

Form And Function

What Is Angle of Attack?

By Ed Kolano

To new pilots with a military inclination, angle of attack might be another way to describe a military flanking maneuver. But the context here is wings, not war.

Angle of attack (AOA) is the relationship between the wing's chord line and the air through which the wing is moving. Wolfgang Langewiesche, author of *Stick and Rudder*, said it in a simpler way, "The angle of attack is the angle at which the wing meets the air."

You can find more sophisticated definitions, but this one suffices. A wing's chord is an imaginary line drawn between the leading and trailing edges. The angle of attack is usually measured between the chord line and the direction of the relative wind.

AOA is a fundamental aerodynamic concept often overlooked in favor of more readily available visual information such as the airspeed indicator and the natural or artificial horizon. Unless your airplane has an AOA indicator, you can't see angle of attack. But understanding AOA unravels many mysteries behind the how's and why's of flight.

Lift and AOA

How much lift a wing produces can be described by the lift equation – $L = \frac{1}{2} \rho V^2 S C_L$. This equation looks intimidating, so let's simplify it. For example, ρ is the symbol for air density, which remains constant for the purposes of this discussion. V is the airspeed (velocity) of the wing, and S represents wing area, which also remains constant. C_L is the wing's lift coefficient, which is related to AOA.

The greater the AOA, the greater the value of C_L , until the wing reaches its critical or stall AOA. In other words, the amount of lift a wing produces increases with increased angle of attack – until the wing reaches its critical or stall AOA.

The only variables in this equation are airspeed and C_L , which is determined by AOA. If airspeed increases, the wing produces more

lift. Likewise, if AOA increases, the wing produces more lift. Of course, if AOA increases too much, the wing stalls and loses its lift.

The airplane's elevator (pitch control) determines the AOA. When you pull the stick back, AOA increases, and when you push the stick forward, AOA decreases. When you're flying straight and level, lift equals the airplane's weight. Increasing the airspeed (by adding power) creates additional lift, causing the airplane to climb, unless you reduce the AOA by lowering the airplane's nose. It's important to realize it's not the nose-down pitch change that keeps the airplane level. It's the decreased AOA that compensates for the increased airspeed.

If you pull the stick back and increase the AOA while maintaining the same airspeed, the airplane will climb because the wing produces more lift. Naturally, you must increase power to maintain a constant airspeed in the climb.

By balancing power and AOA, an airplane can maintain level flight over a range of airspeeds. The slower the speed, the greater the AOA must be to maintain level flight. You see this as a higher pitch attitude, but the wing doesn't care about pitch attitude – only where the relative wind is. Suppose you trim the airplane properly for level flight. If you reduce power and don't move the stick or re-trim, the nose will pitch down, and the airplane will descend at nearly the same airspeed as in level flight. The AOA hasn't changed, but the relative wind has. The slightly nose-down attitude maintains the AOA. The opposite is true when adding power.

The wing doesn't care about airspeed, either. A wing stalls because its AOA is too great, not because the airspeed is too slow. Pilot operating handbooks (POHs) give stall speeds because general aviation aircraft usually don't have AOA indicators.

A published stall speed pertains to a single condition, namely 1G flight in a certain aircraft configuration and a certain weight. Published stall speeds are not valid when pulling out of a dive because the wing is generating lift in excess of the airplane's weight (more than 1G).

Whether you're in 1G flight or pulling out of a dive, the stall AOA is the same. In other words, the wing always stalls at the same AOA

regardless of the airplane's speed or load factor (how many Gs it's pulling). Remember, the lift a wing generates depends on AOA and airspeed, and the stall AOA doesn't change. If you increase the load factor by pulling out of a dive, the wing produces additional lift to overcome the increased load, so the stall speed is necessarily higher than during 1G flight. (Aerodynamicists might argue that stall AOA is not exactly constant, but you can consider it to be constant for practical purposes and this discussion.)

Turns also increase an airplane's load factor, so stall speeds during turns are higher than during straight, 1G flight. The POH usually includes a chart of stall speeds at different bank angles, but it can be misleading because the chart refers to level (constant altitude) turns only. Manufacturers use level turns because they enable engineers to calculate the load factor (and, consequently, lift) when predicting stall speeds.

For example, an airplane in a level, 30-degree bank angle, constant-speed turn has a load factor of 1.15Gs. A 45-degree bank yields a load factor of 1.41Gs, and a 60-degree bank produces a load factor of 2.0Gs. The wing still stalls at the same AOA it did during 1G flight and when pulling out of a dive, but the increased load factor means increased lift, so the stall speed is higher. If the turns are not level, the load factor is different because lift does not equal weight when an airplane is climbing or descending. This condition makes the stall speed chart invalid. The bottom line, however, is – the stall AOA does not change.

The Big Picture

Watching an aerobatic airplane is another way to visualize how AOA, airplane attitude, and airspeed are independent of one another. Imagine an air show performer making a high-speed pass down the runway. When the pilot suddenly pulls the stick all the way back, the airplane pitches aggressively nose-up, but its flight path continues down the runway for a short time. The airplane's speed along the flight path initially remains about the same as before the pitch-up, but its AOA increases dramatically. This occurs because the airplane is no longer flying in the direction it's pointing. Of course, the airplane cannot sustain this situation, and it begins to climb.

When an airplane spins, its flight path is approximately vertical. Although the airplane is essentially coming straight down, it is not pointing straight down. Just as in the previous example, the airplane is not pointing in the direction it's traveling. It still has plenty of airspeed, but its AOA exceeds the stall AOA.

A spinning airplane maintains its turn rate because each wing has a different AOA. Both wings are stalled, but the outside wing (the right wing during a spin to the left) has a higher speed than the inside wing because of the airplane's rotation. The relative wind forms a shallower AOA with the outside wing than it does with the inside wing. Because the inside wing has a higher AOA, it is creating more induced drag than the outside wing. This difference in drag helps sustain the autorotation. Spins are complex phenomena of aerodynamics, inertia, and kinematics, and this AOA explanation is only one part of the total spin picture.

So What Good Is AOA?

You can read an airspeed indicator, and you can see your airplane's pitch and roll attitude by comparing the nose and wingtips to the horizon. But you can't see relative wind. You can get an idea of the relative wind by visually comparing the airplane's flight path with the direction the airplane is pointing, although this is difficult, particularly during turns.

Because most conventional wings have a stall AOA of around 18 degrees or less, eyeballing your airplane's AOA isn't going to do you much good. An AOA indicator provides the necessary information, but this instrument is usually installed in airliners, business jets, and military aircraft –not light airplanes. Besides the cost, installing an AOA indicator on a single-engine airplane would be a challenge. If you mount the AOA sensor on the fuselage, the prop blast can cause erroneous readings. If you put the sensor on the wing, it would most likely have to be boom-mounted, sufficiently forward to avoid the upwash influence of the wing.

Whether general aviation aircraft need an AOA indicator is a good rainy-day hangar topic. To be certificated, general aviation airplanes must demonstrate benign stall characteristics that give sufficient warning through simple stall-warning systems. Given the

airplanes' benign handling, you can make an economic case for not having an AOA indicator.

So why even talk about angle of attack?

Understanding AOA, and its role in producing lift, is fundamental to understanding how wings work – all kinds of wings including helicopter rotors, jet engine compressor blades, ceiling fans, windmills, etc. The better you understand what makes the airplane fly, the better and safer pilot you will be.