What is ONSPEED and How Does the AOA Tone Work?

Note: Click on the hyperlinked text to view demonstration video and related documents (internet access required).

The ONSPEED Concept. ONSPEED is an *angle-of-attack* (AOA) that is used for approach, landing and maneuvering. ONSPEED AOA is *always* the same. It's not affected by bank angle (G load), gross weight or density altitude and is designed into the airplane. ONSPEED AOA is *not* an airspeed. It is optimum AOA for approach and landing. The AOA tone lets the pilot hear ONSPEED and provides easy to interpret cues to make pitch corrections. When the airplane maneuvers, the tone automatically compensates—all the pilot has to do is adjust pitch based on tone cues to maintain a safe, optimum AOA for maneuvering, approach, and landing. If the pilot maintains ONSPEED, the airplane cannot stall.

Introduction. ONSPEED AOA provides an optimum energy condition. Optimum energy occurs when the blend of airspeed, power and turn performance is "just right" in Goldilocks terms… pull any harder on the stick or yoke and you are expending energy (airspeed or altitude) for no gain in performance, don't pull hard enough and you are too fast for landing. It's about the AOA at which maximum power is available in a propeller-driven airplane. Thrust and drag are balanced and specific power is neutral when ONSPEED.

Not too many topics can start as much discussion amongst pilots as the age-old debate of angle of attack vs airspeed. Like most aviation topics, it depends on what you are trying to accomplish or what mental model you're building. If you are fast and maneuvering, say descending from cruise altitude or starting a loop, then airspeed is your primary energy reference. But if you are slow, banked up and turning base to final with an overshooting wind, then using optimum maneuvering AOA as a reference makes more sense. Optimum AOA isn't affected by gross weight, G load/bank angle or density altitude—it's always the same: no cockpit math required. With an accurate, properly calibrated AOA system, it's easier to maneuver and land the airplane by reference to AOA than computing and referencing airspeed—just *do what it takes to maintain ONSPEED AOA*. The best way to frame the AOA vs airspeed discussion is to think of the two as complimentary concepts—know when to apply each one, and how to *blend* them. As a basic rule, if you are faster than L/D_{MAX} it makes sense to think in terms of airspeed and G, and if you are L/D_{MAX} or slower, then it makes sense to think in terms of AOA. If you are slowing down, it usually is a matter of transitioning from airspeed to AOA references.

Energy management is another term that can either confuse or start more "what the hell are you talking about?" discussion. In simple terms, energy is nothing more than airspeed, altitude or some combination of the two. We can generally use the terms "energy" and "airspeed" interchangeably. Technically, energy is power converted into airspeed and/or altitude. The pilot manages energy with pitch, power and roll inputs. In powered airplanes, sometimes we have "excess power" and we can use the throttle to accelerate or climb, sometimes we don't, and all of the throttle available still won't keep the airplane from slowing down or going down (energy is negative). We can think in terms of the power-required curve when we assess energy: if we are faster than ONSPEED (the bottom of the curve), then we've got excess power (or the ability to gain energy using throttle) and if we are slower, then we don't.

All pilots are familiar with the maneuvering envelope of the airplane. Some pilots explore the limits of that envelope flying aerobatics or dogfighting, and all pilots explore the aerodynamic limit every time we take off and land or try to extract maximum performance from the airplane. If we combine what we know about the maneuvering envelope with what we learned about drag and power-required curves in training, we can develop some helpful maneuvering rules of thumb that can keep us out of trouble if we are trying fly a perfect final approach, handle an engine-out situation, execute a maximum performance climb or extract optimum turn performance from the airplane.

The Power Required Curve. When we learned to fly, we studied the drag curve—the sum of parasite and induced drag, and we learned about the region of "reverse command" flying slower requires more power. Most of us have heard the expression "back side of the power (or drag) curve." If you are a jet pilot, then it is proper to refer to the *drag* curve for your airplane. Jets have *thrust* levers (jet engines produce thrust directly). If your airplane has a propeller, it's correct to refer to the *power* (required) curve. Piston and turboprop engines produce power in the form of torque and rotational velocity, and the torque and rotational velocity is converted into thrust by the prop. Propeller-driven airplanes have *power* levers. Figure 1 shows a drag curve for a jet airplane on the left side. The most important thing to note is that L/D_{MAX} occurs at the nadir of the curve. Figure 1 depicts a power-required curve for a propeller-driven airplane on the right. L/D_{MAX} occurs where the line from the origin is tangent to the curve, and minimum power required (ONSPEED) occurs at the nadir. Recalling two of the four forces of flight we learned about in ground school, thrust equals drag in 1G, unaccelerated flight.

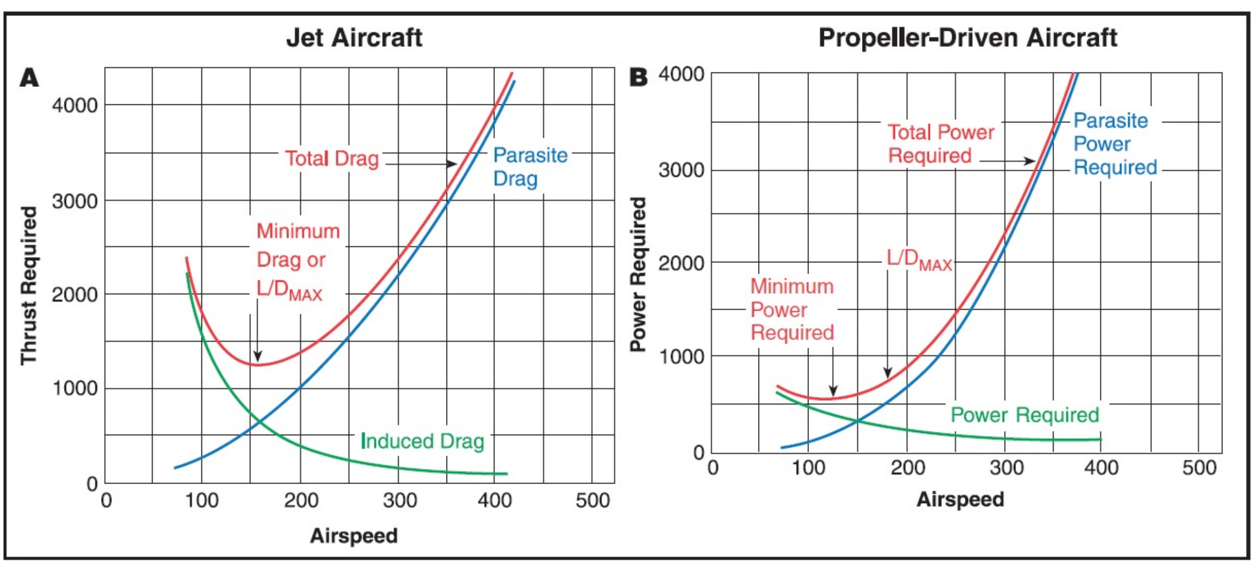

Figure 1. Drag vs Power Required Curves

Maneuvering AOA References. Let's start by talking about the four AOAs that we care about when we maneuver: Carson's speed, L/D_{MAX}, ONSPEED and stall. These AOAs are *designed* into the airplane—we know where to look for them in any airplane with a bit of engineering math. Carson's speed is the angle of attack at which the airplane achieves the greatest increase in velocity for the least increase in fuel flow. Expressed as a speed, it's 32% greater than L/D_{MAX} velocity. In a typical GA piston-powered airplane, it's slower than normal cruising speed, but faster than L/D_{MAX} (best range speed). It is the AOA at which the airplane flies as fast as possible with minimum fuel consumption. It might be handy for holding, initial segment for instrument approach, or optimum cruise climb; but not a reference most pilots use on a regular basis. It is, however, very helpful when we *calibrate* an AOA system in an airplane. All pilots should understand the value of L/D_{MAX}: maximum range, approximate best rate of climb, and maximum *range* glide in a propeller driven airplane. ONSPEED occurs at a speed equal to approximately 80% of L/D_{MAX} velocity flaps up. It is where maximum excess thrust power is available point for a propeller-driven airplane and about the point the wing is producing 60% of its total lift capacity. ONSPEED AOA is used as a V_{REF} (approach speed), is coincident with best *angle* of climb, maximum endurance glide and provides optimum turn performance. Optimum turn performance is best turn rate and minimum turn radius sustained over time. All pilots are familiar with stall. From an operational perspective, we want accurate, progressive stall warning so we don't lose control of the airplane unintentionally. AOA can be a great reference when operating at speeds below L/D_{MAX} and when maneuvering at AOA greater than L/D_{MAX}.

The Flight Envelope. The expression "envelope" was originally applied to what is technically called a VN diagram, because it looks somewhat like an opened envelope. VN refers to velocity plotted "normal" to load factor, commonly referred to as G (modern texts also call this a VG diagram). Figure 2 is the maneuvering envelope for a typical aerobatic EAB airplane. The curved line on the left side of the envelope is the aerodynamic (stall) limit of the airplane. Because critical angle of attack for the airfoil is constant, this line represents critical AOA. Aeronautical engineers and pilots often refer to AOA as "alpha" because AOA is represented by the Greek letter alpha. The terms AOA and alpha are interchangeable. The aerodynamic limit is parabolic, because stall velocity increases proportionately to the square root of the ratio of weight to the coefficient of lift. Herein lies an important concept: ***stall speed changes with weight, G load/bank angle and density altitude, but stall AOA remains constant.*** The top horizontal line of the diagram is the design load limit of the airplane, expressed in G. The right side of the diagram is the airspeed limit of the airplane, usually referred to as red line because this speed is represented by a red line on the airspeed indicator in piston-powered propeller airplanes. In Figure 2, the yellow area of the diagram is defined by maximum structural cruising speed (V_{NO}) on the left and never exceed speed (V_{NE}) on the right and corresponds to the yellow arc on a properly marked airspeed indicator. Like a drag or power-required curve, there is an obvious point on the flight envelope that we can use when are building a mental model to help safely maneuver the airplane: the top left corner of the diagram. This point corresponds to maneuvering speed for the airplane. Because it's at the corner of the envelope, fighter pilots refer to this speed as "corner velocity." The terms maneuvering speed and corner velocity are interchangeable. At speeds slower than maneuvering speed, the airplane will stall before structural limits are exceeded. If we are slower than V_A, then we are likely concerned with AOA (i.e., not stalling if we are maneuvering), but if we are faster, we are likely concerned with airspeed and G (i.e., not exceeding airspeed or G limits if we are maneuvering).

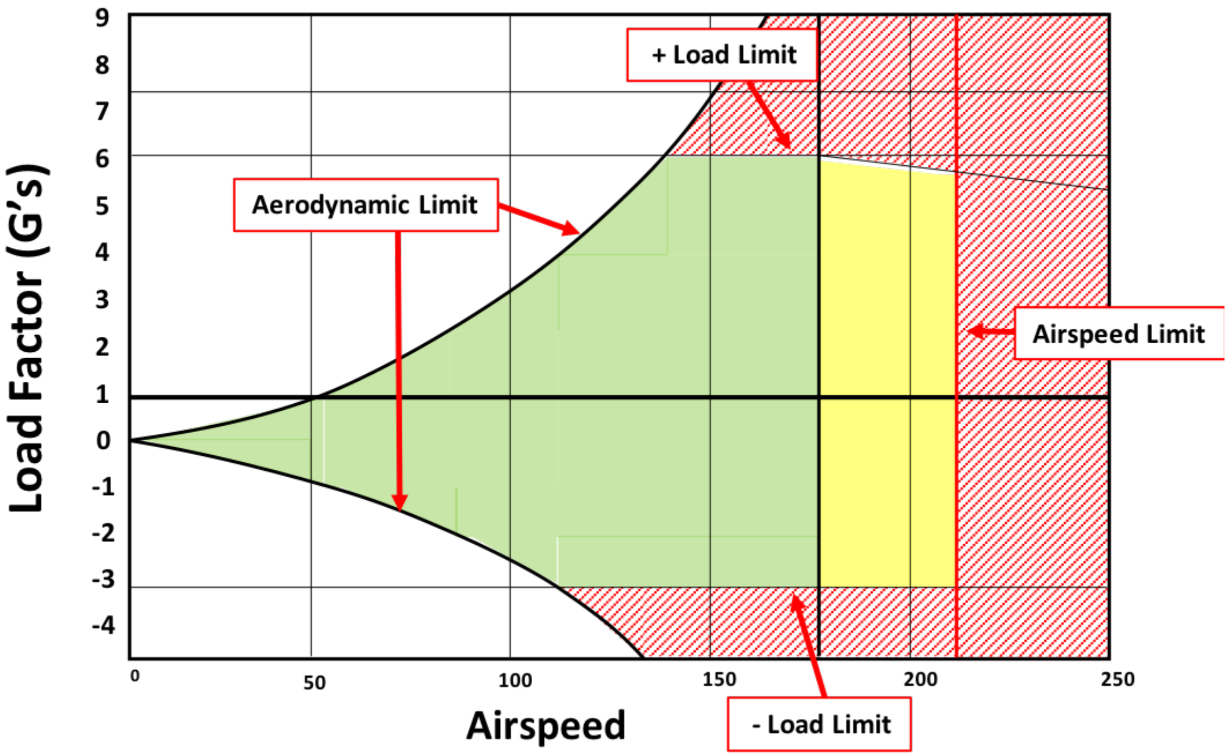

Figure 2. Flight Envelope of a Typical Aerobatic EAB Airplane

Figure 3 shows the ONSPEED band superimposed on the flight envelope. This is the AOA associated with ONSPEED, plus or minus about 1 degree, and represents the Goldilocks "just right" AOA for optimum energy maneuvering. The obvious question is why it's just right? In simplest terms it's just right because if you increase AOA above ONSPEED, you will lose energy (either airspeed, altitude or both). In this region, specific excess power is negative: there is more drag than thrust. The airplane will go down (loose altitude) or slow down unless the pilot makes an adjustment (increased power, if available and/or reduced AOA). This effectively creates a part of the envelope (highlighted in yellow in Figure 3) that it makes no sense to fly in (unless the intent is to bleed energy or stall). There is one important exception: emergency dive recovery. In that case, maximum instantaneous vertical turn performance is required, which means going right the aerodynamic limit of the airplane to avoid hitting the ground. Because most of us don't fly too many emergency dive recoveries, this leads us to an *important rule of thumb for most flying:* ***<u>don't get slower/pull harder than ONSPEED AOA</u>***. If you do, you are unnecessarily expending energy for no real performance benefit. Remember, when you are ONSPEED, thrust and drag are balanced, and the airplane achieves optimum turn performance for a given power setting and weight. The other benefit of knowing ONSPEED AOA is that it is an optimum energy state for approach and landing (not too fast and not too slow), and although there is no aerodynamic relationship with stall, ONSPEED happily occurs at a *speed* approximately equal to 130% of stall speed—which should sound awfully familiar (i.e., the standard 1.3 x V_S used to compute V_{APP}). This is why fighter pilots have used AOA for decades as the primary reference for landing, including carrier landings: ***ONSPEED AOA is always the same, isn't affected by gross weight, G load (bank angle) or density altitude; thrust and drag are balanced; and kinetic energy is optimized for approach and landing.***

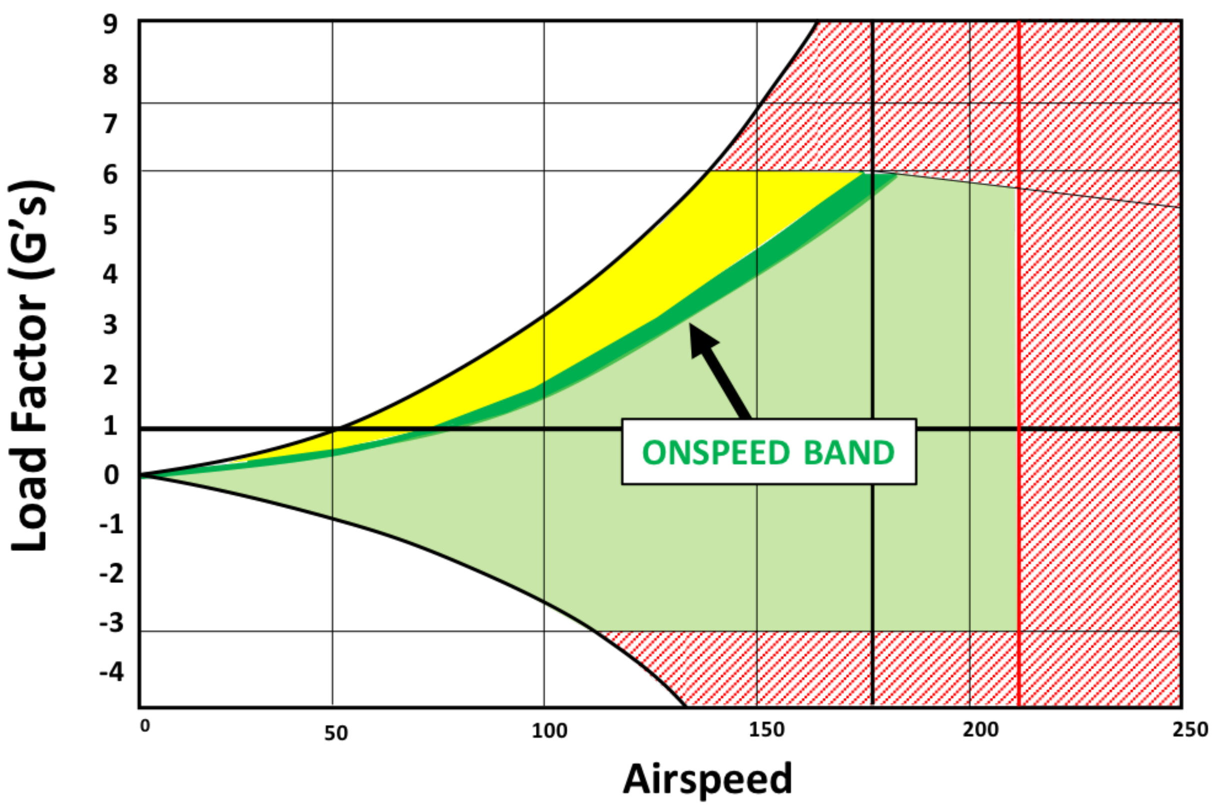

Figure 3. ONSPEED "Band" Superimposed on the Flight Envelope

Putting it All Together and Flying the Aural AOA Logic. If we are flying faster than L/D_{MAX}, we are generally concerned with airspeed (and G) limits, and if we are flying L/D_{MAX} or slower, it makes sense to reference AOA if we want to optimize performance. The two key performance AOAs we are concerned with are L/D_{MAX} and ONSPEED. There isn't usually a reason to fly any slower (or pull any harder) than ONSPEED, because that will only bleed energy for no increase in performance. For most non-aerobatic flight, we may want to reference ONSPEED or L/D_{MAX} for takeoff/initial climb, and then think in terms of airspeed, power setting and/or fuel flow during cruise and descent, and then transition to ONSPEED AOA for approach and landing. Remember, *ONSPEED AOA is always the same, it's not affected by gross weight, G/bank angle or density altitude.* For a best angle of climb takeoff, rotate and climb on the steady tone until obstacles are cleared. For best rate, climb at L/D_{MAX}: the start of the "fast" tone. For a maximum performance takeoff, use ONSPEED initially for best climb angle and then transition to L/D_{MAX}

for best climb rate. If we are landing on a short strip, we definitely don't want to be any faster than ONSPEED for final approach. The aural AOA logic makes AOA management simple and allows the pilot to listen to "the backside of the power curve." For a normal landing, slow to the steady tone, configure the aircraft and adjust pitch and power to maintain the steady tone to landing. Avoid the slow tone until the final alignment/flare. The aural logic is depicted in Figure 4. Note that fast is to the right and slow is to the left so if you are slowing down, you'd hear the logic from right to left on the diagram. For example, if you were trying to maintain an ONSPEED condition for approach, and you heard a "slightly slow" tone (1600Hz slow beeps), you would reduce AOA slightly (by easing back pressure on the stick or yoke) to re-establish an ONSPEED condition, simultaneously adjusting power (if necessary) to control glidepath angle. The aural logic is simple to use—it takes longer to read about it and decipher the diagram than it does to learn how to use it in the airplane.

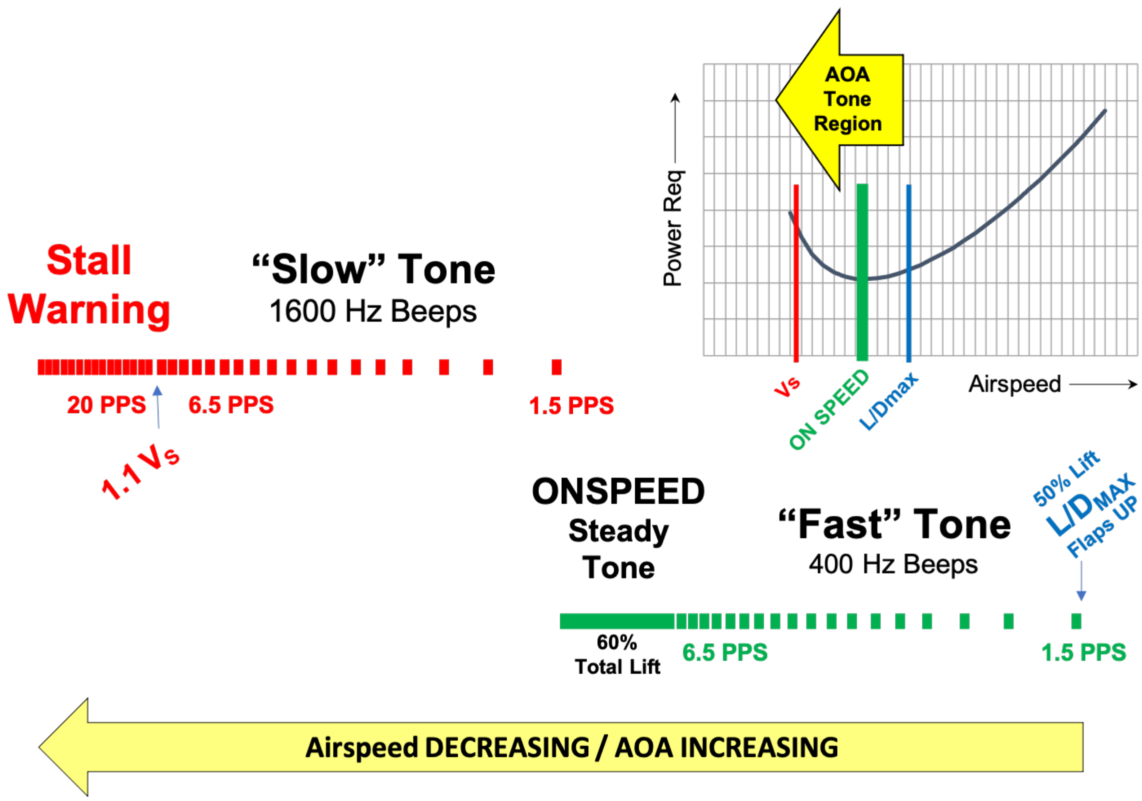

Figure 4. Aural AOA Logic (Flaps UP)

Flying ONSPEED. Figure 4 makes the aural logic seem more complicated than it is (it's easier to listen to a symphony than to read it off the conductor's score). Figure 5 is a simple "push/pull" model that demonstrates how the ONSPEED logic works in flight: if you hear any slow tone, push the stick; and if you hear any fast tone, pull the yoke—do whatever it takes to maintain a steady tone. It's that simple.

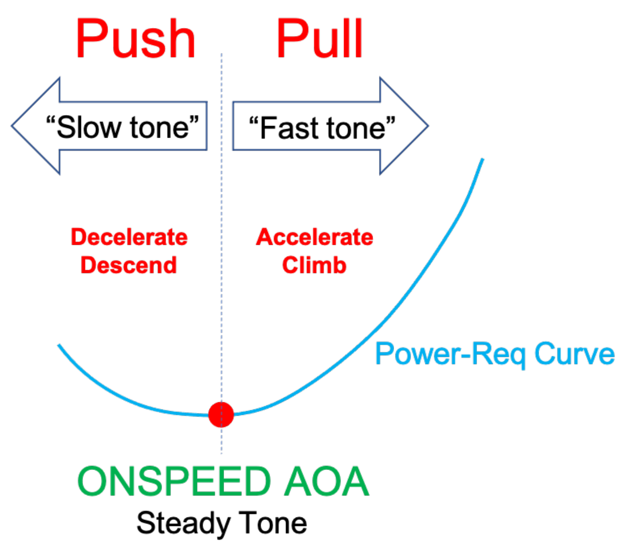

Figure 5. "Push/Pull" Model.

Why an Aural Cue for AOA? Flying is primarily a visual endeavor and hearing is an underutilized cockpit resource. Translating AOA into sound taps into that resource and frees up the pilot's eyes for other tasks. One advantage of an auditory cue is that the brain processes aural cues faster than visual cues, so the feedback loop between the tone and your wrist is reduced. But the substantial benefit of aural AOA cuing is that the pilot's eyes need not be in the cockpit. Because the tone is always present at AOAs above L/D_{MAX}, the presence of the tone indicates that the system is working. Operationally, we "trust but verify" when using the logic for landing, i.e., cross check ONSPEED against a known airspeed to confirm proper operation at 1G. Once proper operation is confirmed, the tone can be used as a primary reference. The tone is readily internalized after first exposure, so it peacefully coexists with radio chatter and other cockpit sounds. Volume is fully adjustable, and the tone may be turned off if desired. The tone is sufficiently damped (i.e., not "noisy" in engineering terms) so that small, low gain control inputs are sufficient for AOA control. Under turbulent or gusty conditions, a "slightly fast" aural cue may be used until landing transition. The bottom line is that flying with the aural AOA cues is like flying with a flight instructor or another crew member—it's there to back you up when you do that "pilot stuff."

FlyONSPEED.org is a non-profit, open source volunteer effort of aviation professionals to provide high-quality AOA, energy management and training resources to the EAB community.