Why Fly Angle of Attack (AOA)?

by Ron Renz

Angle of Attack (AOA) systems increase safety by indicating and alerting the pilot when entering a critical phase of flight which might result in LOSS OF CONTROL due to a stall or spin unless immediate and appropriate action is taken. An AOA system does this by increasing pilot awareness of the MARGIN FROM STALL.

How does AOA accomplish that? Perhaps a short engineering lesson will help.

The ability of an airplane to fly depends on the lift produced. As the AOA increases approaching stall, airflow begins to detach from the top surface of the wing, losing efficiency, until at some point airflow separates with a corresponding large decrease in lift. This is the critical AOA where the aerodynamic stall occurs (see Figure 1).

Figure 1: Wing Flow Separation at Stall

Aircraft stall speed varies with weight, load factor (i.e. G's), bank angle, power and density altitude. There are other factors that affect stall speed but these are the big ones. Angle of attack is defined as the angle between the relative wind acting on the wing and the wing chord line. This is depicted in Figure 2. During testing,

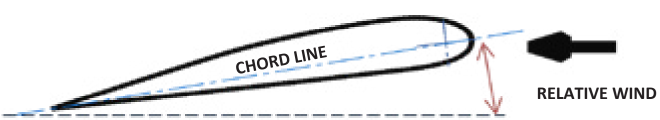

Figure 2: Define Angle of Attack

engineers measure lift and convert it into a dimensionless term called Lift Coefficient (C_L). Generally we represent the lift characteristics of the airplane using a graph of Lift Coefficient (C_L) vs Angle of Attack (for AOA, we typically use the term Alpha or use the Greek symbol α).

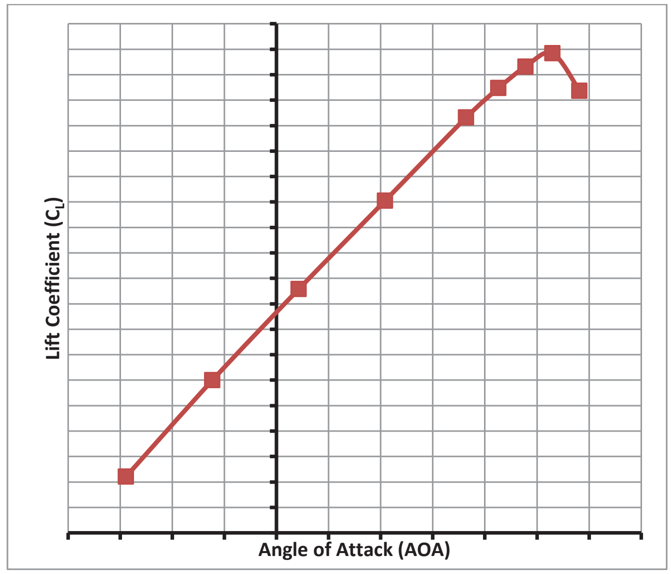

Figure 3: Typical Lift Curve Slope

Figure 3 presents a typical C_L vs α curve. Note the slope of the curve is approximately 0.1 C_L per degree of AOA. The beauty of this depiction is that C_L is a dimensionless quantity that includes lift (i.e. weight or G's) and airspeed in its calculation and allows engineers to analyze the airplane lift in any situation regardless of weight, wing loading (i.e. as it changes due to bank angle), etc. The stall of the wing is well defined by this curve as it occurs at the peak that is shown at the highest C_L. This is where the flow separates from the top of the wing, and the wing stalls aerodynamically. **THE WING WILL ALWAYS STALL AT THE SAME ANGLE OF ATTACK**, regardless of the airspeed, wing loading etc. All pilots should be familiar with the stall Speed vs Bank angle chart that appears in all Airplane Flight Manuals. Figure 4 presents the chart for the MU-2B-60 (Marquise). What this graph shows is how the airspeed changes as the load factor increases (i.e. increasing C_L) in level flight due to bank angle. Note that load factor can be increased not only by turning in level flight, but

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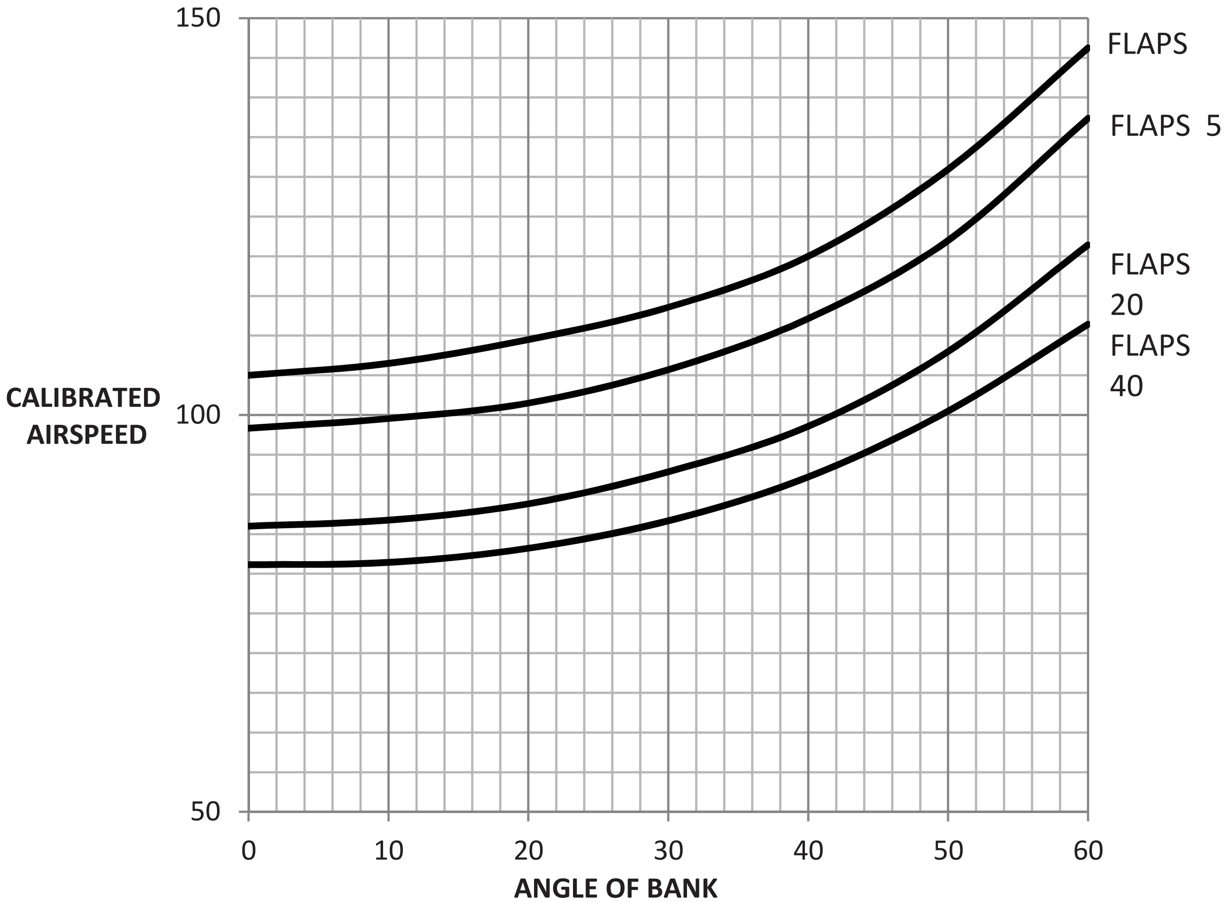

Figure 4: Stall Speed vs Angle of Bank MU-2B-60

also by pulling back on the yoke in any attitude, including wings level, so long as the airfoil has not reached the critical AOA. Incidentally, aerobatic pilots know they can fly an airplane at very low speeds, even zero airspeed, as long as there is no wing loading, and use that knowledge to perform various very slow speed maneuvers under full control.

Why have we not had Angle of Attack Systems before?

Actually, all certified airplanes have some means to measure angle of attack. These have traditionally been used to trigger the stall warning system. On the MU-2B airplane this Angle of Attack Sensor is a stall vane located on the leading edge of the right wing, and it triggers the stick shaker. So even though you may not have been aware of it, pilots have been flying with an angle of attack warning system since they started flying airplanes. For many decades, Navy pilots have been using angle of attack as the primary indicator to fly approaches to aircraft carriers. Many commercial airplanes have had angle of attack indication systems installed to aid the pilot, although some of these earlier AOA systems were quite costly.

Recent technology advances have allowed production of Angle of Attack Systems that accurately measure and display angle of attack information to the pilot at a low cost. An example of the system in the final approval process for the MU-2B is shown in Figure 5. A probe

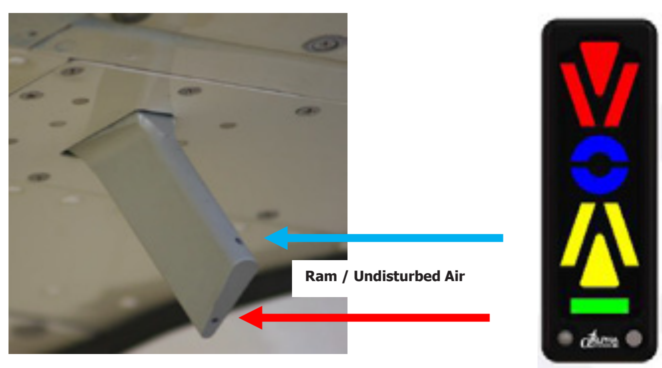

Figure 5: Alpha Systems Angle of Attack Indicator and Under Wing Probe

with no moving parts is used to sense the angle of attack. Pressure differential between the 2 ports on the probe is directly proportional to the angle of the air flowing across the probe, and thus AOA across the wing. This pressure difference is measured and the angle of the air flow is presented on a cockpit display that shows the AOA as 14 unique steps. How these relate to the

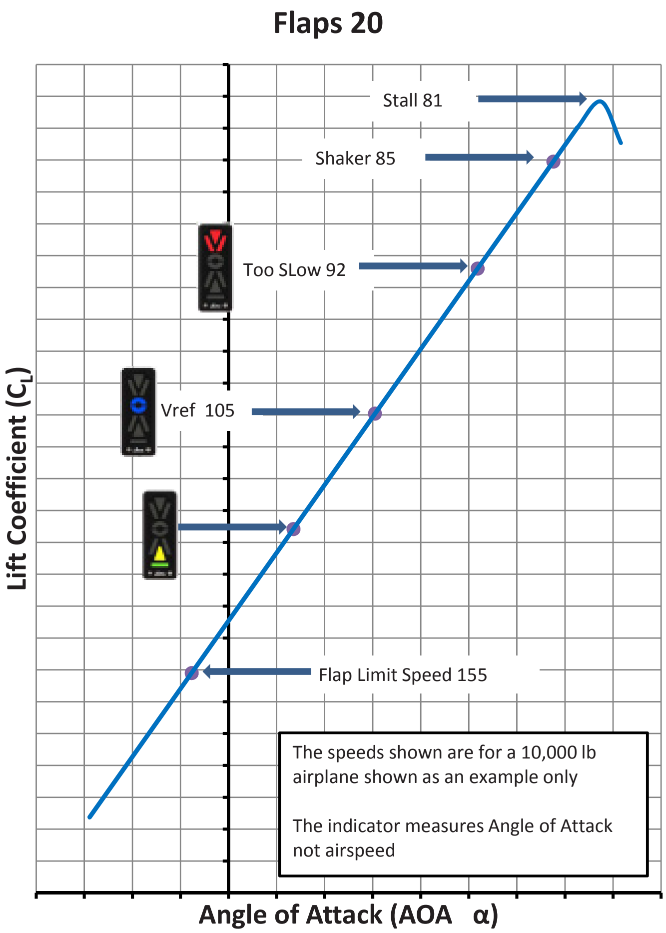

Figure 6: Lift Curve Slope and Angle of Attack Indication

lift curve slope is shown in Figure 6. The important understanding from this Figure 6 is that; **AS YOUR ANGLE OF ATTACK INCREASES, YOUR MARGIN OF AVAILABLE LIFT PRIOR TO STALL DECREASES**, which is displayed to the pilot in an easy to understand method.

Displaying Angle of Attack to the Pilot

This AOA system for the MU-2B uses an intuitive design to indicate to the pilot the relative angle of attack of the airplane and assist in establishing the appropriate approach speed. As the pilot slows the airplane, the angle of attack increases, the display steps thru the various segments as shown in Figure 7, where green is high speed, yellow is slowing toward approach speed, blue indicates normal approach speed, and red indicates **TOO SLOW** (or too high a G load). The red indications are coupled with a voice alert through the headset stating "TOO SLOW" prior to stick shaker. The basic premise used in the display logic is that the RED chevrons intuitively point down advising the pilot to lower the nose. BLUE is the appropriate approach speed, a circle, and yellow is GOOD, with the chevrons pointing up advising the pilot to raise the nose to achieve the appropriate approach speed.

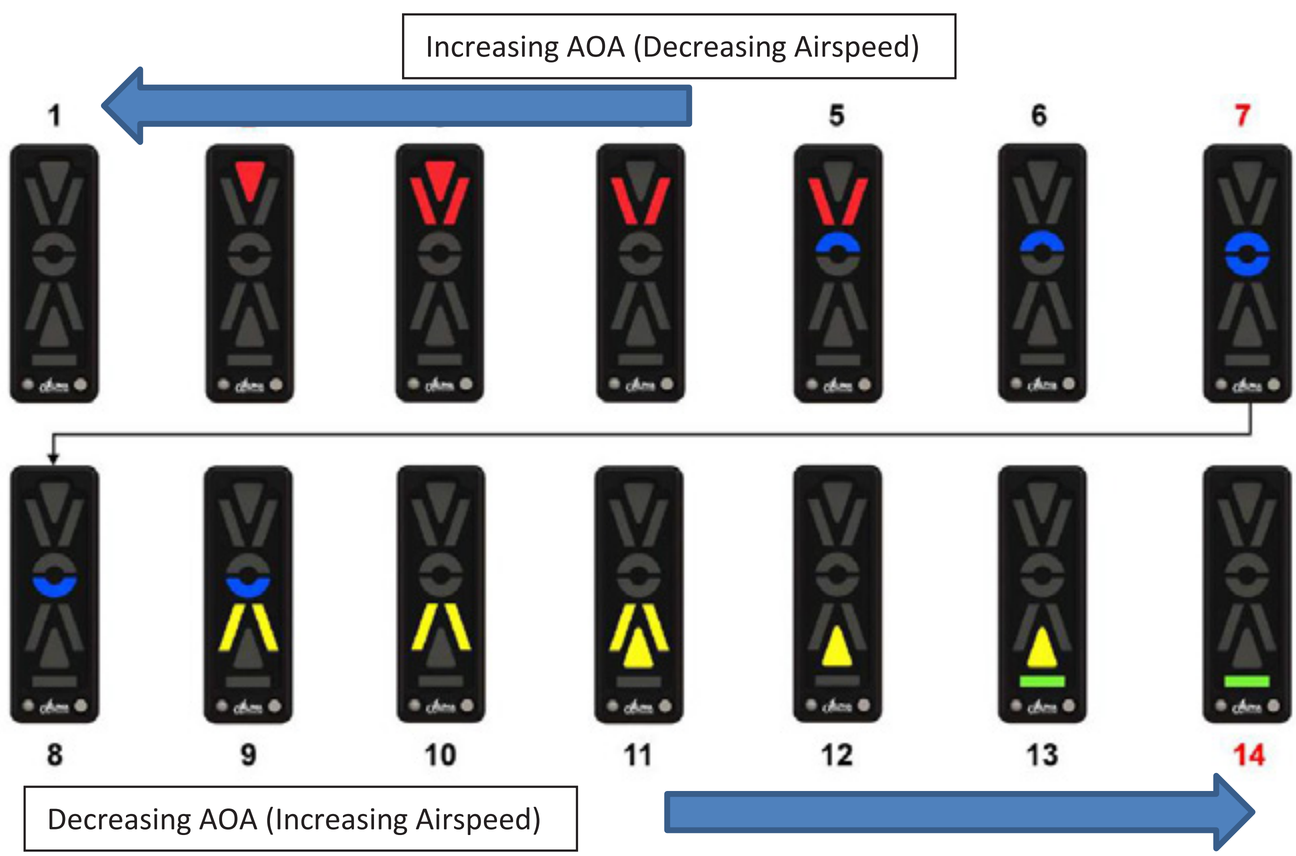

Figure 7: AOA Display Progression

How AOA improves safety.

When the military began installing angle of attack indicting systems in their airplanes, they reduced fatalities significantly. The FAA has determined that a very large portion of approach accident fatalities in general aviation airplanes occur on the base to final turn, in slow flight, or in accelerated stalls. The MU-2B AOA system provides visual and aural warnings as these flight conditions deteriorate. To be most effective, AOA indicators must at a minimum always be in the pilot's peripheral vision, so that when the pilot's focus is outside of the cockpit an indexer or display is **INSTANTANIOUSLY RECOGNIZABLE**. An ideal location is on the windshield center post of the MU-2B. With an AOA indicator in his peripheral vision as it changes from yellow to blue to red and then a "TOO SLOW" voice sounds in his ear, it will draw attention back into the airplane to the instruments, making the pilot aware of the deteriorating flight condition. The AOA system directly provides the pilot **AN INCREASED AWARENESS OF THE MARGIN FROM STALL** and intuitively indicates the action to take by pointing in the direction towards which the nose should be moved.

Angle of Attack is not just about identifying STALL.

AOA can be used to help pilots fly consistent and stabilized approaches. On the system developed for the MU-2B the AOA indicator blue donut is set to match the MU-2B V_{Ref} speeds at all flap settings (0, 5, 20 and 40). Flying the blue donut will automatically place the aircraft at the proper weight-adjusted AFM threshold speeds, providing a safe margin above stall. Other benefits of flying precise approaches are reduced tire and brake wear, and less float on flare and landing.

In a follow on article I plan to discuss how pilots can use an AOA system to help fly more precisely and get the most out of the airplane and the AOA system.