CARRIER PILOTS' SECRET

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Sport aircraft may be designed with high wing loading for speed or a low wing loading for flights into short strips. Both missions require exacting piloting skills. If you're flying either, you may benefit by unlocking the secrets that Navy and Marine carrier pilots know.

Imagine this scenario. You are flying home from a stressful evening of work; it's pitch black; you have about 25 minutes of fuel remaining before you start sucking air. The closest landing strip within 200 miles is a heaving aircraft carrier whose deck is as slippery as wet grass, and only 600 feet long. To make things even worse, your approach speed will be 166 miles per hour all the way to touch down. Land just over 120 feet short and you will crash into the ship's stern. Sixty feet long and you'll bolter (miss the last wire) and have just enough fuel for one more quick go around and another landing attempt or an aerial refueling. Too slow and you'll stall into the ocean. A few knots too fast and the tail hook will skip the arresting cables (hook skip). A bit faster than that you could rip out the carrier's arresting cable (two block the gear) leaving all your flying buddies in the pattern behind you in a world of hurt.

This precision flying requires being within three feet vertically and five feet horizontally from the optimum touch down point on the carrier deck and within just a knot or two of the optimum approach/touch down speed. How do Navy and Marine pilots do it?

Marine and Navy carrier pilots use exclusively one onboard aircraft instrument, angle-of-attack (AOA)!

Angle of attack is the angle between the chord line of the wing and the relative wind. This is not to be confused with attitude that we read from our artificial horizon. To make this point very clear, a looping maneuver as shown in Figure A could be performed by holding a fixed AOA of 11.0 degrees around the entire loop. The attitude would be changing between 0 degrees plus 90 degrees and minus 90 degrees.

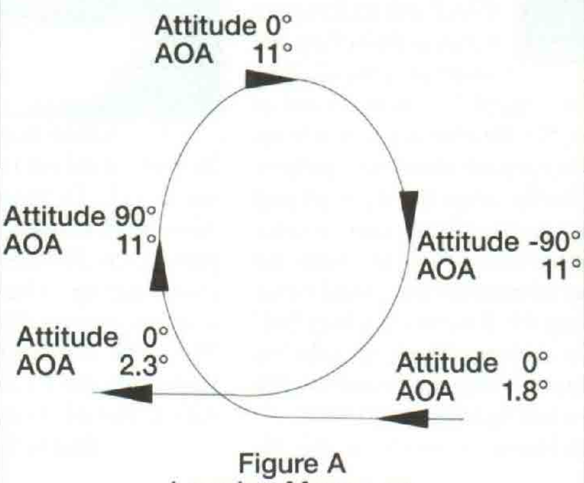

Figure A
Looping Maneuver

Navy and Marine pilots are trained to make carrier approaches using angle of attack instrumentation exclusively, mostly ignoring the airspeed indicator. The military spin entry and recovery procedure and tight high performance maneuvers are all made referencing AOA. The airspeed indicator is just not accurate enough, has too much instrument error, and does not factor in bank angle, fuel load and turbulence. AOA instruments on the other hand are self-compensating and become more accurate as the speed decreases and the angle of attack increases.

Now back to reality. Let's fly our pride and joy around the pattern and demonstrate how and why to fly AOA.

TAKEOFF AND CLIMB

On takeoff (T/O) we rotate to an attitude referencing the earth's horizon or the attitude indicator. The rotational pitch attitude is what we estimate will result in the proper IAS for climb. Shortly after lifting off and while holding this attitude we cross check the indicated airspeed indicator and make fine adjustments to our attitude bracketing the desired climb IAS. This IAS might be the best angle of climb, the best rate of climb or some higher speed depending upon the desired climb gradient. Although this method has served most of us adequately in the past, we need to understand that Vx and Vy do not occur at fixed indicated airspeeds.

The second drawback is that the attitude we initially rotate to on takeoff is only an educated guess of what will produce the targeted climb speed. The most common error students make in mountain flying is rotating on takeoff to the same pitch attitude that worked for them at their home strip in the lowlands. Invariably this results in an attitude on takeoff that is near the critical AOA (stall) at these high density altitudes. This is called "operating behind the power curve" or "operating in reverse command." Using the same pitch attitude for all T/Os ignoring gross weight and density altitude has resulted in many short flights into the trees at the end of the runway. All T/Os should be flown referencing IAS and AOA. Higher density altitudes and higher gross weights will require lower T/O attitudes. Flying to the proper AOA on rotation will result in the proper attitude for every departure regardless of density altitude or gross weight.

APPROACH AND LANDING

Does your aircraft's operating manual suggest a single approach IAS no matter what your aircraft's gross weight and bank angle? Wow, many a fatality has resulted from this oversight! Let's explore why. We'll assume that your aircraft stalls at 60 mph and at an AOA of 15 degrees when operating at a gross weight of 1,500 pounds in 1 G flight. After loading your aircraft with additional fuel, passengers and baggage, it now weighs 2,200 pounds. What is the stalling speed and critical AOA now?

$$Vs_{(2{,}200\#)} = 60\sqrt{2{,}200/1{,}500} = 73 \text{ mph}$$

The above relationship shows that the stalling speed increases from 60 to 73 mph due to the increased gross weight but the critical AOA (stalling AOA) remains the same at 15 degrees.

Suppose we turn the aircraft from base to final using a 45 degree bank angle to compensate for the stronger than anticipated crosswinds aloft which blew us beyond the runway intercept. Now what is the stalling speed and critical AOA?

$$Vs_{(45°)} = 73\sqrt{1/\cos 45} = 87 \text{ mph}$$

The stalling speed increases from 73 to 87 mph but the critical AOA is still the same at 15 degrees.

Now add a +1.5 G turbulence bump while in the turn at the higher weight.

$$Vs_{(1.5G)} = 87\sqrt{1.5} = 107 \text{ mph}$$

The stalling speed is even higher, but, as before, the critical AOA remains 15 degrees.

Since any given airfoil always stalls at the same critical AOA, all approaches should be flown using a fixed AOA regardless of GW, bank angle, turbulence, density altitude, etc. This is one of the reasons why flying AOA is worth its weight in gold. Those base to final banked turns, turbulence encounters and changes in gross weight are all flown using a fixed AOA and you are relieved of all the above computations.

Let's go flying with Captain Ace (the local airport legend) using an AOA indexer manufactured by Proprietary Software Systems, Inc. and demonstrate how approaches are flown (or not flown in this example) using the elevator to control AOA and power to adjust the rate of descent. Ace is flying the proper approach AOA for this particular instrument when the four bottom lights are lit (Figure 3). Flying AOA is similar to keeping the IAS pointer on the reference bug. In this case the reference bug would be permanently affixed to the middle yellow

Fig 1 *best glide, max endurance* — *Fig 2* *approach AOA too low* — *Fig 3* *approach AOA Just right* — *Fig 4* *Watch out* — *Fig 5* *Critical AOA*

bulb. In Figure 1 Ace is flying the best glide or maximum endurance AOA, which in some flight regimes would be appropriate. But this is too low an AOA and too high an airspeed for final approach, so Ace increases the back pressure on the stick/yoke. In Figure 2 the AOA is still just slightly too low for the optimum approach AOA so Ace continues to increase the back pressure. The AOA is perfect in Figure 3 and Ace should trim out the back pressure in 1 G flight so that no elevator stick/yoke pressures are required. In Figure 4 the aircraft's AOA is getting dangerously close to critical and way too high for approach. An aural warning "angle push" sounds, and Ace should increase the forward pressure on the stick/yoke, and decrease the bank angle. The aircraft is at the critical AOA (starting to stall) in Figure 5. Ace blew this approach big time and immediately executes a stall recovery maneuver saving his life. Upon returning to a lower AOA as depicted in Figure 1, Ace collects his thoughts and wonders how this could have happened thinking that he had plenty of airspeed. But Captain Ace recalls some training from long ago — it's AOA and $$$ that keeps aircraft flying, not IAS. Ace has become another AOA convert.

AOA instruments fall into three categories: pressure, stagnation and vane. Vane and pressure based unit are often mounted on the side of the fuselage for multi-engine or pusher aircraft and on a wing mounted boom for all others. Stagnation based units are cut directly into the leading edge of the wing.

A vane (Photo A) is a wedge shaped airfoil mounted to a rotating shaft sensing the airflow. The vane is free to rotate and is precisely counter balanced so that the position of the vane is determined entirely by the air stream direction. Vanes are subject to ice accumulation and are heated. The vanes must be located well ahead of the wing to give accurate results and are usually quite expensive. The vanes you see on the nose of airliners and corporate jets may cost $4,000 or more not including the AOA computer and display.

The typical direct reading two pressure device is a probe with pressure taps drilled at unique angles in relation to the probe. The pressures are used to directly drive a pressure sensitive indicator as shown in Photo B. These systems are generally called reserve lift devices because they do not directly measure AOA.

Stagnation based AOA devices sense the stagnation point on the leading edge of the wing and correlate the location of the stagnation point with angle of attack. These units use a protruding movable vane to locate the stagnation point and look almost identical to the common stall warning tabs common on Cherokees and lots of other aircraft. The tab is also subject to rime and clear ice accumulation and is usually heated.

An example of a vane based system is EM Aviation's RiteAngle which was developed by an airline pilot, Elbie Mendenhall. The vane is attached to a potentiometer which regulates the input to an electronic module. The vane is mounted on a 12″ long boom outboard of the prop wash. The display is available in two configurations both using a ladder of light emitting diodes (LED) to provide angle of attack information. The more LED's lit, the closer you are to the critical AOA. When the top LED's are lit, a buzzer will sound and/or the green LED's will flash. There are two models and several options.

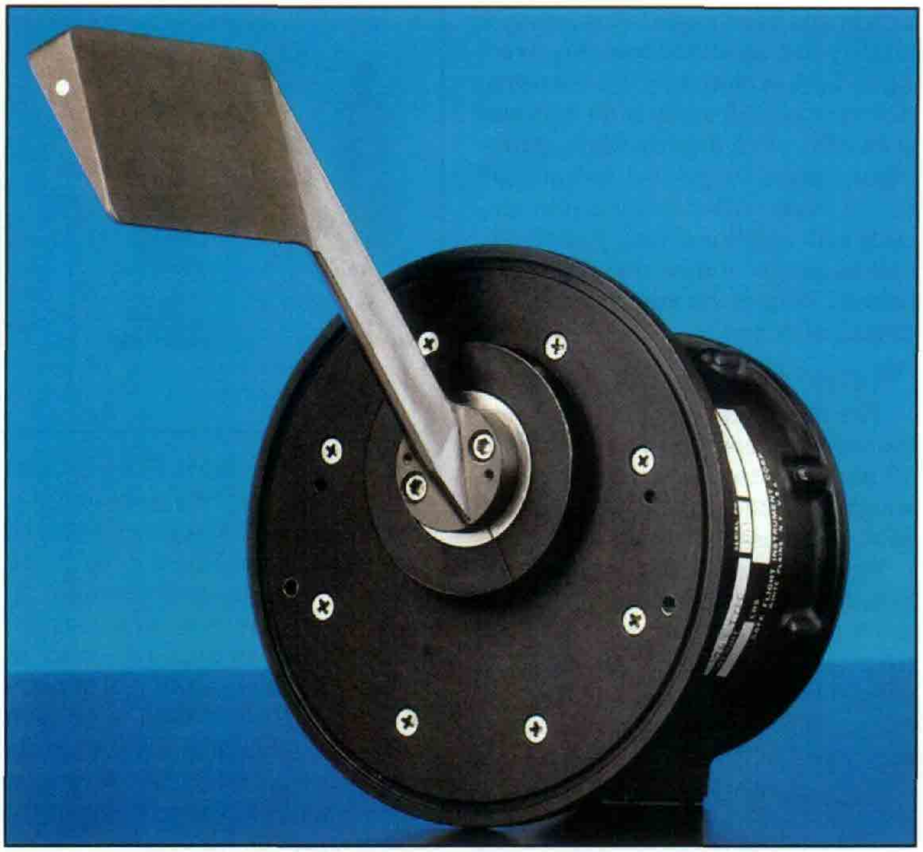

Photo A - Safe Flight Instrument's AOA vane used on large aircraft.

The Lift Reserve Indicator (LRI) is a two pressure port reserve lift indicator. It is sold by Lift Reserve Indicator Company. The inventor, Morgan Huntington, died in 1992 with more than twenty patents to his name, ranging from the LRI to oil shale and sewer treatment. With about 400 units sold, his son Jim is revitalizing the LRI. Jim says, "My father's dream was to invent a safety pin, elegant and simple, that everybody would use. This is it!" The LRI uses an aerodynamically shaped air stream probe that provides pressure input to the display. The display is analog with an arc divided into three sectors. The red sector indicates the aircraft is no longer generating enough lift to sustain level flight. The instrument has marks for rotation, liftoff, maximum angle of climb, flare and more. The instrument requires no power unless the optional probe heater is used.

Stall warning was invented by Safe Flight Instrument Corporation during World War II. Their SC-1500 speed

Photo B - Reserve Lift Indicator and Probe.

control system is based on the stagnation principle and uses a lift transducer mounted on the lower leading edge of the aircraft wing. The transducer vane, which is very similar in looks to the stall tab we are familiar with on many GA aircraft, protrudes into the air stream and is positioned during flight by local airflow velocity and direction. By correlating lift with airflow characteristics at the stagnation point on the wing, the lift transducer measures changes in angle of attack. The output signal electrically enters the computer which drives a visual analog display divided into three colored pie shaped sectors with indexes for best climb angle, short field approach, normal approach, and stall AOA. This unit has optional anti-icing capability. The system can optionally activate the aircraft stall warning device whenever the lift transducer signal approaches the stall angle of attack.

If you were to make a wish list for the perfect AOA, it should be accurate and display minimum lag or hysteresis. It should be lightweight but rugged and easy to install. No moving parts would increase reliability and keep costs down. Protruding parts are prone to damage by airplane enthusiasts with good intentions. The AOA should not be affected by aircraft configuration. The display must be easy to read and understand. There must be audio and visual warnings when approaching the critical angle of attack.

Until recently AOA instrumentation with these features would not have been feasible but there have been new and amazing technological advances. It's now possible to eliminate the probes and vanes which results in less complexity and lower cost. The powerful microprocessor, voice playback chips used in your digital answering machine and a variety of pressure sensing devices are now available and affordable.

Proprietary Software Systems owns patent pending technologies becoming the only aviation AOA instrument manufacturer with no moving parts or protrusions. Their products are all solid state, have color AOA displays (Photo C, Fig. 1-5), and voices aural warnings and cautions.

The liquid crystal display, AOA Professional (Photo C), has a green donut shaped target for the optimum approach AOA familiar to all Navy

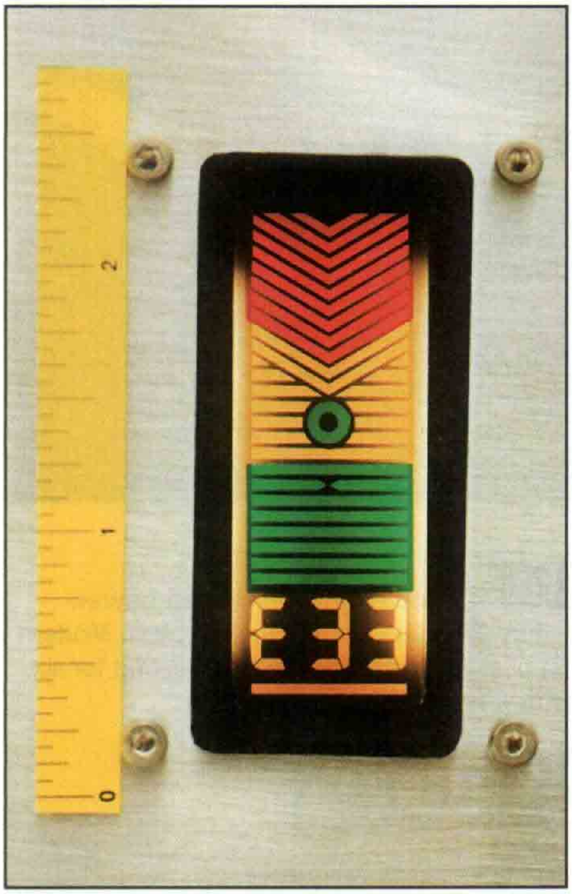

Photo C - Proprietary Software Systems' Professional

carrier pilots and red chevrons indicating when the AOA is dangerously high. A green split bar is called the performance bar which may be set to the best engine out glide, maximum endurance, or best lift to drag AOA. The AOA Sport (Figures 1-5) uses a three color LED ladder display. Both instruments have self-testing features that check accuracy and verbalizes, "AOA PASS," when completed successfully. The AOA instruments are programmed to talk to you announcing warnings of high angles of attack, "Angle Angle Push," instrument problems and installation errors. It can also be used to drive stick shakers and buzzers. An aural warning, "Landing Gear," will help prevent inadvertent gear up landings when the airspeed is slow and the gear is not down. And if you are into aerobatics, racing or just an aerotechi, the Professional also has a TS-232 data port which can be connected to your notebook computer, recording to the disk airspeed, G loadings, wing pressures and AOAs — all time stamped for the entire flight. The AOA Sport is in the process of being FAA certified.

The need for affordable angle of attack instruments became imperative with the increasing numbers of high performance sport aircraft like RVs, Glasairs, GlaStars, Lancairs, Stallions, Legends, Seawinds, Europas, Velocities, Thunder Mustangs, etc., and the many slower STOL type aircraft flying into shorter strips. High wing loaded warbirds and aerial applicators can also benefit. Carrying unnecessary speed when landing these performance machines is foolish. Similarly, the unacceptable fatality rate resulting from loss of aircraft control and contact with the ground (stall/spin) has taken too many of our friends and acquaintances.

AOA instrumentation will increase the awareness and thus the safety of every pilot. The Navy cut their fatality rate in half when switching to exclusively AOA for carrier operations. Sport aviation pilots could do the same.

AOA and Reserve Lift Instruments

Contact	Protrusions Vanes Probes	Weight lb.	Calibration Method	Cockpit Display in.	Outputs and Warnings	Other Features	Power Required	Cost
Bacon Saver 618-594-2681 troneill@midwest.net	moving vane mounted on boom	N/A	several flights	none	none	vane on SS bearing	none	$95
EM Aviation RiteAngle I and II 360-260-0772 www.riteangle.com	moving vane on 12" boom	1.0	3 flights	LED ladder 3.9x2.1 or 2x3/8	buzzer	can be powered with 9V AA battery pack	9 or 14V	$300 to $475
Lift Reserve Indicator Co JimRHunt@WCO.COM PO Box 643 Occidental CA 95465	probe below wing	2.0	multiple flights to adjust probe	round analog	none	icing heat optional	none unless heated	$750 to $830
Proprietary Software Systems, Inc. 612-474-4157 PSS@angle-of-attack.com www.angleofattack.com	none Two small pressure taps in wing	0.5 Sport 0.9 Pro	1 flight	four color LCD or LED Ladder 1/2x11/4	Voice & Open collector &RS-232	Landing Gear warning	12 to 28V 4 Watt max	$890 to $1.495
Safe Flight Instrument Corp SC-1500 914-946-9500	vane on leading edge of wing	.9	multiple flights to adjust vane	round analog 2.375	optional signal output	icing heat optional	14 or 28V 0.3 amp 50 Watt	$1,950

Dave Trousdale *is a former Navy instructor pilot and fleet aviator. Dave taught carrier landings in the T-2C Buckeye and served a nine month tour of duty in Viet Nam flying the A-7E Corsair. He also flew the bush in Alaska and has worked as a NWA check airman.* ***Jim Frantz*** *is a bush pilot, flight instructor, software designer and electrical engineer, with over 18,000 flying hours in everything form J-3s to MD-80s. He built his own award winning Lancair 360 and is the president of Proprietary Software Systems, Inc. which develops and markets AOA instruments. Jim will be giving AOA forums at EAA AirVenture '99 and other airshows. See www.angle-of-attack.com for forum dates and times.*