Takeoff and Landing Using Aural AOA References

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

AOA Challenges and Benefits. In 2014, NASA conducted a Review of Research on Angle-of-Attack Indicator Effectiveness. It concluded that "definitive works that determine the requirements for an AOA display were not found" and "definitive works to determine the requirements for training and for and AOA information were not identified in this review." In addition to a lack of training resources, there are a couple of other challenges to note as AOA systems become more prevalent in a GA environment. First, not all systems are created equal—some do a better job of accurately measuring and displaying AOA and others are simply very good progressive stall warning systems. This is especially true of coefficient of pressure systems which are only as good as the sensor, algorithm used to process the information and how the information is conveyed to the pilot. Second, any system, no matter how good, is only as good as its calibration. The old axiom "garbage in = garbage out" applies.

Perhaps the biggest challenge is educating the GA community on how to apply AOA in daily flying. With the exception of takeoff and landing, most pilots spend most of their time right side up in the heart of the envelope at 1 G. AOA is only an academic consideration discussed when practicing stalls. Even then, most pilots think in terms of "stall speed," not critical alpha. Unusual attitudes and envelope limits are something to be avoided. When flying from point A to point B, airspeed serves as an effective surrogate for AOA. If, however, we incorporate AOA and energy management techniques in our daily flying, we can mitigate loss of control risk during takeoff and landing; and increase the precision with which we fly our airplanes. The NASA study noted "…AOA can be a beneficial display and may be used in the following phases of flight: take-off, climb, turning, maximizing cruise, descent, final approach, low speed maneuvers, maneuvers to flare, landing as well as high G turns, approach to stall and identifying and recovering from stalls at low and high altitudes."

The fighter community in the military was an early adaptor of AOA, and has considerable experience using AOA for aircraft control and energy management, including air combat and landing aboard ship, maximum performance flying that requires extreme precision. The term ONSPEED and its use come from the fighter community and can be adapted to *any* airplane with the right equipment on board. This article will explore an aural AOA cuing logic adapted from a successful military system that can provide useful performance and energy cues to the pilot; and how to apply those cues during takeoff and landing.

AOA and IAS are complimentary concepts. AOA is particularly useful for precise aircraft control and energy management when operating at L/D_{MAX} speed and slower. The accuracy of a properly calibrated coefficient of pressure AOA sensor *increases* as AOA approaches stall, whereas the accuracy of IAS *decreases* under the same conditions. We operate in this "maximum performance" region every time we take off and land the airplane. Every pilot can benefit from a better understanding and application of AOA during takeoff, approach and landing. An accurately calibrated AOA system that captures the aircraft curve (using a multiple point calibration) should provide four key performance cues to the pilot: stall warning, ONSPEED, L/D_{MAX} and Carson's Speed. Unlike indicated airspeed, AOA cues are *not* affected by aircraft gross weight, G load (bank angle) or density altitude. ONSPEED and L/D_{MAX} have direct application in takeoff and landing operations.

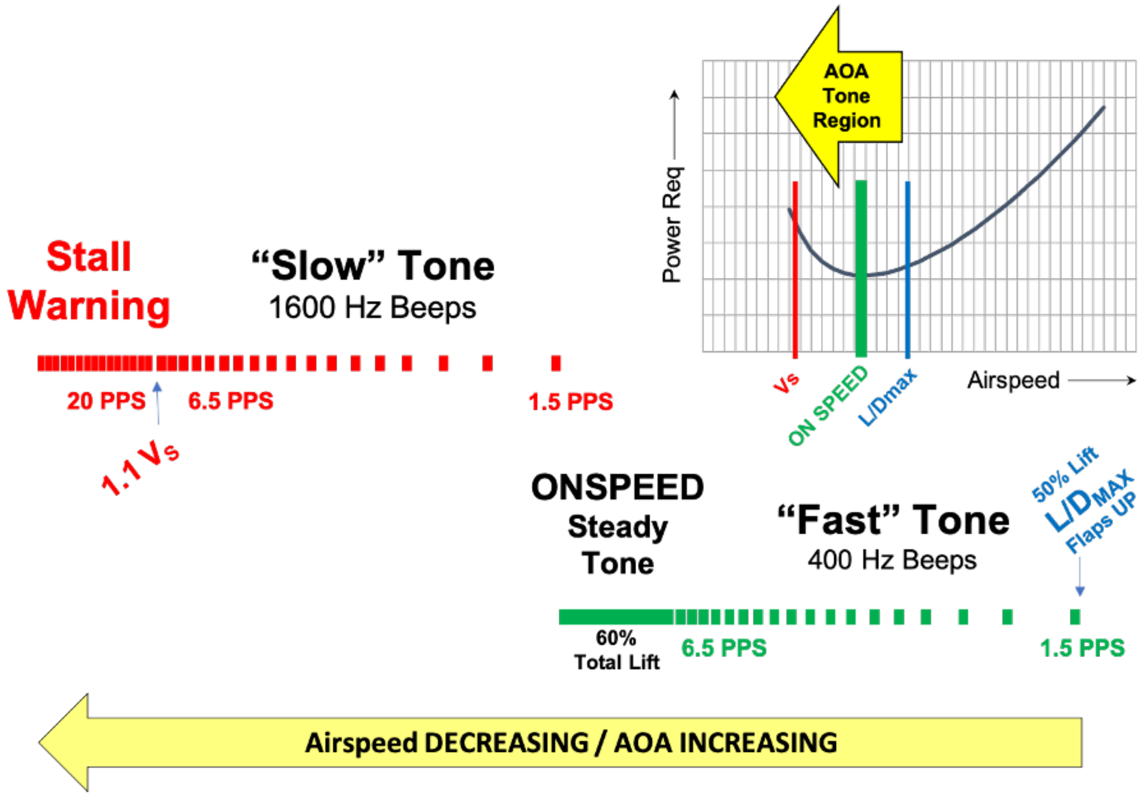


Figure 1. Aural AOA Logic

Tone Review. Figure 1 depicts the aural AOA logic. The right side of the diagram is "fast", and the left side is "slow." Notice I just used the terms fast and slow in conjunction with AOA—alpha is measured in degrees, or even referred to in non-dimensional units; so, it should properly be referenced as "high" or "low." If, however, our objective is to build a pilot-friendly mental model, it's much easier to think in terms of ONSPEED, fast or slow (relative to ONSPEED). In this simple sense, AOA and speed are interchangeable when we *think* about our energy state. When the pilot is using the steady ONSPEED tone for approach and landing or during a maximum performance takeoff, the variable pulse rate and frequency difference allows the pilot to easily distinguish between ONSPEED and a fast or a slow condition.

Figure 2 is another way to visualize the information the tone conveys: we call it the "Push/Pull Model." The tone provides direct, timely damped AOA (pitch) control feedback to the pilot. If the pilot hears slow tone, he pushes the stick, and if the pilot hears fast tone, she pulls back on the yoke. The Push/Pull Model also shows us another important concept: if slow tone is present, there is more drag than thrust and overall energy is negative. Unless the pilot makes a change (reduce AOA and/or increase power), the airplane will slow down, go down or both. If fast tone is heard, the opposite is true: there is more thrust than drag and overall energy is positive. Figure 3 relates the different tones to some familiar 1G airspeed references during takeoff and landing.

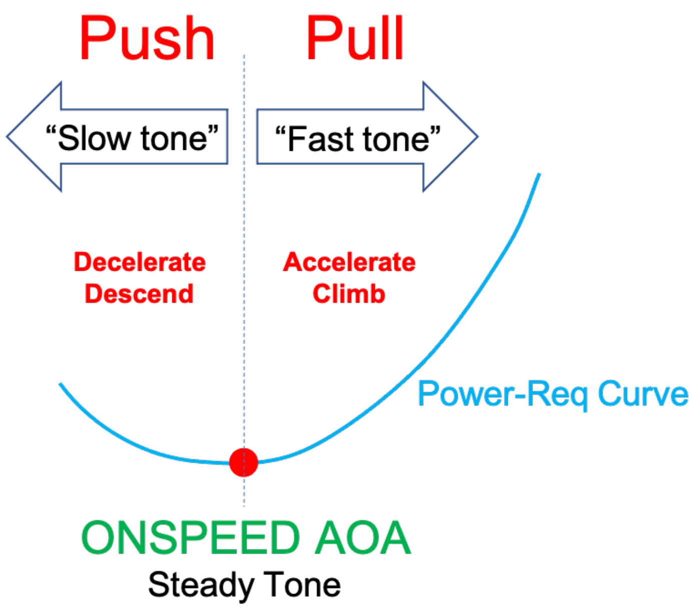


Figure 2. The ONSPEED AOA Push/Pull Control Model

System Operation. Depending on configuration, the aural logic is controlled by a simple mechanical rotary switch that serves as both ON/OFF and volume control. The volume is fully selectable, and the system may be turned off at any time. Depending on how the system is wired, intercom and/or headset capability, the tone may be attenuated during radio transmission and reception. Speeds at which the tone becomes active during takeoff roll or ceases after landing are selectable by the pilot. To achieve usable cues for takeoff, the speed selected should be slow enough to allow the pilot to listen as the pilot accelerates to ONSPEED. It's recommended that this speed should provide at least 10-15 kts of margin. If wired in stereo, the system provides "3D audio" cues. The tone moves left and right in the sound field with the slip/skid ball providing an aural cue to assist the pilot with properly coordinating rudder input during all phases of flight.

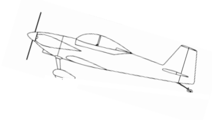
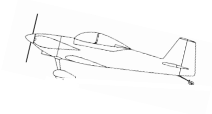
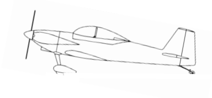
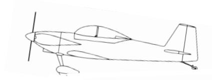
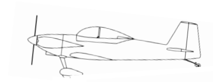
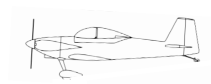
1G IAS as % V_S	Aural AOA Cues	Attitude
<1.15 V_S	Stall Warning	
1.16-1.25 V_S	Slow	
1.25-1.29 V_S	Slightly Slow	
1.3-1.35 V_S	ONSPEED	
1.36-1.4 V_S	Slightly Fast	
>1.4 V_S	Fast L/D_{MAX}	

Figure 3. Aural AOA Logic in Takeoff and Landing Environment.

Takeoff Performance Aero Review. There are three V speeds we are concerned with during takeoff: V_R, V_X and V_Y. V_R is rotation speed. As the airplane reaches V_R, the pilot rotates to establish desired takeoff pitch. V_X is best *angle* of climb speed. It is a speed at which maximum excess *thrust* from the propeller is available. It is relatively close to stall speed and provides the steepest climb *angle* during initial climb phase. On a power required curve, it occurs at the minimum power required point at the nadir of the curve (V_{PRmin}). V_Y is best *rate* of climb. It is the speed that gives you maximum vertical velocity (fastest climb per unit time). V_y occurs when the engine is producing maximum *power*. On the right side of Figure 4, it occurs where there the most excess power is available (maximum distance between power required and power available curves). It is a speed slightly faster than L/D_{MAX}. Like any speed, V_X and V_Y are affected by weight and density altitude. As altitude increases, V_X increases and V_Y decreases. We can translate the two key takeoff V speeds to AOA. Since ONSPEED is coincident with minimum power required; best angle of climb will occur ONSPEED. Initial best rate of climb will occur at approximately L/D_{MAX}.

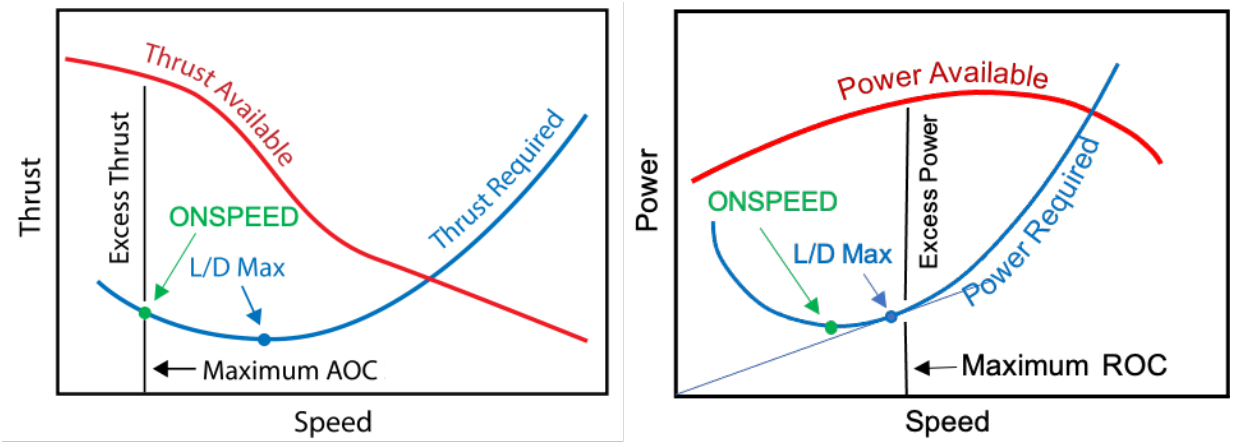


Figure 4. Best Angle and Rate of Climb, Propeller-driven Airplane

Takeoff Using Aural AOA Cues. More pilots lose control during takeoff and initial climb segment than come to grief during approach and landing. Having usable, calibrated AOA cues available during takeoff can provide performance feedback and reduce LOC risk during this critical phase of flight.

Let's consider how the aural AOA logic sounds as we accelerate during takeoff and the initial climb segment. The tone becomes active as the airspeed increases during the takeoff roll. In my airplane, that occurs at 25 KIAS. The airplane is deep in the stall region, so I hear a stall tone initially. As the airplane accelerates, the stall tone changes to a "slow" tone and the pulse rate of the beeps gradually decreases approaching rotation. ONSPEED occurs at about lift-off. As the airplane accelerates, the solid ONSPEED tone changes to a "fast" tone until I'm faster than L/D_{MAX}.

EAB types may or may not have accurate performance data (including climb V speeds), because the quality of flight test data for individual airplanes varies. An accurate, ergonomic, properly damped AOA cue is beneficial in any airplane but in an EAB type in particular. Recall that ONSPEED and L/D_{MAX} AOA are designed into the airplane. Thus, if the pilot knows when the airplane is ONSPEED or at L/D_{MAX}, it becomes relatively easy to precisely manage energy during takeoff and initial climb. Precisely managing energy means converting power as efficiently as possible into altitude and airspeed.

Maximum Performance Takeoff Using Aural AOA Cues. Figure 5 depicts an AOA-based technique that optimizes energy during takeoff, allowing obstacles to be efficiently cleared and then altitude gained as rapidly as possible to complete the initial climb segment. It is impossible to provide a specific rotation rate or exact pitch angle, because that will vary from airplane to airplane. For example, in my 160 HP RV-4 equipped with a fixed-pitch propeller, I use a 3^{o}/second rotation rate to 15^{o} of pitch. In airplanes with less performance, a slower rotation to a lower pitch angle may be appropriate and vice versa for a more powerful airplane. Some experimenting is required to determine the best way to rotate and capture ONSPEED for initial climb in your airplane.

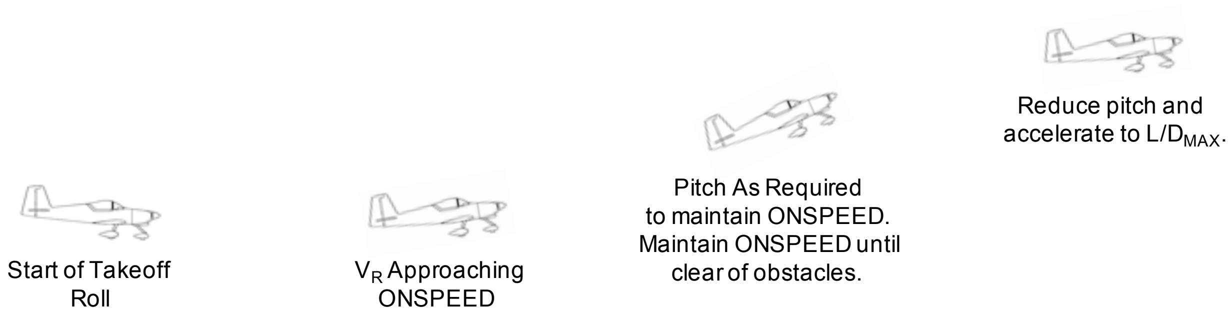


Figure 5: Maximum Performance Takeoff, Obstacles

Figure 6 is a similar energy efficient technique if obstacles are not a factor. In this case, a lower rotation pitch angle is established as the airplane transitions through ONSPEED, and the airplane continues to accelerate to L/D_{MAX} after liftoff and a positive rate of climb is established.

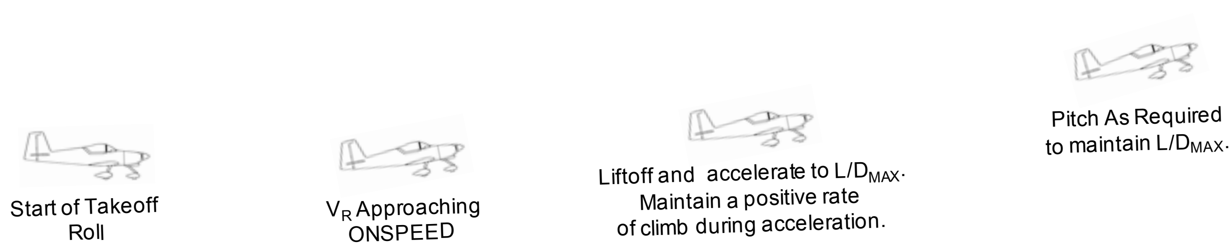


Figure 6: Maximum Performance Takeoff Profile, No Obstacles

Loss of Control During Takeoff. The aural AOA logic assists with maintaining aircraft control during takeoff. Some high-performance airplanes (including most of the Van's types), become less stable in climb at high pitch attitudes with high power. Any tone slower than desired climb condition would tell the pilot to reduce pitch. For example, if the airplane is supposed to be at maximum climb angle (ONSPEED), any slow tone would indicate excessive pitch. Similarly, if the airplane is supposed to be at L/D_{MAX} to approximate best rate of climb, any increase in pulse rate tells the pilot that pitch is too high. In this example, an absence of tone would mean that pitch is too low. Another energy problem occurs if there is a loss of power during climb—especially a steep climb attitude. In this case, significant pitch change may be required to maintain aircraft control and establish a best glide condition. A good energy management rule of thumb is "angles = angles" so if the airplane is pitched up 15^{o} when power is lost, then it's probably going to take a 15^{o} push to establish a best glide condition. The aural AOA logic assists the pilot in this case: if power is lost, adjust pitch to establish L/D_{MAX} or ONSPEED (if flaps are extended)—the slow tone will keep you honest if you don't get the nose down far enough.

Approach and Landing Using Aural AOA Cues. Fly ONSPEED for approach and landing. *ONSPEED AOA is always the same regardless of gross weight, G load (bank angle) and density altitude.* To land using the aural AOA cues, the airplane is slowed to ONSPEED, configured for landing and ONSPEED is maintained until the flare. Figure 7 shows an energy efficient pattern that allows the pilot to use a simple technique: pitch to control tone (AOA), power to control glide path and bank angle to control ground track. Because the airplane is configured for landing, and a constant AOA is desired, *the pilot need only concentrate on flying the airplane from the point the base turn is begun until landing roll-out is complete.* The continuous base turn minimizes the chances of over-shooting final and makes wind adjustments intuitive. 10-12 Seconds on final approach allows the pilot to analyze and correct for cross-wind and stabilize parameters prior to touchdown. Exact glidepath angle flown depends on the airplane and whether or not any power is used during the base turn and final approach. This pattern is very similar to the "180 power off approach" you practiced for your private check ride.

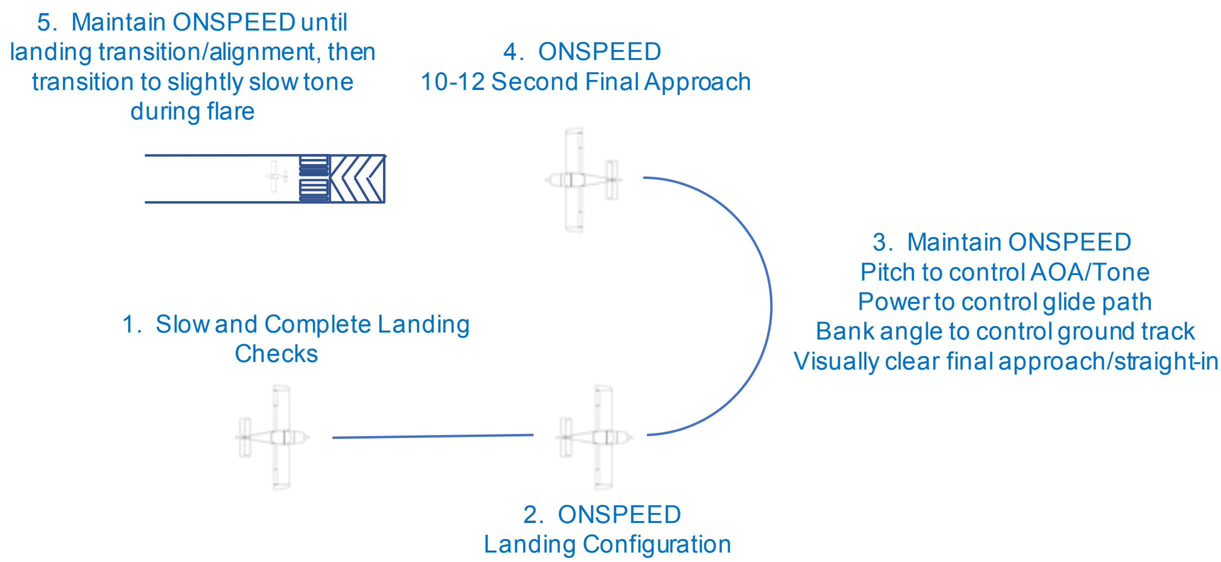


Figure 7. ONSPEED Visual Landing Pattern

Loss of Control During Approach and Landing. Because most pilots spend most of their time at 1 G and typically utilize limited bank angles for "normal" flight, many aren't well tuned to effects of G load on IAS for stall. The aural AOA logic provides immediate feedback if the pilot increases bank and fails to relax back pressure to maintain a constant AOA. Pilots used to flying IAS without AOA cues or advanced instrumentation don't always understand when they are eating into the aerodynamic (energy) margin when turning. Some EFIS depict this as a variable airspeed "foot" that moves up and down relative to stall IAS. If properly calibrated and programmed, this type of visual speed indication provides a utility similar to the "slow" tone of the aural AOA logic, although it requires the pilot to look inside the cockpit. Stay faster than the "foot" and you have sufficient margin to avoid a stall. Another consideration is carrying too much energy into the landing transition: too fast can be as dangerous as too slow. ONSPEED is the right energy state for landing transition: not too fast or too slow, and not affected by ambient conditions. When you can *hear* an ONSPEED condition (and fast or slow cues), it's caveman simple to manage pitch without looking in the cockpit—any slow tone tells you that energy is negative and corrective action is required.

Gust Additive. Adjusting V_{REF}/V_{APP} for conditions is a technique that applies to using IAS as a reference for approach and landing. ONSPEED AOA is not affected by ambient conditions. However, there is a limit to how precisely a pilot can control AOA and airspeed under turbulent or gusty conditions. A "slightly fast" approach may be utilized until transition to ONSPEED landing to assist with mitigating the need for a high gain power or control input that can lead to over-control.

Summary. Here's how the aural AOA logic works in areas that NASA thinks AOA information can be helpful. Click on the link to a view a video demonstration of each maneuver:

Takeoff/Climb
Turning
Descent/Final Approach/Landing
High G Turns
Progressive Stall Warning and Recovery

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.