

# Flight Test – PROTOTYPE SOFTWARE - (7/17/11)

## Enhanced Audio Alerts and Buffered Cascading Lights

### Alpha Systems Angle of Attack Stall Warning System

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This flight test was focused on—and limited to—evaluation of the ability of AOA-experienced- and AOA-unfamiliar-pilots to interpret and correctly use the information displayed. Given that this Stall Warning System is functionally identical to AOA devices tested earlier in a Bonanza and King Air, and that the accuracy of the device was not in question, this Flight Test was executed to analyze **ONLY the human-factors interface** provided by a **prototype** software <REV RB> design—the **“Enhanced Audio - Cascading LED”**—in normal flight configuration and attitude combinations of the Beechcraft King Air C90, as well as the H-35 and S-35 Bonanza aircraft to determine the usefulness of that information at enhancing safety in the operation of general aviation aircraft.

## EXECUTIVE SUMMARY

**CONCLUSION:** *The Alpha Systems Angle of Attack (AOA) Stall Warning System offers an accurate, repeatable, and very early warning of impending aerodynamic stall. Such clear stall proximity information mounted prominently in full view of the pilot offers enhanced safety in the operation of general aviation aircraft. A display of AOA as a cross-check to the primary Airspeed Indicator is particularly useful when operating in steeply banked and/or G-loaded flight conditions because the angle of attack at aerodynamic stall is independent of aircraft weight and/or wing loading.*

Specifically, within the scope of these test flights, the following germane conclusions were reached:

- *The “Optimum Alpha Angle (OAA) Calibration” technique recommended by the Alpha Systems AOA Stall Warning System Installation Manual is an accurate and repeatable method that can be used to reliably set an AOA target that will be adequately before the aerodynamic stall AOA.*
- *The target AOA, once calibrated, presents data to the pilot so as to provide early warning of an impending stall, prior to the aircraft stall warning audible system, thereby ensuring a safe margin above stall throughout the entire gross weight envelope.*
- *The instrumentation provides clear, un-ambiguous, and easy-to-comprehend stall proximity information.*

## BACKGROUND

In November 2010, an initial test flight of the **Alpha Systems AOA Stall Warning 4" Classic Electronic Display System** was terminated when the pilots quickly rejected the device as unworthy of further testing. Why did they think that?

The Flight Test Plan had (and still does) three goals, one of which was to determine **"is the AOA instrumentation clear, un-ambiguous, and easy to comprehend?"** The Classic AOA provided an entirely accurate display of Alpha throughout its normal operating range and it functioned well, but the **pilots strongly objected to the "intuitively backwards display logic"** <in software REV AC>. This scheme illuminated more and more LEDs as the aircraft accelerated: from Red to Blue to Amber and Green—with almost all LEDs remaining illuminated. **Having many LEDs alive as warnings in "Normal Operations" made no sense to the test pilots, and having Red (Danger) or Amber (Caution) LEDs alive—at the same time—in "Green (Safe) Alpha regions" didn't, either.** The pilots suggested major changes; by July 2011, these were implemented. After additional flight tests, the new scheme evolved further into a buffered cascade of lights as shown below in Table I.

### DANCING LEDs evolving to BUFFERED, CASCADING LEDs

The subsequent test flights (of the **prototype** Table I display scheme) were informative. In calm air, it worked well; but the LEDs flickered and danced wildly in turbulence, initially appearing to be random and making no sense. After considerable observation, we realized that the **prototype** display was exactly correct, but that it was operating at electron-speed—much too fast for any pilot to follow. Accordingly, we asked the manufacturer to incorporate 1: a short delay buffer and 2: a cascade of lights so that when a large Alpha change occurred, the display would appear as if a tube of colored fluid were being quickly drained/filled instead of making a sudden jump to a non-adjacent or distant LED. The revised **prototype** software was delivered on July 12, 2011. These two software changes had a strongly positive impact, offering significant improvements in pilot comprehension and "flyability". This report evaluates **ONLY the human factors of the latest prototype software version <REV RB>**, which includes the buffers and the cascading display. (The other two goals of the flight test plan were successfully achieved earlier, on nearly-identical systems. See Executive Summary above, first two bullets.) Because the observations of the test pilots and the observer-pilots are so important to any "human factors" research, we will explain the test methodology later.

We begin with their post-flight conclusions:

### Qualitative Conclusions

#### Observations and Opinions from the test pilots:

→ **An American Airlines MD80 Captain, a Bonanza owner:** "On our first test flight, the Airspeed/Alpha trends got lost as the LEDs jumped bizarrely from Green to Red and back to Yellow all in a third of a second...or less, but the new buffered software with the cascading display fixed all that! There is good awareness of the stall margin available, much better, much more so than any Airspeed Indicator can

ever provide. I had never flown any AOA; yet almost immediately I wished we had a similar AOA on the MD80 airliner that I fly professionally. Interpretation of the AOA display was very straightforward; it is an intuitive display, easy to learn, and it doesn't take much time to learn how to 'Be On Target'. A pilot, unfamiliar to AOA, would readily learn this display in an hour or so. A solid transition to full comprehension would not take long. It is very easy to fly—precisely—with this AOA display.

"The chime '*DingDong!*' prior to the voice call '*Getting Slow*' is really good. Absent the chime in a busy cockpit, it would be much too easy to miss 'Slow Sarah's' gentle voice call. The 'listen up' chime makes that call easy to catch."

→ **A Bonanza owner/pilot, an A&P:** "On my first flight with any AOA device, I quickly realized that it could not possibly be more obvious what the stall buffer is. The Classic LED Bar gives a really good visual and aural display of 'safe airspeeds' to fly in all normal regimes. I do listen out for 'Slow Sarah'; her '*Getting Slow*' voice calls are great. We are especially pleased with the steadier lights in the latest cascade display."

→ **A TWA captain, retired now, a Beechcraft Bonanza owner:** "The voice call '*Getting Slow*' is fabulous! It's exactly like when the Pilot Not Flying is making callouts. When I hear the voice call '*Too Slow...*', I'll just release the slightest bit of back pressure on the yoke and ...done! It's really hard to miss that voice call."

"Nothing in our cockpits can give us the same information as this AOA device. Nothing. In tight maneuvering turns, the AOA really shines. When we know that we have a safe stall margin, we can slow way down and turn in a very tight radius, in unbelievable security and confidence! I do like the newer buffered cascade a lot better than the previous display scheme; it's much more intuitive and it will be better at night, because of the fewer illuminated LEDs."

→ **An Airline Transport Pilot and Regional Jet crewmember, a CFII, now flying an AOA-equipped Pilatus** "This simple yet effective device has the potential to significantly reduce the number of general aviation incidents attributed to low altitude stall/spin scenarios. The angle of attack indicator has been standard equipment on large turbojet equipment for years...and stall/spins in these aircraft are almost unheard of. Alpha Systems has developed an affordable AOA system for the general aviation community. Although my only previous experience with Alpha Systems products was with the Legacy AOA in the King Air 90, this Classic LED bar display would be just as useful in any light single or twin. Enhanced safety would be my primary reason for installing it in my aircraft, but an added benefit is that the AOA simply makes you a better pilot. With a direct indication of angle of attack in the cockpit, my approach is more stable and my landings are more consistently On-Speed, with less float in the flare. I have now flown both the Legacy with its fewer number of segments and more gradual visual transitions as well as the rapidly-changing Classic LED bar. Even with the buffered cascade in the Classic AOA, the Legacy display is still much less 'busy'; accordingly, I prefer the Legacy."

→ **A Chief Pilot (with 20,000+ hours flying AOA-equipped corporate jets worldwide) and Bonanza owner** who flew the Enhanced (voice alerting) Legacy display in the King Air: He says: “With the addition of the *‘DingDong!’* and the voice annunciation, I see that I immediately glance at the AOA display, which is easily interpreted. I am now even more anxious to get a Legacy AOA display installed in our family Bonanza.” He also helped with the latest flight tests: “I was quite favorably impressed with the cascading light bar AOA in the Bonanza. I really like the cascading display, it’s much better than the original light sequencing. It’s a very intuitive display now; I observed that my pilot-flying was able to see right away that the AOA presents a big aid in ‘flying the wing’ in all realms of flight. As any pilot will: the more he flies with the AOA, the more he will appreciate what the AOA does for him. The early warning *‘Getting Slow’* from ‘Slow Sarah’ was coming alive just as the last yellow light was going out and the blue (Vref) light came on in several approaches-to-stall in different configurations. Early warning. Perfect.

“I am so thankful that we can now have reasonably-priced AOA presentation in the cockpit of our small aircraft, similar to the \$100,000+ AOA information we have had for decades in our corporate aircraft”.

→ **A Marine F/A-18 Hornet test pilot, a retired American Airlines flight officer. Bonanza F33 owner:**

“Having the choice of five different audio/voice aural schemes avails the pilot the optimal early stall warning possible for his or her style of flying. I prefer the *‘Deedle-Deedle’* tone, ultimately followed by *‘Too Slow...Too Slow...Too Slow’*. It is what I was used to in my USMC F/A-18 Hornets and my Bonanza doesn’t have many competing tones that might otherwise confuse. “

→ **A Civilian Aviator, flying a King Air:** “During one evaluation flight, I watched a CFII and a former AA 767 Check Airman fly these same Enhanced Audio Alerts for his first time. He was new to this particular cockpit—flying downwind abeam the runway numbers, planning for two turns to landing and he was mentally-focused outside at the fairly short runway—when he heard *‘Boing! ... Getting Slow’*. That alert clearly got his full attention; his head swiveled right back to the airspeed indicator. Sure, he was a little bit slower than he intended, but wasn’t even close to being at risk. The warning came early enough and he reported that it was really helpful.

“The addition of voice annunciation is a very positive improvement to an already good device. It is nearly impossible to overlook the helpful “Early Warning” when the chime sounds and she says *“Getting Slow”*. It didn’t take me long to begin a habit of saying ‘Thanks, Sarah.’ The fact that she warns early, that she’s not a nag and is quietly unobtrusive when no alert is needed, makes her a credible and trustworthy observer who is welcome in a businesslike cockpit. “

# FLIGHT TEST METHODOLOGY

**PROTOTYPE SOFTWARE.** How does it display? In this <SOFTWARE REV RB> variant of the Enhanced Audio 4" LED Classic Bar AOA indicator, a single traveling LED of the cascading display illuminates—as the aircraft slows—through the Green, Amber, Blue, regions. When Red, the LEDs accumulate and blink.

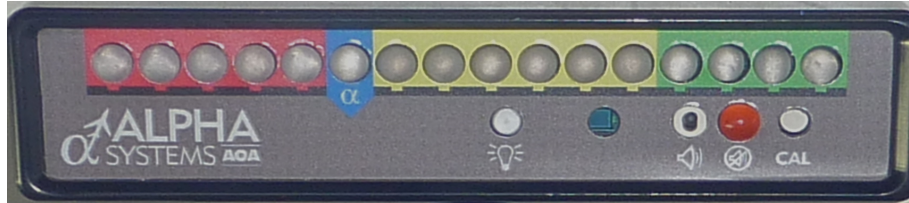


Figure 1

Alpha Systems AOA Stall Warning Classic 4" Electronic Display

(LEDs are numbered left to right #1 to #16):

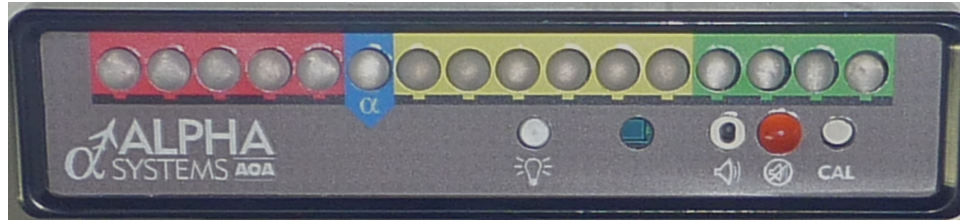
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
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R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G
R	R	R	R	R	B	A	A	A	A	A	A	G	G	G	G

Table I

The **PROTOTYPE** Cascading and Traveling Light Sequence

UPPER CASE text = "ON". *Italics* = "~200m/sec blink", lower = "OFF"

**PROTOTYPE SOFTWARE <REV RB>. Enhanced Audio and Visual Presentation.** The Alpha Systems Enhanced Audio 4" LED Classic Bar indicator provides visual and audible indications as shown in Figure 2 and Table II.



**Figure 2**  
**Alpha Systems AOA Stall Warning Classic 4" Electronic Display**  
*(LEDs are numbered left to right #1 to #16):*

Condition	Display Indication
Cruise	Green 16
Slow Cruise	Green 16 to Green 13
Very Fast	Amber 12
Fast	Amber 8 (a chime <b>"Ding-Dong!"</b> and <b>"Getting Slow"</b> is audible)
Slightly Fast	Amber 7 and Blue 6
On Speed (Optimum Alpha Angle - OAA, or Vref)	Blue 6
Slightly Slow	Blue 6 and Red 5 (a repeating <b>"Too Slow..."</b> is audible)
Slow	Red 5 AND Red 4 AND Red 3 (Blinking) (a repeating <b>"Too Slow..."</b> is audible)
Very Slow	Red 5 AND Red 4 AND Red 3 AND Red 2 AND Red 1 (Blinking) (a repeating <b>"Too Slow..."</b> is audible)

**Table II**  
**Alpha Systems Classic AOA display -- PROTOTYPE -- Enhanced Audio and Visual Indications**

### Safety

Test flights were conducted on June 15 and 17, 2011 at KSHD and 50F airports during daylight hours at a minimum of 3,000 ft. AGL in weather conditions exceeding 5,000 ft and 5 miles visibility. We sought relatively smooth air to enhance data fidelity. No aerobatic flight occurred. Surface winds were quite gusty at the Texas location (and were helpful; the gusts disclosed the dancing flicker). Subsequent flights occurred at KSHD and 50F on July 13-16, 2011. Additional safety considerations may be seen in the Flight Test Plan.

## Test Procedures and Results

### Phase I: Can a pilot interpret the display easily and correctly?

Approach-to-stall, stall warning, and actual stall at representative weights and Center of Gravity locations were tested on several test flights with six different pilots, in three different aircraft, in clean and dirty configurations and at two attitudes: wings level and 30 degrees (deg.) angle of bank. Six pilots (three were AOA-experienced and three were AOA-unfamiliar) flew the aircraft. The AOA-experienced pilots were encouraged to maneuver at will, and to approach normal stall and accelerated stall in varied configurations. A bare minimum explanation of the system was briefed to the AOA-unfamiliar pilots who were encouraged to explore use of the display on his/her own. An in-cockpit observer recorded the response of all the pilots and observed their growing awareness of, and confidence in using, the device.

### Phase II: Operational scenario flights to determine usefulness of Alpha Systems AOA Stall Warning Classic Electronic Display System

During the test flights, maneuvering flight in clean configuration; terminal area flight in gear-up, approach flaps configuration; and landing pattern flight in gear-down full flaps configuration was conducted to qualitatively evaluate the use of the Alpha Systems AOA Stall Warning Classic Electronic Display System as a secondary stall avoidance tool when used in conjunction with the installed airspeed indicator. Maneuvers were conducted in turns up to 30 deg. angle of bank and climbs up to a positive 10 deg. pitch attitude. In all configurations and attitudes tested, the Alpha Systems AOA Stall Warning Classic Electronic Display System consistently provided adequate secondary indications of available stall margin.

**VISUAL DISPLAY.** The Classic Display LED bar proved easy to learn and intuitive. It was clear in its information, unambiguous, and easy to comprehend. The arrangement and colors of the LEDs in the display provided distinct information on proximity to stall that proved helpful at avoiding a near-stall condition considerably before the aircraft's normal audible stall warning system became effective. When slowing or accelerating through the range of indications on the Classic Display, display segments could sometime change very rapidly up and down—especially in rough air—as the display transitioned from one indication to another. The Cascading LEDs smoothed these large transitions and made for easy understanding.

**BACKGROUND: “Enhanced” TONE/VOICE ALERTS:** Incorporated in a March 2011 version of the Alpha Systems AOA Stall Warning System (thenceforth incorporated in all the company's electronic displays) are two Alpha points at which VOICE and/or TONE warnings can alert the pilot. These points are programmed with “intelligence” so that the “Early Warning” point will only annunciate when AOA is increasing (aircraft is slowing) and with a slight delay thereafter so that it does not repeat too often and become a nuisance that pilots will mute. The “Last-Chance” warning of imminent stall comes later. Even so, in the Bonanza and King Air the “Last-Chance” warning still alerted considerably sooner than the

factory stall warning did. The evaluation team found that both Enhanced Alerts were timely, clear, and helpful—especially helpful when a pilot’s eyes were outside the cockpit. The voice alerts, in particular, represent a major improvement in capability and effectiveness. These observations remain true in the revised software <REV RB>, the buffered cascade tested here.

**SETUP of Tone/Voice Alerts:** As the pilot initially configures the installation, he will have a choice—which can be changed prior to any subsequent engine start—of a single audio alerting scheme. Two of these alerts include a gently-spoken female voice:

1. **Three Beeps.** A “*Beep-Beep-Beep*” audio tone occurs once at the “Early Warning” Point (~1.4+Vs...just as the Green Donut is coming alive.)
2. The **Space Shuttle Master Alarm (SSMA).** A “*Deedle-Deedle*” warble audio tone occurs once at the “Early Warning” Point, for 1.5 seconds.
3. **SSMA + Female Voice.** A “*Deedle-Deedle*” warble audio tone occurs once at the “Early Warning” Point and a feminine voice (“*Too Slow...Too Slow...Too Slow*”) repeats a “Last-Chance” warning every ~1.5 seconds when only the red chevron is illuminated.
4. **Female Voice - Two Messages.** A chime and feminine voice (“*Ding-Dong! Getting Slow*”) occurs once at the “Early Warning” Point and a feminine voice (“*Too Slow...Too Slow...Too Slow*”) repeats a “Last-Chance” warning every ~1.5 seconds when only the red chevron is illuminated.

**“Early Warning” AUDIO ALERT – TREND CHECK.** The “Early Warning” alert will only sound off when angle of attack is trending higher (the aircraft is slowing down). The manufacturer has now included angle-sampling data that is intended to suppress the occasional spurious alert when flying in the vicinity of that particular Alpha point or when speeding up and down through that same Alpha point. The software functions well in this regard.

**DURING TAKEOFF – “Early Warning” AUDIO ALERT IS SUPPRESSED.** The visual display is always alive. But the voice/tone alerts first come alive shortly after rotation so as to eliminate spurious warnings in normal operation. A normal, smoothly executed takeoff will be silent; an aggressive pull aft at rotation can trigger the “*DingDong! Getting Slow*” voice as an “Early Warning”. The feature works well.

**“LAST-CHANCE” AUDIO WARNING GOES SILENT ON LANDING ROLLOUT.** There is no need to warn of stall after a landing is assured, and this end-of-roll auto-muting is a nice feature.

**CALIBRATION:** After the first few test flights of a similar AlphaSystems AOA display on November 3 and 10, 2010, the test pilots began to wonder if it would be possible to configure the system so that the Classic segments (Red, Amber, Green) would represent smaller ranges of airspeed. By example: the King Air was originally calibrated at Set Points of ZeroKIAS, the Optimum Alpha Angle (OAA or Vref) at 94KIAS, and with “AlphaSystems Cruise” at 180KIAS. That was changed to become ZeroKIAS, Vref at 94KIAS, with “AlphaSystems Cruise” at a lower 130KIAS. The effect was (while slowing from high cruise speeds) that the display remained dark longer and each segment range became more precise. Believing that alerts in normal operations are not helpful, we therefore recommend that all installations adopt this methodology and set their “AlphaSystems Cruise” at/near the Flaps Full upper limit speed.



## **Phase III: Free flight and unusual attitudes**

Flight Maneuvering in attitudes considerably exceeding those normally experienced in general aviation operations was investigated to determine the usefulness of the Alpha Systems AOA Stall Warning Classic Electronic Display System as a secondary stall margin indicator when used in conjunction with other aircraft instruments.

Relatively level steep turns to 59 deg. angle of bank were flown with deceleration to the Blue LED (OAA, the Optimum Alpha Angle or  $V_{ref}$ ) on the AOA Stall Warning Classic Display with airspeed reading well over 100 MIAS (in a Bonanza) but with adequate stall margin remaining with no aircraft stall warning horn. Steep turns were followed by steep climbs to 20 deg. positive pitch angles with wings level decelerating to OAA ( $V_{ref}$ ) again with adequate stall margin remaining and no stall warning horn. Finally, pitch and bank were combined to 59 deg. bank angle and positive 15 deg. pitch decelerating to OAA at which point the aircraft stall warning horn began to chirp. The aircraft was allowed to decelerate further to the very slow AOA indication with the stall warning horn continuous. At that point, the nose of the aircraft was raised slightly further without stall...proving that some stall margin still existed even in this "very unusual attitude".

## **DISTRIBUTION**

- The Flight Test Report is placed in the public domain by its authors and will initially be distributed by them to the manufacturer of the Alpha Systems AOA Stall Warning System as well as to the FAA if installation guidance is sought for the Alpha Systems AOA Stall Warning Systems. Any applicant for any FAA Supplemental Type Certificate, PMA certification, or TSO approval, etc. may use this data freely.
- This Flight Test Report will also be available to the American Bonanza Society's Air Safety Foundation, to the Aircraft Owners and Pilots Association (AOPA) Air Safety Foundation, and to the Experimental Aircraft Association (EAA) as well as others seeking information on the applicability of AOA Stall Warning Systems on general aviation aircraft. Other than payment for reproduction costs, no charge may be made for use of this research.

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## **IN HONOR OF**

**David Ingalls Brown and Robert H. Baldwin**

**TWA Captain Ray Rotge and TWA Captain Mack Johnston**