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Using Angle-of-Attack Indicators

It may not be a primary indicator, but its information can be primo.

By Richard N. Aarons

If you want to get a good discussion going in the crew lounge, ask your fellow pilots how they use angle-of-attack (AOA) instrumentation, assuming they use it at all. We did that recently with a number of experienced corporate turbine aircraft pilots and got answers ranging from "I don't — it's placarded," to very sophisticated descriptions of how alpha can be used to maximize range and endurance.

We also noticed that U.S. Navy-trained pilots tended to have many uses for the AOA indicator than did Air Force or civilian-trained aviators. And we know from our own experience that the AOA indicator is rarely mentioned in type rating courses at the major flight training centers.

So why are AOA indicators stealth instruments getting little or no notice from a large segment of the pilot community? Why do Navy pilots love the things? And, could most pilots gain from taking more notice of them?

For the answers we went to Randy Greene and his staff at Safe Flight Instrument Corp., in White Plains, N.Y. Greene is president and CEO of the company that pioneered stall warning and angle-of-attack systems for general aviation and ultimately grew to provide AOA systems for corporate jets, airline transports and military aircraft from just about every manufacturer. What we learned from our conversation with the Safe Flight team follows.

Every pilot is introduced to the concept of angle-of-attack, that is the angle between the chord line and the relative wind, early in flight training. And most pilots are familiar with the lift curves and lift equations. The lift curve, you'll remember, demonstrates that for a given set of conditions, lift produced by a wing increases as the angle-of-attack (alpha) increases up until the point that airflow over the upper surface breaks down and lift is destroyed.

The mathematics of lift tell us that total lift depends on wing surface area, air density, airspeed and wing geometry (indirectly, angle-of-attack). It follows, then, that low-speed, high-alpha maneuvering such as occurs immediately after takeoff or during the final stages of approach, leave little margin of safety. The airplane is operating near maximum alpha, and a slight increase in the angle-of-attack can lead to stall.

We usually think of stall in terms of airspeed. (The airplane in relatively level, unloaded flight stalls at approximately this or that speed.) But we've also learned that airspeed is only one factor in the equation. Increase the g-load and the airplane will stall at a higher airspeed (accelerated stall) but at the same angle-of-attack. So airspeed is a secondary measure of angle-of-attack, but only if we are in one-g flight and have calculated weight properly. That's why we set bug speeds for takeoff, second segment climb and approach VREF after consulting weight and density altitude charts. What we are really doing in that exercise is finding an indicated airspeed that should deliver a target angle-of-attack if we're right on the other factors, including weight, density altitude (temperature and pressure altitude), and so forth.

In theory, we have a choice of instruments to consider to assure proper

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lift. If we know the target angle-of-attack for a given maneuver (final approach, for example) we could fly it directly, assuming we have an accurate and appropriately calibrated AOA indicator. Or we can use an airspeed indicator assuming flight near one-g and appropriate weight and air density adjustments.

Even though the brothers Wright used an angle-of-attack indicator — a stick with a piece of yarn — on their first flying machine, the industry they created grew up using the indirect indicated airspeed method. So all angle-of-attack related certification criteria are published in the aircraft flight manual in terms of calibrated and indicated airspeeds (CAS and IAS), respectively. It is left up to the flight crew to use performance tables to find the appropriate airspeeds.

Of course, the airframe manufacturers pay close attention to actual angle-of-attack during flight test and certification and all turbine aircraft are delivered from the factory equipped with systems to detect angle-of-attack (directly or indirectly). Often, the direct angle-of-attack information is presented to the pilots. Regardless, AOA data certainly are used by aircraft systems such as auto-throttles, FMSes, stick shakers and other stall warning devices.

If angle-of-attack information *is* presented to the flight crew, it is usually placarded as advisory only. In other words, it can't be used as *primary* indication for any flight mode for which there are published airspeeds.

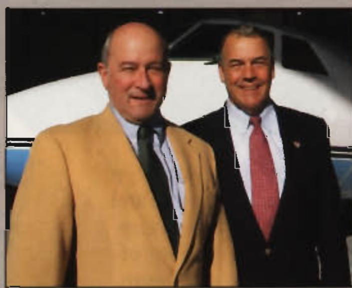
Suppose, for example, we plug in the variables during let-down and determine that VREF should be 110 knots. Also suppose we know that the 110-knot VREF approximates 1.3 times the stall speed in our configuration. Finally, suppose our AOA indicator is calibrated so we can look at it and determine the actual angle-of-attack relative to 1.3 VSO. To stay legal we *must* fly the airspeed indicator, not the alpha indicator.

But that is not to say the AOA indicator has no practical operational value in this situation. Suppose when we set up the 110-knot IAS, we glance over at the AOA indicator and discover that its indication is significantly below or above the 1.3 Vso target? Could we have blundered in our table work? Did we mess up the weight computation? Did the passengers sneak in a few kegs of beer when we weren't looking? If the AOA says we are closer to the stalling AOA than 1.3 Vso, it's time to accelerate and rework the numbers later.

Suppose the tower reports poor braking conditions or the runway length is marginal. We glance at the AOA indicator after setting up Vref and notice our calculated VREF target has put us significantly above our AOA target associated with 1.3 VSO. We may elect to reduce speed a few knots or take it around and recalculate Vref. The important thing to do is to put the AOA indicator in your scan, especially for low-altitude, high-alpha maneuvering. Any significant differences between what you were expecting and what you are seeing is cause to increase your situational awareness. Is the airplane configured properly? Is the error on the fat side or skinny side? In short, what's going on?

Interestingly there is no "standard" for AOA-indicator markings. To be sure, flight test instrumentation displays alpha in

AOA All the Way



AoA advocates Greene and Hurley at HPN

Over the years Safe Flight Instrument Corp. has employed a wide array of aircraft to serve as flying test beds, executive transports and, well, interesting diversions with unusual characteristics. Those that have served include a dutiful Beech King Air 200, a Baron, Aerospatiale Gazelle and Bell JetRanger, a Lake amphibian, a Hiller Hornet YH32A, a 1950s-vintage ramjet helicopter more rare than a Faberge egg, and a Shemp-Hirth Duo Discus and Paris Jet because, well, why not? The current fleet royalty is N300SF, a 1972 Dassault Falcon 20F-5 that is pampered and at rest in a hangar just out of sight of the company's one-story headquarters and manufacturing facility across the street from New York's Westchester County Airport.

The Falcon has done Safe Flight's flight test and transport bidding for nearly a decade, and has been outfitted with a variety of upgrades and test gear in the doing. Naturally, it features the company's AutoPower automatic throttle system that permits speeds to be set by true airspeed, indicated airspeed, Mach number or angle of attack.

In 2005, the company reengined the aircraft at Garrett (now Landmark)-Springfield, Ill., switching out its General Electric CF700s with Honeywell TFE731-5BRs, a popular STC (see *20/Twenty,* page 120). The upgrade upped range considerably, giving it nonstop capabilities that simply were impossible with the older GEs. Impressed, CEO Randy Greene decided to put it, his company's autothrottles and AOA performance to the ultimate test. A member of the Smithsonian's National Air and Space Museum board, he was to attend an NASM meeting in San Diego and planned to make it from HPN to SAN nonstop, if possible.

Fully fueled, with copilot Dave Hurley — a friend, AOA advocate, fellow board member and vice-chairman of PrivatAir — aboard, they lifted off from HPN's Runway 16 at 9:45 a.m. on Wednesday, March 1, with Long Island Sound and, beyond, the Atlantic Ocean, glistening in the morning sun. Turning west towards Bellaire, they climbed to an FL 400 cruise altitude, set the autothrottles to 0.33 AOA and left them there for the duration of the flight.

Flying AOA, rather than Dassault's recommended long-range cruise Mach speeds, provided maximum lift over drag with a modest speed penalty. After the first hour, the Falcon had burned 1,950 pounds of fuel and was cruising at 0.76 Mach. After 2.5 hours, it had burned 3,900 pounds and was down to 0.74 Mach, and by Albuquerque, 6,640 pounds had been consumed, the aircraft was burning 1,150 pounds/hour.

Greene and Hurley began an AOA descent at 5.5 hours and soon had the Pacific Ocean in sight. They touched down at San Diego Lindbergh Field after 6+41 in flight and having burned 8,200 pounds of Jet-A, with 950 pounds, or VFR reserves, remaining. During the flight, average headwinds were 85 knots.

According to postflight calculations, Greene determined that had he followed Dassault's Mach-based long-range cruise recommendations, he would have arrived 18 minutes sooner, but with 250 pounds less fuel — which would have been too thin a margin, and therefore would have required a fuel stop.

"Flying angle of attack may not be the best overall economic solution, since it can cost you more in time," Greene said later. "But if flying AOA means the difference between getting there or going swimming, there's no better solution."

Angle of attack indicators are usually calibrated in units between zero and one with 1.0 equal to a stall. Typically, an AOA of 0.8 will trip the stall warning or stick shaker. An indication of 0.6 approximates 1.3 Vso (typical VREF). Often the background between 0.6 and 0.8 is shown as yellow to indicate operating configurations that require caution. Best LD is usually found near 0.5. The indicator to the left has a bug that can be set for V/Vs.

degrees. The flight test engineers are able to get real alpha numbers by putting their AOA detecting devices on booms and getting them at least a chord-length in front of the wing leading edge. This is a tricky business, especially the task of stabilizing the boom (a story for another day.)

On production aircraft, even AOA becomes a derived number. The fuselage probes and paddles actually are measuring fuselage angle from which wing AOA can be derived. Wing sensors usually measure stagnation point movement or other pressure differentials on the leading edge and derive alpha from those measurements.

Typically, what you see on a cockpit AOA indicator is a needle (or digital scale) showing a range of numbers between 1.0 and 0.0 where 1.0 represents stall and 0.6 represents angle-of-attack that is about 30 percent margin above stall in the current configuration and weight. It's less confusing than it sounds because the AOA instrument background typically has color wedges — red from stall to about 0.8; yellow from 0.8 to 0.6 and green from 0.6 to 0.0.

So, like most things in life, if you stay in the green, you should be out of harm's way — at least when it comes to angle-of-attack. If you are at the yellow-green border, you are just where you want to be for low-speed, max-lift maneuver with a 30 percent margin. If you get to 0.8, the stick shaker or stall warning devices will operate. You may want to be there in certain wind-shear escape maneuvers, but only if the aircraft manufacturer and trainers tell you that's where you want to be. At 0.8 you may be at max lift, but you are also a hairbreadth away from a stall.

Certain long-distance pilots — sometimes lacking much else to do — pay a lot of attention to angle-of-attack vs. published cruise and range figures. On many aircraft, an AOA reading of 0.5 approximates maximum lift (L/D max). It is here you get the most efficient fuel burn in a zero wind condition. Max L/D is usually a good holding speed too. If ATC cooperates, flying constant angle-of-attack on long-range missions is often easier than flying Mach/IAS because the targeted alpha is unaffected by temperature. By comparison, Mach and IAS are highly temperature sensitive and you have to continually consult the cruise charts to get max cruise performance.

At least one airplane — the Lockheed L-1011-500, initially set up for long transpacific runs — was delivered with an autopilot that had an alpha-hold mode. It worked like Mach-hold or IAS-hold except that it held a preset alpha. In theory, you could set up a climb at your origin and hold that climb alpha until you hit top of climb (TOC) near your destination. That's the theoretical best-range technique. (Alas, it's not altogether practical in today's airspace structures.)

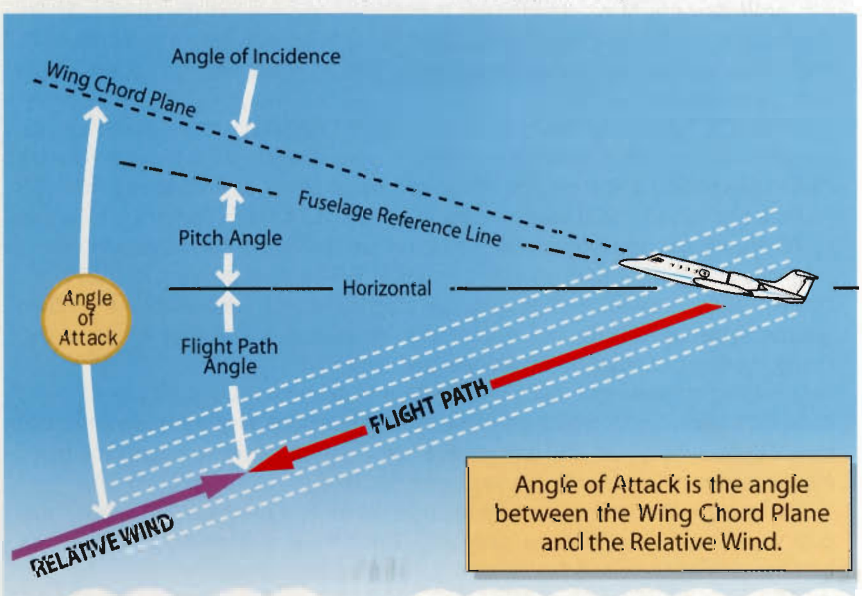
The lesson to take away from the long-range cruise guys is that you can learn a lot about your airplane's performance simply by watching the AOA gauge and taking notes. Suppose you are in a holding pattern and notice the autopilot is generating an increasing angle-of-attack to maintain altitude. Could you be picking up ice? Then again, suppose you notice that AOA is always indicating on tight size during the final phases of approach. Does the airplane really weigh what you think it does, or did someone fat-finger a calculator when they did the last weight and balance?

If you watch your AOA indicator and associate what you are seeing with what the airplane is doing, you'll probably develop more trust in both, and you may end up revising your checklists to include an occasional AOA crosscheck.

It is important that everyone read the AFM supplement that deals with the AOA indicator. Its functions differ from type to type and sometimes even within families of airplanes. Be sure you understand exactly what the instrument is telling you in each airplane you fly. (For example, the AOA fast/slow glareshield chevrons usually indicate relative to 0.6, not to the AOA bug.) If you didn't understand that sentence, read your manual — it's important.

How much can we trust these things? Earlier I noted that U.S. Navy pilots seem to use them more often than pilots trained by the Air Force or in civilian schools. The reason is simple. Once most Navy aircraft are on final approach to the carrier, their pilots are looking at the "meatball" approach guidance light on the carrier and angle-of-attack indicator in the aircraft — nothing else. Once you discover that AOA can hit a moving, heaving target within five feet vertically and horizontally time after time, you become a believer.

Experiment with your AOA, talk to your colleagues and you too may become a believer. **B&CA**



Angle of Attack is the angle between the Wing Chord Plane and the Relative Wind.