How do they fly? – lift and pitch stability and how to achieve it

by George Lungu

- This tutorial explains basics of airplane flight focusing more on what is lift and what it takes to get a stable flight.

What is a flying wing?

- A flying wing is an aircraft without a tail, typically without a horizontal stabilizer.
- Usually, this type of plane has vertical surfaces at the tip of the wings which besides lowering drag also improve stability to a certain extent.
- Despite many years of development from many directions, this type of structure is not practical for real world aviation (drastic stability issues function of the gravity center position and low maneuverability).
- The stealth bomber and some other planes (mainly experimental) have been using this configuration.
-The advantages of the flying wing, a somewhat lower drag and very good looks are relatively minor compa-red to its practical drawbacks.
-As long as the design teams are mainly composed of guys who are charmed by nice shapes, somebody somewhere will always try to design "the plane of the future" in the shape of a wing.
-For the RC enthusiast the flying wing is a boon: simple to build, sturdy, cool looking and interesting to fly.

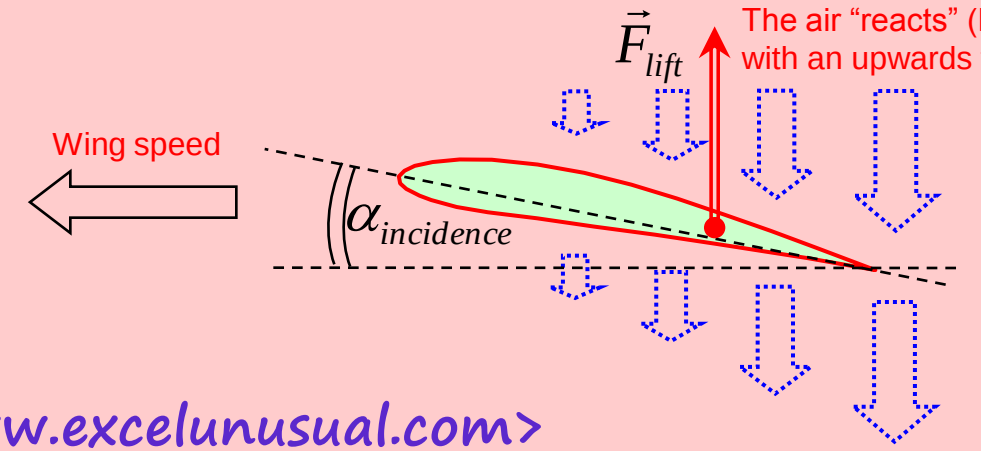
"The X-48 is an experimental unmanned aerial vehicle for investigation into the characteristics of blended wing body (BWB) aircraft, a type of flying wing. It is currently under development by Boeing and NASA." - Wikipedia

A quick practical introduction – how do planes fly:

- Relatively few people other than designers, some pilots and some airplane modelers truly understand this issue. There is so much misunderstanding published everywhere. This introduction deals strictly with lift generation and flight stability, not with controlling the aircraft and secondary effects.

Lift generation:

- The main factor in generating lift is the "wedge effect" and NOT the Bernoulli effect. While driving at 40-50 mph get your hand out of the window and holding it like a blade try tipping it at various angles and see how the lift can be varied with the angle of incidence, between positive and negative.
- There are planes with symmetric airfoil (no significant Bernoulli effect) which still fly, and they fly well. Most of regular airfoils will fly inverted with the proper angle of incidence.
- Efficient airfoils (especially on gliders) rely on some Bernoulli effect but the main mechanism for generating lift still remains the "wedge effect", by which a positively tilted wing will deflect the air down hence will impart an acceleration by exerting a down force on the air molecules (Newton's 2nd law). By Newton's 3rd law, the air will react with an opposite and equal force pushing the wing upwards.
- Just remember this, your bedroom door will fly OK with the proper speed and angle of incidence.



Air is being accelerated by the positively tilted airfoil in motion (due to tilt and speed, the airfoil exerts a down force on the surrounding air). ***It's similar to hitting ping-pong balls at a grazing angle (the bat exerts a down force on the balls and the balls will react by exerting an up force on the bat –> the lift).***

Flight stability – compensating momentums and the role of the horizontal tail:

- Empirically building airplane models from an early age (simple cardboard planes occasionally with rubber motors) I found out that a plane had to be balanced to fly by adjusting both aerodynamic surface angles and the position of the center of gravity.

- I found out by trial and error that an increase in the angle of attack of the main wing for instance can be compensated by a forward displacement of the center of gravity. I also found out that a down tilt of the horizontal stabilizer is equivalent to the same but opposite tilt in the angle of attack of the main wing. I later found out that the larger the difference between the incidence angle of the main wing and the horizontal stabilizer the more stable the plane but the higher the drag (lower efficiency and steeper the gliding ratio).

- Even later, while in grad school, I understood how a flying wing works with either the tips of the swept wing acting as a horizontal stabilizer (negative angle of attack at the extreme tip) or by using a special "reflex" airfoil with a raised trailing edge which acts as a airfoil-incorporated horizontal stabilizer.

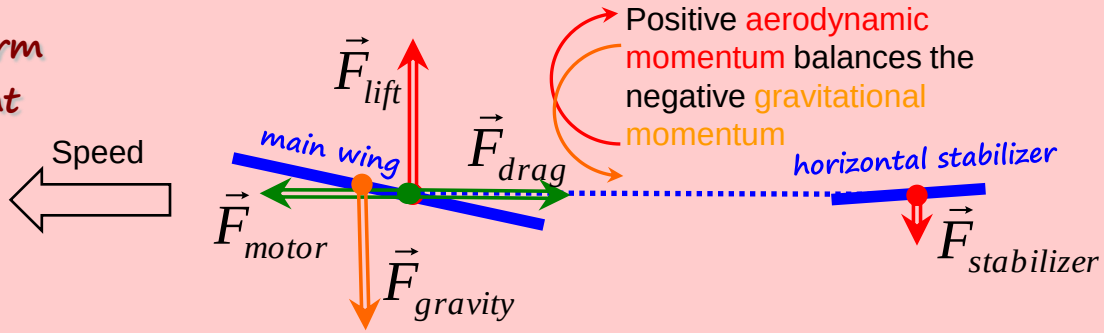
- Flight stability involves two simultaneous conditions: positive aerodynamic momentum and negative and equal in magnitude gravitational momentum. The positive aerodynamic momentum is created by having the tail at a negative angle compared to the main wing. Good stability is insured by having these two momentums much larger than the plane momentum of inertia.

- The negative gravitational momentum is created by having the gravity center in front of the plane (more correctly in front of the aerodynamic center of pressure). Have you ever wondered why the crew of a partially filled plane will always talk the passengers into moving to the front seats? The answer is stability. If hypothetically, all the passengers of an airliner would crowd near the back bathroom at once, the plane will loose control and fall off the sky. The plane is calculated to fly stable at full capacity with the passengers uniformly distributed but not with half capacity and all passengers in the back.

Flight stability – continuation:

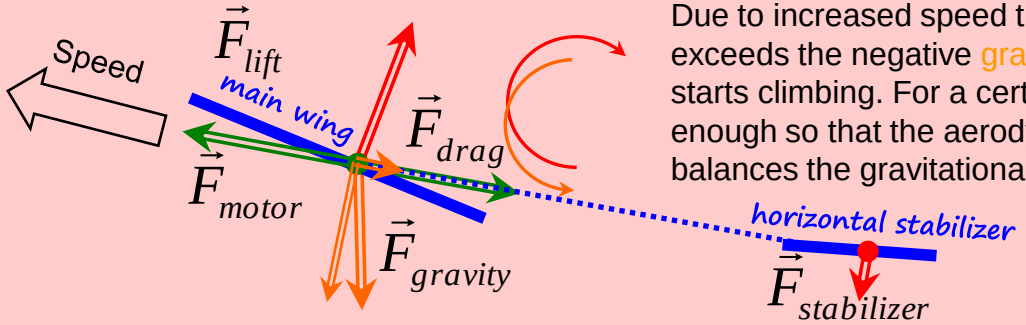
- You can clearly see the negative tilt of the horizontal stabilizer (upper right) compared to the main wing.
- Let's prove that the two momentums, a positive aerodynamic momentum and a negative gravitational momentum, while balanced create a stable configuration. This means we will try to prove that introducing a disturbance will lead to a change in flight parameters to compensate for the disturbance.

Case 1. Uniform and level flight



The resultant of all the forces is zero and the two momentums are balancing each other, the plane is in uniform, level flight

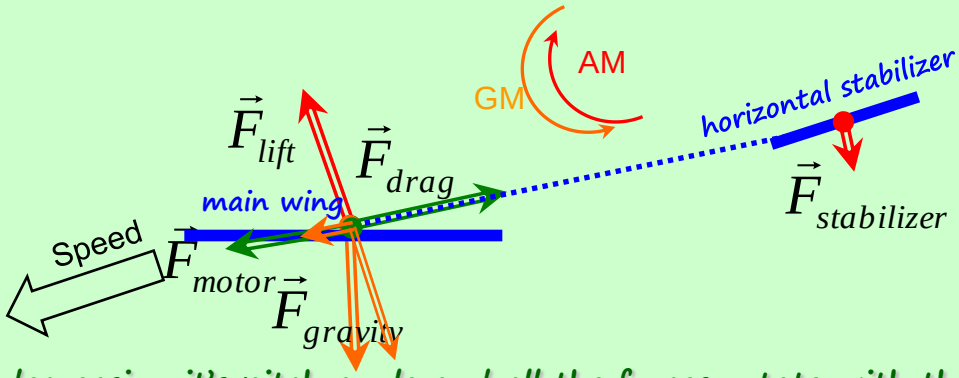
Case 2. Introduce a disturbance by increasing the throttle



Due to increased speed the positive aerodynamic momentum exceeds the negative gravitational momentum and the plane starts climbing. For a certain climb angle, the plane slows down enough so that the aerodynamic momentum decreases and it balances the gravitational momentum again.

The plane starts increasing it's pitch angle and all the forces rotate with the plane except one, the gravity. The gravity remains vertical and we can decompose it in a component parallel with the direction of flight and one perpendicular to the direction of flight. The parallel component will be oppose the thrust. The more the plane rises its nose the slower becomes. The upwards tilting continue until the plane slows down enough so that the two momentums become equals in magnitude. Therefore increasing throttle will result in a stable but climbing flight.

Case 3. Introduce a disturbance by decreasing the throttle



Due to decreased speed the positive aerodynamic momentum gets smaller than the negative gravitational momentum and the plane lowers the nose increasing its speed. For a certain angle of descent the plane speeds up enough so that both momentums will balance each other again.

The plane starts decreasing it's pitch angle and all the forces rotate with the plane except one, the gravity. The gravity remains vertical and we can decompose it in a component parallel with the direction of flight and one perpendicular to the direction of flight. The parallel component will be augment the thrust. The plane therefore will speed up as it's lowering its nose. The tilting will continue and the plane accelerates until it builds enough speed so that its aerodynamic momentum increases to become equal in magnitude with its gravitational momentum. Therefore decreasing throttle will result in a stable but descending flight.

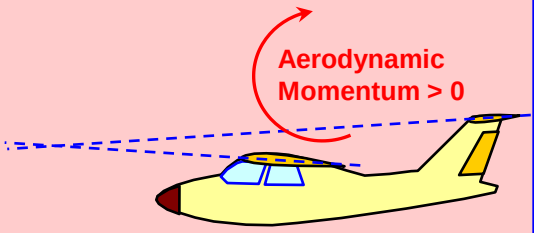
Case 4. Introduce a disturbance by decreasing the angle of the horizontal stabilizer

The plane starts increasing it's pitch angle since its aerodynamic momentum increases and all the forces rotate with the plane except one, the gravity. The gravity remains vertical and we can decompose it in a component parallel with the direction of flight and one perpendicular to the direction of flight. The parallel component will be oppose the thrust. The more the plane rises its nose the slower becomes. The upwards tilting continue until the plane slows down enough so that the two momentums become equal in magnitude. Therefore decreasing the angle of the horizontal stabilizer will result in a slower, climbing but stable flight.

Case 5. Introduce a disturbance by increasing the angle of the horizontal stabilizer

The plane starts decreasing its pitch angle since the aerodynamic momentum decreases and all the forces rotate with the plane except one, the gravity. The gravity remains vertical and we can decompose it a component parallel with the direction of flight and one perpendicular to the direction of flight. The parallel component will be augment the thrust. The more the plane lowers its nose the faster becomes. The downwards tilting continue until the plane builds up enough speed and enough aerodynamic momentum so that it becomes equal in magnitude to the gravitational momentum again (the two momentums balance each other). Therefore increasing the angle of the horizontal stabilizer will result in a faster, descending but stable flight.

Creating the positive aerodynamic momentum:

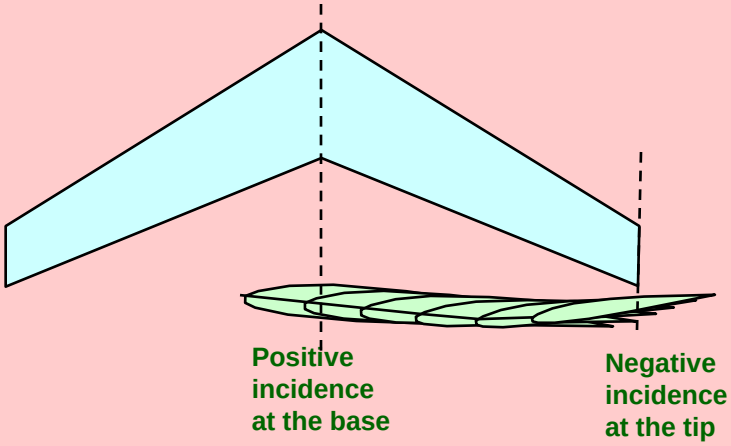


A regular plane: As we have seen in a regular airplane, the horizontal stabilizer (which is part of the tail) has a negative incidence angle with respect to the main wing. The shorter the tail, the more angle difference is needed to create the proper amount of momentum.

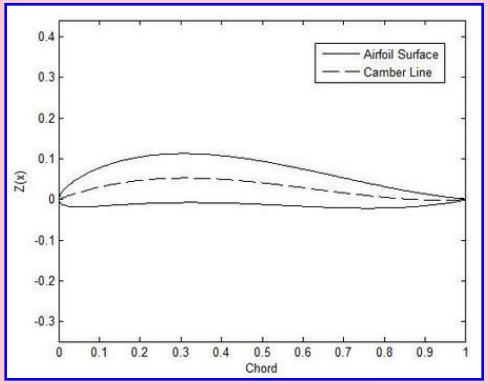
A regular flying wing: There are two different types: regular flying wings and planks.

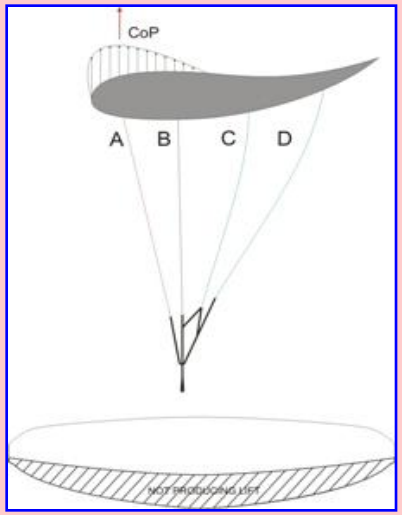
-A regular flying wing has the wings strongly swept back (typically 30 degrees on each wing) and the tips of the wing have negative angle of incidence.

- The base of these wings serve the purpose of "regular" wings in a regular airplane. The tips however, function as horizontal stabilizers since they are placed back and have a negative incidence angle compared to the base of the wings.



A "plank" type airfoil: Though sometimes swept back for added yaw stability, these type of wings can be straight, since the horizontal stabilizer effect is incorporated in the airfoil itself. The airfoil which is called a REFLEX AIRFOIL has a raised trailing edge which creates a positive aerodynamic pitch momentum. Regular airfoils have an intrinsically negative pitch momentum.





Two different "reflex" airfoils. The one to the right is from a paraglider. Notice the raised trailing edge.