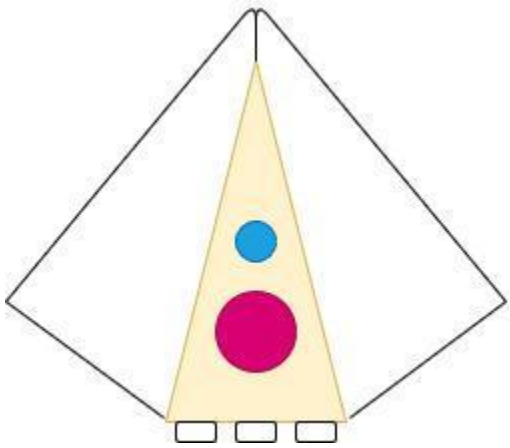
Relative Location of COL and COM

COL and COM may lie on an aircraft or outside an aircraft. The relative location of these points defines the stability of an aircraft. A key element of aircraft aerodynamics is to decide the location of various parts including wings, aerodynamic fuselage parts and control surfaces keeping in mind the location of COL and COM. To know why, let's analyse this aircraft –

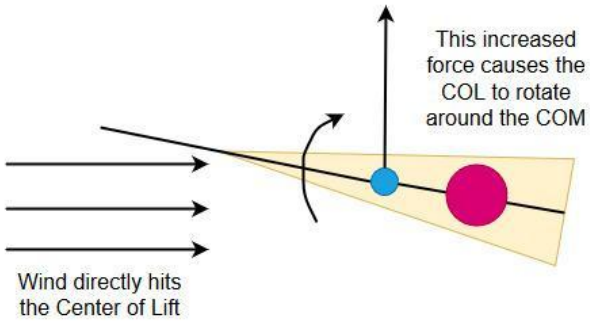


Top View

There's something different in this aircraft. Did you notice that the heavier parts (fuselage, jet engines) are concentrated behind the relatively lighter part (the wing). However, the parts which are responsible for the lift force is concentrated relatively ahead of the parts which won't generate lift. This makes the COM be behind the COL. If you have a good idea of how to find the COM, you know why.



The COM will be somewhere in the grey ball and the COL will be somewhere in the blue ball. COM and COL are actually points, but i've used these balls to just illustrate their rough position.



Side View of Aircraft

Now, what this does is that, as you get your aircraft to a nose high position, the wind hitting the wings and is applying pressure on that blue ball. This created a torque and pushes it around the center of mass increasing the Angle of Attack, this further increases the force thereby having an unstable situation.

I suggest you to open up Kerbal Space Program, and try this on your own. Make a similar aircraft in the spacecraft hangar in KSP (of course XD) and see what happens.
So where should we exactly position the COL and COM in order to have a stable flight? Well, let's analyse all situations.

1. We already know that placing the COL ahead of COM will lead to an unstable flight.
2. If the COL is inside the COM, i.e. we position the aircraft parts in such a way that the blue ball lies inside the grey ball, the aircraft is maneuverable. However, it is still not perfect. In order to know why, try out this in Kerbal Space Program!
3. The aircraft is more stable and maneuverable is we place the COL just behind the COM. This is because the air pressure coming from the front is not able to rotate the COL around the COM. In order to do that, the air should come towards the aircraft from the opposite direction.
4. Placing the COL very far behind the COM is not a good idea either.

However, deciding the position of aircraft parts isn't this simple. This is because the location of COM of a particular aircraft isn't constant. As the aircraft is continuously using its fuel, the mass of the aircraft in the region where fuel tank is placed is getting reduced continuously. So, you need to analyse both situations – first, before takeoff when it hasn't used any fuel and then make sure that the COL is never ahead of the COM when the fuel is being consumed.

Control Surfaces

Flying an aircraft not only requires lifting it up and landing it, but it also involves controlling its orientation, in order to make it more stable. The technical term for orientation in this context is attitude. Attitude is the orientation of something in space, measured on 3 angles. The angle around the –

- X-axis (along the length of the plane) is called "roll",
- Y-axis (along the length of the wings) is called "pitch"
- Z-axis (vertical axis) is called "yaw"

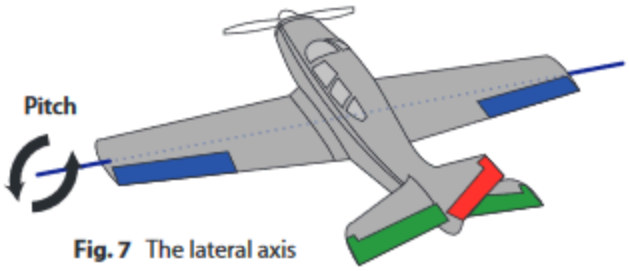


Fig. 7 The lateral axis

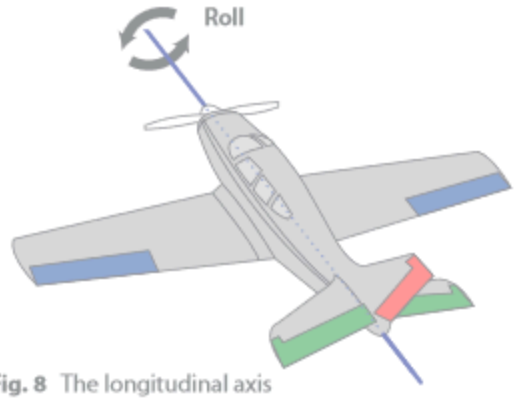


Fig. 8 The longitudinal axis

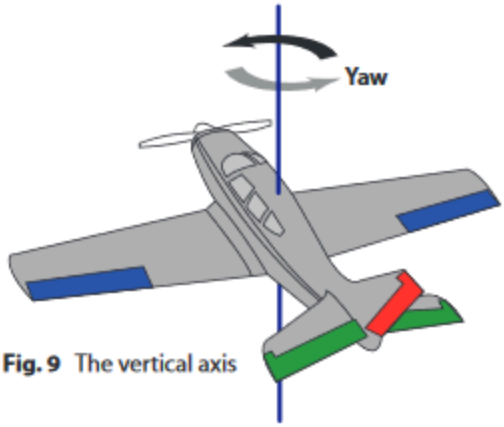
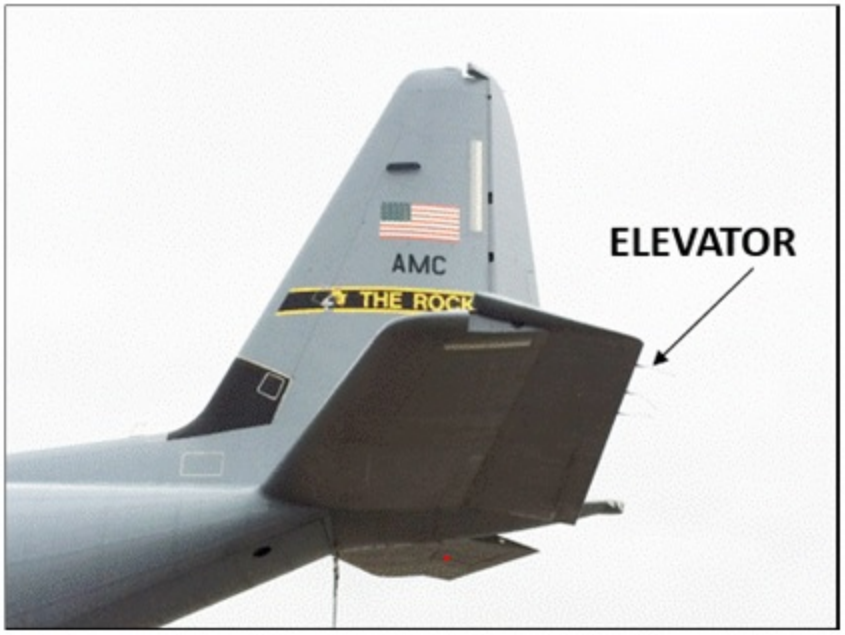


Fig. 9 The vertical axis

Source

Now, the attitude of an aircraft can be controlled using control surfaces.
There are many types of control surfaces including: elevator, aileron, rudder (to alter the pitch, roll and yaw respectively), flaps and wingtip devices.

1. Elevator: Elevators are placed at the rear end of an aircraft and are used to control its pitch. When the pitch of an aircraft changes, its angle of attack also changes. So, they are used to either increase or decrease the angle of attack, in order to make it climb or descend.



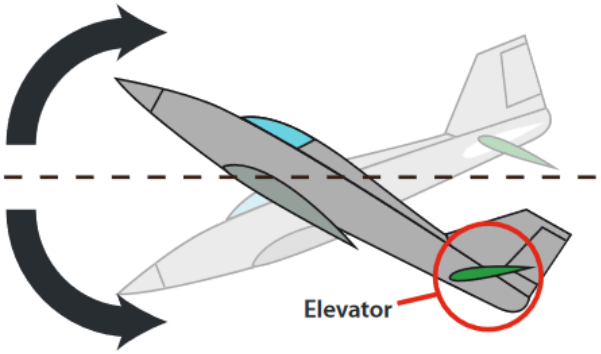


Fig. 4 Elevator and pitch movement

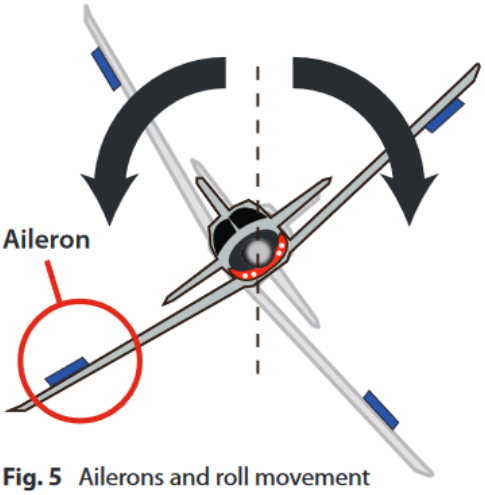
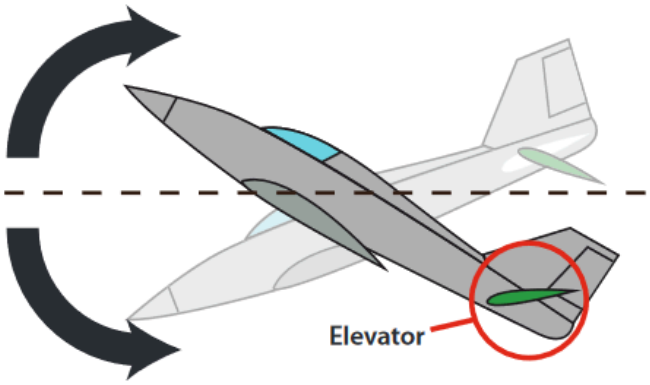


Fig. 5 Ailerons and roll movement

2. Aileron: An aileron is located at the trailing edge of a wing, and are used to alter the roll of an aircraft. They work together such that when one's lifted up, the other goes down. This changes the lift force on the two wings causing a rotation about the length of an aircraft.



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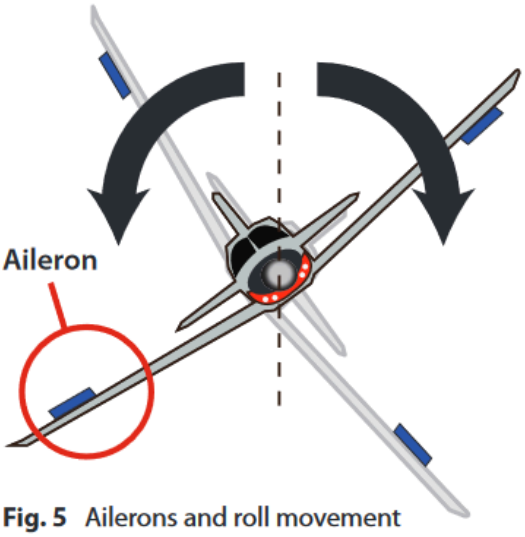
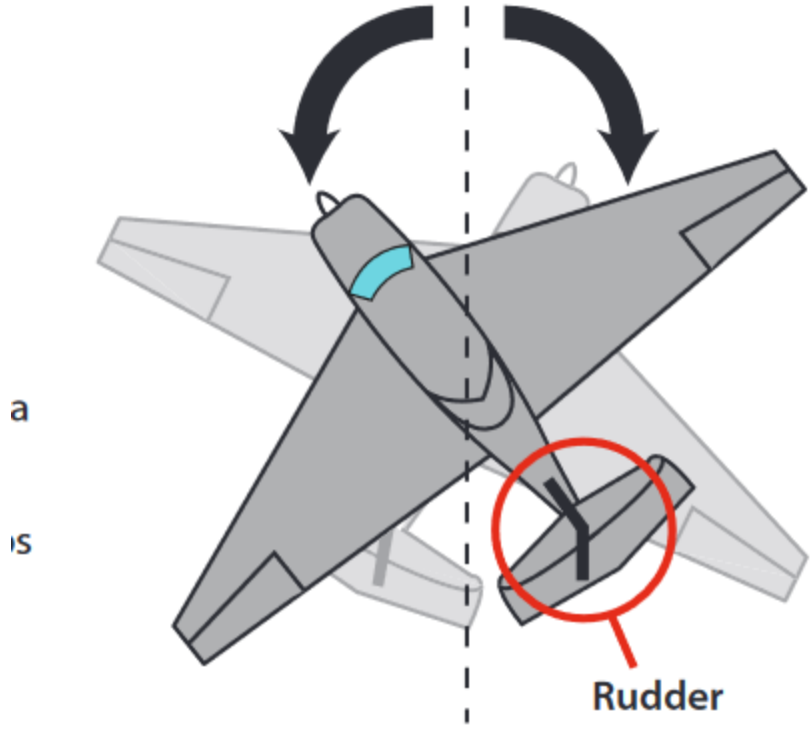


Fig. 5 Ailerons and roll movement

3. Rudder: These are attached to the fins of an aircraft and are used to alter its yaw. That is, it's used to steer the aircraft left and right. However, when an aileron is lowered, it produces drag, and the main purpose of a rudder is do reduce that drag.

Rudder – marked red



In order to turn, aircraft use a combination of all three control surfaces. First, the aircraft enters what is known as a bank, wherein it uses its ailerons to tilt in the direction it wants to turn. Next, it uses its elevators to pitch "up," which ensures that the aircraft maintains altitude and some of the upward force from the elevators is being put into the turn, making the aircraft turn very efficiently. All this time, the rudder is used to decrease the radius of the turn by adding a yaw moment.

If you have studied rotational motion, you might realize that the placement of these control surfaces will be key in determining their effectiveness. Even if you have not, this is pretty easy to understand – it's the same mechanism that makes it easier to open a door by pushing on it at the handle instead of the hinges. The farther away the control surfaces are placed from the COM, the more effective they will be. This is why ailerons and elevators are always on the wingtips and tail.

Assignments on stability and control

1. What happens if the COL is very far behind the COM?
2. By what mechanism do control surfaces exert torque on the aircraft?
3. What are spoilers? What is their role?

Further research

- https://i.imgur.com/GqLQktX.jpg (highly recommended)

- https://www.boldmethod.com/learn-to-fly/aircraft-systems/canards/
- https://www.youtube.com/playlist?list=PLYu7z3I8tdElgyB7BU0J1bHIYai1Qqn3U (3 video playlist)
- https://www.nasa.gov/sites/default/files/atoms/files/axes_control_surfaces_5-8.pdf