How Control Surfaces Work

An Excerpt from the Flight Instructors Training Manual at RealCFI.com

It is a common misconception that control surfaces work by simply "deflecting air." Control surfaces do deflect air, but not by merely hanging out in the breeze so the airstream strikes the surface and is redirected. Most control surfaces are displaced by incredibly small amounts at most flying airspeeds, yet they still produce strong forces that change the attitude of the aircraft.

It is the change in angle of attack created by the control surface that causes an acceleration of the air perpendicular to the relative wind, producing lift or an aerodynamic force substantially greater than a simple deflection effect. This is the key idea behind how these surfaces actually work. See the following discussion and diagrams.

Rudder, Elevator and trim tabs. The horizontal and vertical stabilizers are typically symmetric airfoils which have a symmetric pressure distribution with zero lift at zero degrees of angle of attack. When the elevator or rudder are displaced, the cord line changes and these airfoils will produce lift in either direction efficiently. Cambered airfoils can produce lift in either direction but require significant AOA below zero to produce negative lift. It is common misconception the displacement of the control surface impacts and thus "deflects" the airstream to produces the required pitch or yaw moments. *The force generated by impact of the free air stream against a displaced control surface is very small compared to the lift force generated through AOA created by the same control surface.*

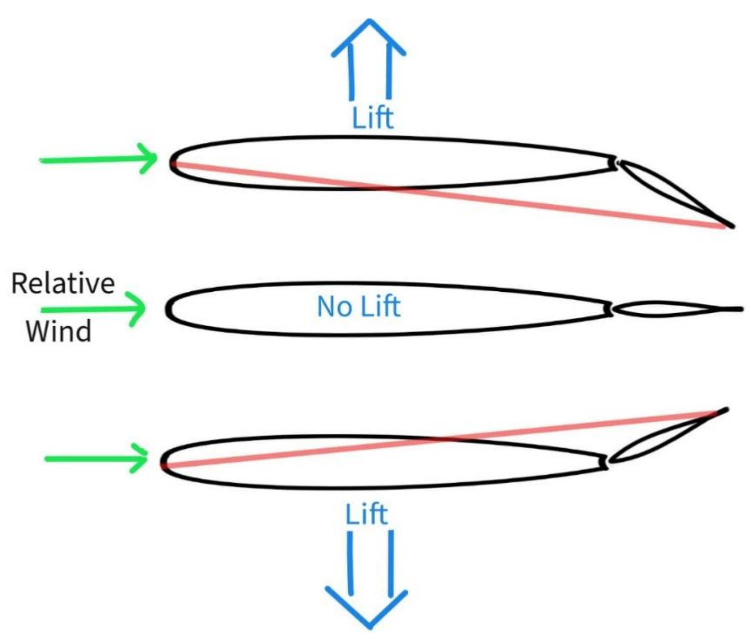

Figure 25

Trim tabs work in the same way as other control surfaces. However, the trim tabs move opposite as the desired primary control surface direction. In the diagram below, the local negative AOA moves the elevator down till it reaches equilibrium with other aerodynamic forces or reaches zero local AOA. The Elevator displaces downward causing the AOA to increase in the horizontal stabilizer. This creates lift in the upward direction on the horizontal stabilizer moving the tail up and the nose down (*aircraft rotates around CG*).

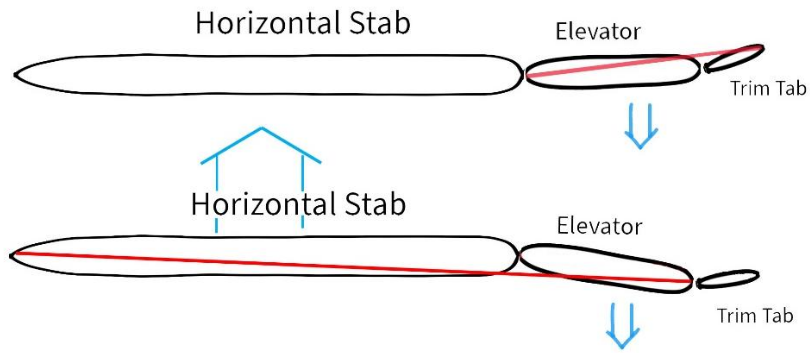

Figure 26

The elevator changes the pitch of the aircraft relative to the head and feet of the pilot. If the aircraft is in level flight, moving the controls aft, the nose moves up toward the head of the pilot. Moving the controls forward, the nose moves down toward the feet of the pilot. In a 90^0 bank, moving the control aft, the nose moves inside the turn and moving the control forward moves the nose outside of the turn. In a level 45^0 bank, moving the control aft moves the nose toward the head of the pilot which results in equal amount of nose travel vertically (up) and horizontally (into the turn). In all cases, there is a "turning" of the aircraft along the axis between the pilot's head and feet. Turning flight includes a curved flight path in the horizontal and vertical planes and anywhere in between. See the previous discussion on loads in turns.

The elevator is the primary control of AOA and load in most regimes of flight. In positive G flight, moving the control aft increases load and AOA, forward reduces load and AOA. The opposite is true for inverted (negative G) flight. In either case, the change in load is produced by turning flight. For example, as we pitch up to a climb attitude, there is a brief period of turning flight where both the AOA and load factor increase. This is commonly experienced if the aircraft is briskly rotated on take-off, the stall warning horn will chirp. Once the pitch attitude and climb rate stabilizes, the aircraft is no longer "turning", and the load factor returns to 1. Similarly, while in level flight or on stall recovery, if we pitch down briskly, we enter a brief moment of turning flight with a load factor opposite of gravity we experience as negative Gs (load factor) and feel light in the seat. Lastly, if we roll into a bank, the horizontal component of left initiates a turn and increases the load on the aircraft. However, the elevator is still the primary control of the AOA and load. While in the level turn, if we pull the control stick aft, we increase the AOA and total lift. This "tightens" the turn with an increase in the rate (and decrease of the radius) of the turn.

The Rudder and coupled roll reaction. Application of the rudder produces a side force by increasing the AOA to yaw the aircraft. There is complex interaction of aerodynamic forces that induce a roll in the same direction as the yaw. For a detailed discussion of the factors at play I would recommend the discussion on Jonh Denker's website AV8.com https://www.av8n.com/how/htm/roll.html#sec-roll-budget

The rudder, slips, skids and coordination. The rudder controls yaw and thus slips, skids and controls the direction of the aircraft on solid surfaces.

Ailerons & Flaps

Control surfaces on cambered wings (flaps and ailerons) in normal flight regimes work by changing the AOA to change the coefficient of lift on the wing. For example, downward deflection of an aileron increases AOA which increases lift and drag up to the critical AOA (max lift). Upward displacement of ailerons decrease the AOA which decreases lift and drag.

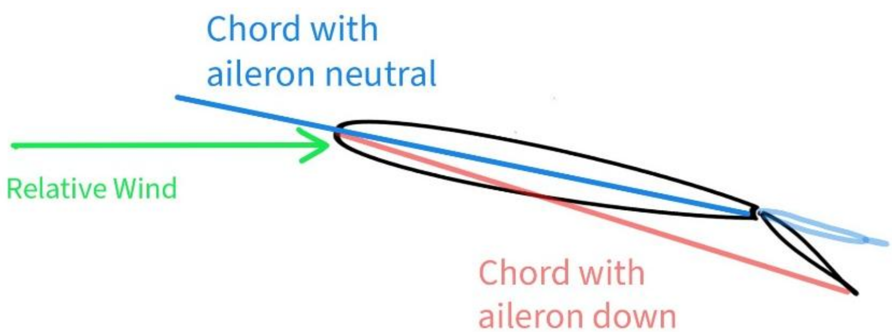

Figure 32.

This is the source of "Adverse Yaw" when initiating a turn with ailerons. The downward displaced aileron creates more drag; the upward aileron decreases drag which causes a yaw in the opposite direction of the bank. This is why rudder is required during aileron displacement to keep the longitudinal axis (nose) of the aircraft pointed into the relative wind (coordinated flight). After moderate bank angle is established, the ailerons are brought to neutral to equalize the lift on the wings and arrest the bank at the desired angle. As the ailerons are neutralized, adverse yaw dissipates (at low bank angles), and rudder inputs can also be neutralized. Bank angles much larger than 30 degrees will require some OPPOSITE aileron input to arrest the over banking tendency. At higher bank angles, the outside wing travels significantly faster than the inside wing creating more lift and drag. In this case, slight opposite aileron is required to maintain bank angle and a small amount of "inside" rudder to maintain coordination.

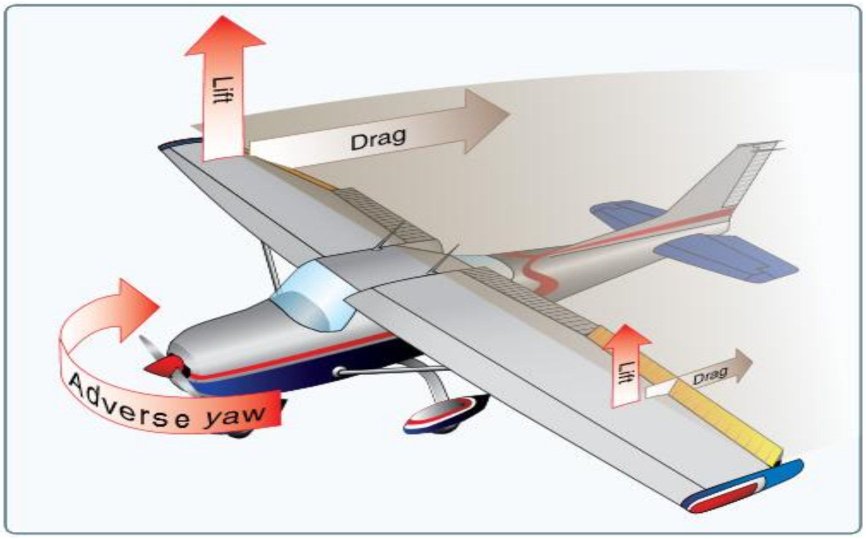

Figure 33. *Adverse yaw is created by outside wing producing more lift and drag.*

Aileron use for taxi, takeoff, and landing in cross winds. Failure to use cross wind correction allows wind to lift a wing and amplifies *<u>weathervane forces which may overcome rudder authority and lead to un-intend runway departure or ground loops</u>*. It is a common error to relax aileron input during taxi, take off and especially after touch down. When the aircraft is moving slowly, FULL aileron deflection is required to reduce “wing” lift on the upwind side of aircraft. If a wing lifts, weight shifts onto opposite wheel. This decreases aircraft stability to weathervane. Aileron input for wind should be practiced on every taxi, take-off and landing. *Full deflection is required on taxi, initial aircraft acceleration for take-off, and as aircraft slows after touch down.*