Critical Angle of Attack – The Rest of the Story

C. Zavatson, 1/8/2017

When the topic of Angle of Attack (AoA) comes up in various on-line discussions, I often come across the saying: “A wing can stall at any airspeed, but only one angle of attack”. While this sounds neat and concise, it really isn’t correct. Here are five variables that will influence the critical or stall angle of attack.

1. **Flap Position**. After-market AoA indicators require calibration in cruise and landing configurations because deploying flaps will lower the critical angle of attack. Thus any AoA instrument must adjust for flap setting. In reality this calibration must span the continuum of flap settings. For simplicity however, it is common to only use the end points. As an example, let us look at the airfoil used on the Lancair 360, the NLF-0215F. Three flap settings are shown -10 degrees, 0, and 10 degrees in Figure 1. In a cruise setting of -10 degrees the critical angle is about 15 degrees. This decreases to 13 degrees at zero flaps and then decreases to 12 degrees at 10 degree flaps. As an aside, note how much the angle of attack is reduced to maintain a given lift coefficient when flaps are deployed (Figure 2). At a lift coefficient of 1.6, the required AoA starts at 15 degrees and reduces to about 6 degrees. The wing produces the same lift at a much lower angle of attack.

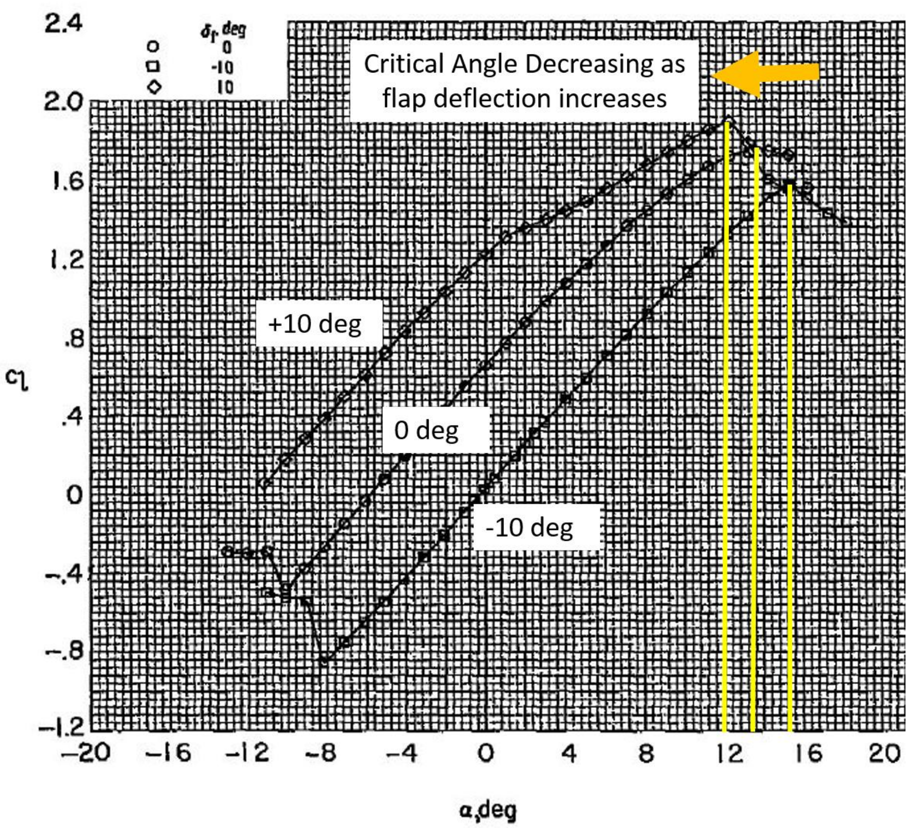

Figure 1, Effect of Flap Deflection on Critical AoA, NASA TP-1865

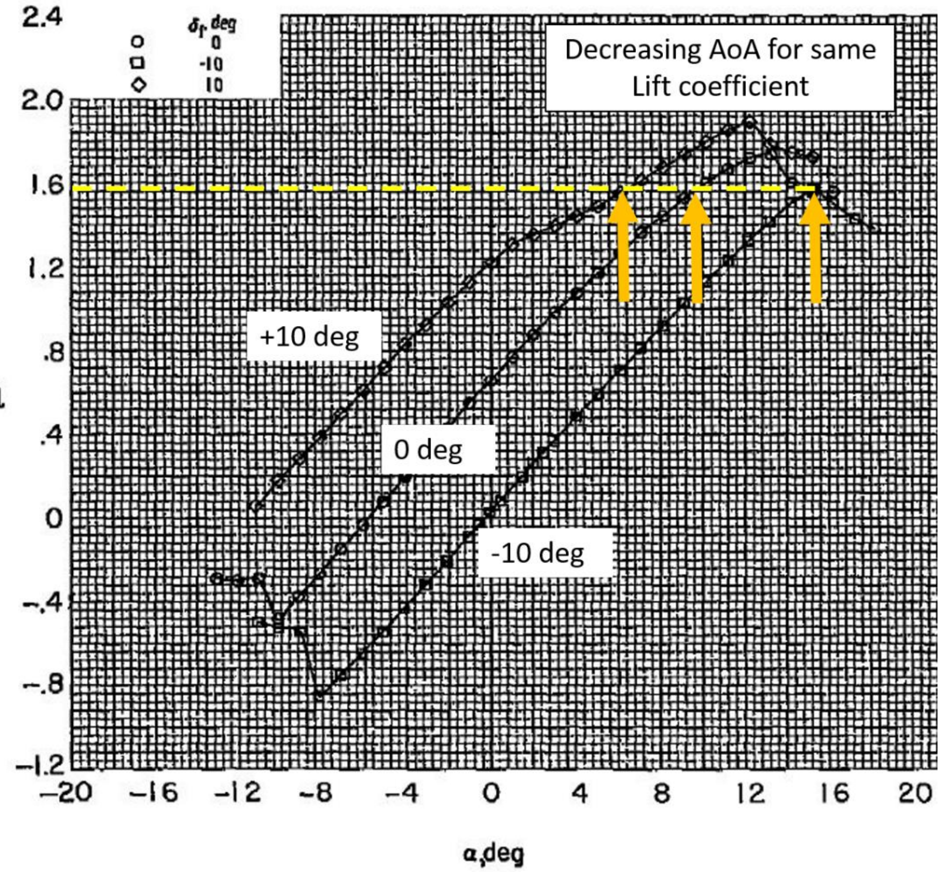

Figure 2, Effect of Flap Deflection on AoA at constant CL, NASA TP-1865

2. **Ground Effect**. Ground effect does two things. First in tends to lower the critical angle by some amount. This amount is very difficult to determine. Short of extensive CFD, we are left guessing to some extent. All is not lost however, since the lift curve slope increases at the same time. Effectively this means you can produce the same lift as before, but it will occur at a lower angle of attack (Figure 3). Flying our home-built aircraft, we are generally not too worried about this level of detail, but it can be deadly in aircraft that use AoA as a guide. The Gulfstream G-650 crash during certification flights in 2011 was caused by an incorrect estimation of the critical AoA in ground effect. The real decrement from the 'out-of-ground-effect' critical angle was higher than assumed and so the pilots were pulling up too far during simulated single engine take-off testing and stalled. The stick shaker was also set too high for the same reason and did not activate until well into a stalled condition.

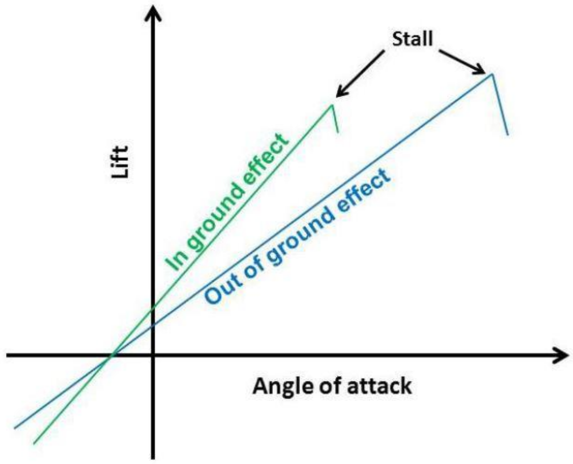

Figure 3, Critical AoA Change in Ground Effect, from NTSB report on G-650 accident

3. **Reynolds Number and Mach Number**. For both of these parameters this just translates into airspeed. Reynolds number is a function of velocity, the viscosity of air and chord length. Our chord length is fixed and we can't change the viscosity of the air. If you stall the wing at a higher airspeed, the critical angle will be higher.

4. **Entry Rate**. The FAA controls the methods used in determining stall speeds for aircraft because the rate of approaching stall can influence the outcome. Approaching the stall quickly will lead to a slightly lower stall speed. You can get to a slightly higher AoA. 1 kt per second deceleration is the target to establish uniformity.

5. **The Propeller.** This factor can be rather significant and will vary by aircraft type. A close examination high AoA flight in different configurations reveals is a strong dependency of stall speed on the propeller. The air behind a propeller is never clean, but the air behind a wind-milling prop is particularly bad. It has just extracted energy out of the slip stream to turn over the engine. What is left is a turbulent air mass with less energy going over the center section of the wing.

Figures 4 and 5 below show the difference in critical angle and indicated stall speed as a function of manifold pressure (AoA is referenced the aircraft longeron). Stall here is defined as minimum sustainable flying speed while in the pre-stall buffet region. In other words, these test points can be maintained indefinitely. For reference, 12 inHg is enough to sustain level flight (~46 hp and 160 lbs thrust). This drops to zero thrust very quickly, just below 10 inHg.
The impact on the aircraft is significant. The critical angle drops ~2.5 degrees and the stall speed at the weight tested climbed 7 knots. The critical angle is an aggregate of the entire wing. So if the performance of one section of the wing is diminished, the remainder needs to compensate. If unable (washout may allow the outboard sections to do more work), the critical angle for the entire wing is reduced.

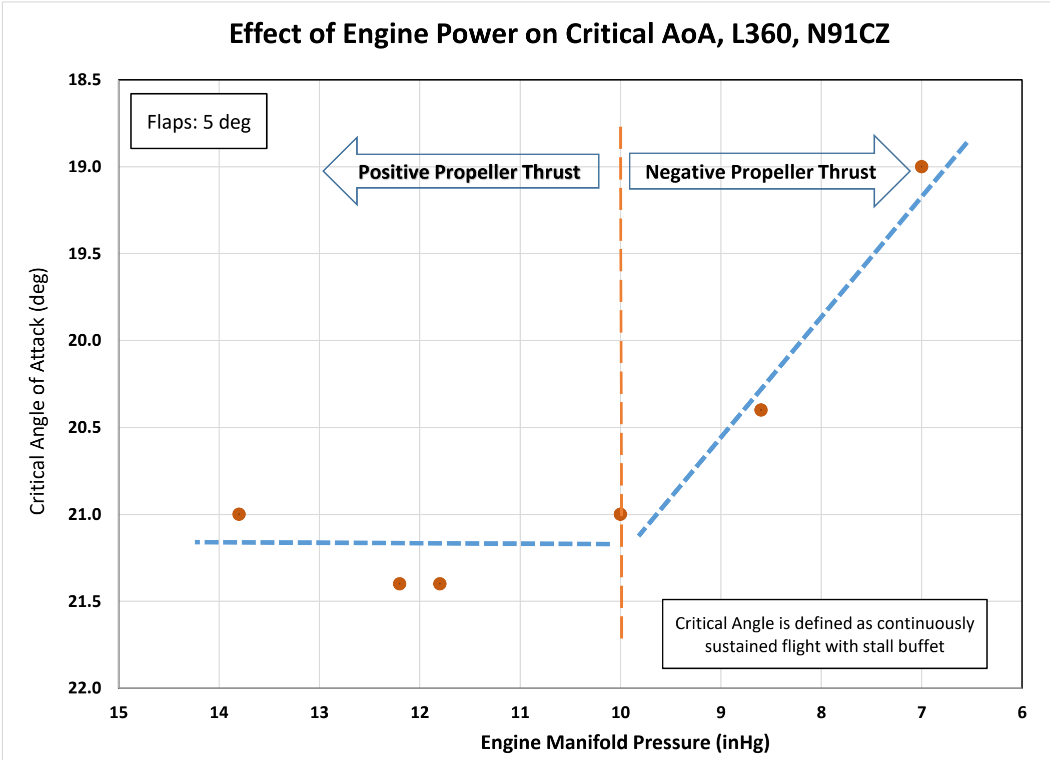

Figure 4, Effect of Propeller Thrust on Critical angle of Attack

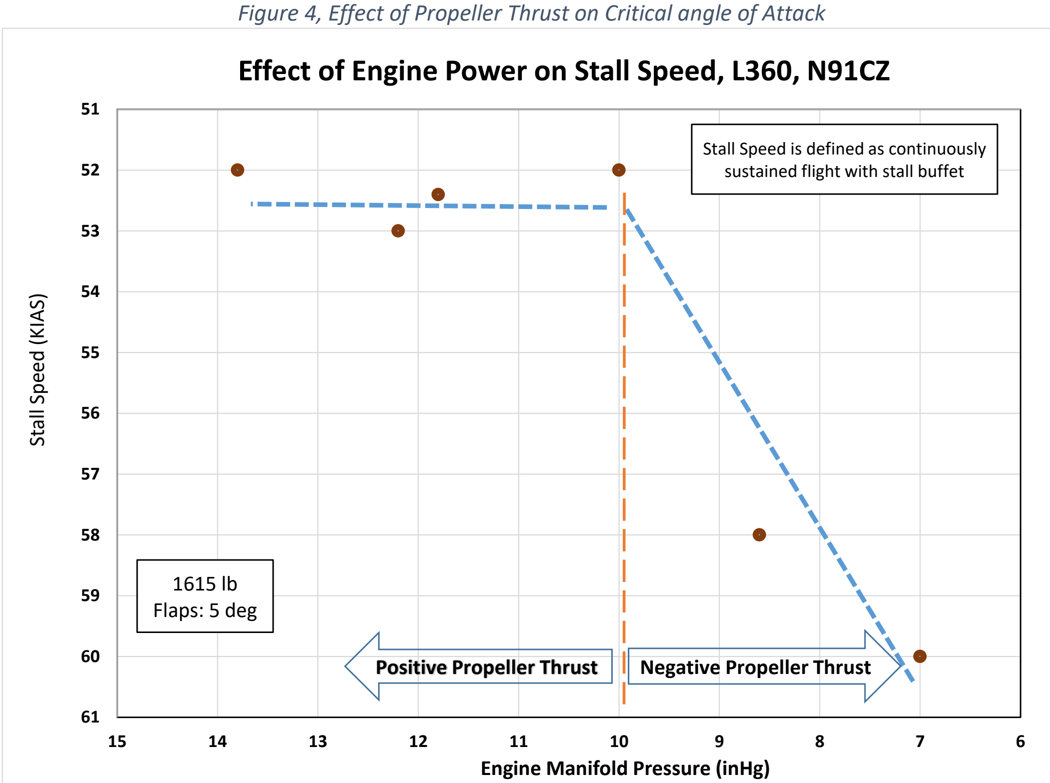

Figure 5, Effect of Propeller Thrust on Stall Speed

Summary. The magnitude of each of the above effects will vary by aircraft type. While most flying is done well above stall speed and far below the critical angle of attack, it is beneficial to be aware of the factors that can affect the critical angle of attack. A wing can stall at any airspeed and many different angles of attack.