Flight Test – FINAL REPORT – Revision 1 - (3/30/11)

Beechcraft Bonanza S-35

Alpha Systems Angle of Attack Stall Warning System

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This Flight Test was flown to analyze the information provided by the Alpha Systems Angle of Attack (AOA) Stall Warning System as displayed on the Legacy indicator in six normal flight configuration and attitude combinations of the Beechcraft 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 on the glareshield 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.***

Safety

Test flights were conducted on September 20 and October 16, 2010 (Flights 1-3. Software Rev AC) & October 19, 2010 (Flight 4. Software Rev AD) and November 3, 2010 (Flight 5. Software Rev AE) at KSHD airport during daylight hours at a minimum of 3,000 ft. AGL in weather conditions exceeding 5,000 ft and 5 miles visibility in relatively smooth air to enhance data fidelity. No aerobatic flight occurred. Surface wind conditions did not exceed 7 knots with no gusts, and crosswind conditions did not exceed 5 knots. Additional safety considerations may be seen in the Flight Test Plan.

Test Procedures and Results

Phase I: Stall Performance Data Verification Compared to Aircraft Pilot Operating Handbook (POH)

Approach-to-stall, stall warning, and actual stall speed data at representative weights and Center of Gravity locations were tested on the first of two test flights in two configurations, clean and dirty and at two attitudes, wings level and 30 degrees (deg.) angle of bank. Conditions during the stall testing included altitudes between 5,500 ft. MSL and 4,500 ft. MSL and an outside air temperature of 15 deg. Celsius. Deceleration rates to stall warning and actual stall did not exceed one mile per hour (MIAS) per second.

In the clean configuration at idle power and wings level with a gross weight of approximately 3,100 pounds (lbs), stall warning occurred at 75 MIAS and consisted of activation of the aircraft stall warning audible horn. Actual stall occurred at 62 MIAS, and was defined as a mild drop in nose attitude. Recovery was immediate as the nose dropped.

In the same clean configuration, weight and idle power, but 30 deg. angle of bank, stall warning occurred at 84 MIAS and again consisted of activation of the stall warning audible horn. Actual stall in the 30 deg. bank attitude occurred at 64 MIAS consisting of a similar mild drop in nose attitude. Recovery was again immediate as the nose dropped.

In the wings-level dirty configuration, with gear down and full flaps at a power setting of 15 inches manifold pressure and the prop at low pitch and weight at approximately 3,100 lbs., stall warning occurred at 61 MIAS with activation of the stall warning audible horn. Actual stall occurred at 51 MIAS and was defined as initial loss of directional control with near full right rudder applied.

In the 30 deg. bank attitude in the dirty configuration, stall warning again consisted of the stall warning horn at 66 MIAS with actual stall occurring at 52 MIAS as directional control was again lost with near full right rudder applied.

Data from these verification tests are presented in Table I below:

Configuration	Bank Angle (Deg.)	Power (MP/Pitch)	Stall Warning (MIAS)	Stall (MIAS)	POH Stall (MIAS)
Clean	0	Idle/Low	75	62	71
Clean	30	Idle/Low	84	64	75
Dirty	0	15/Low	61	51	57
Dirty	30	15/Low	66	52	63

TABLE I

Verified Stall Speeds

It is interesting to note the verified stall speeds were significantly lower than those specified in the POH. Possible contributors to that outcome include; the airspeed indicator had not yet been calibrated, possibly introducing some errors there, and the POH may have been published with somewhat conservative stall speed data. Regardless, the actual stall speeds found in Table I were used for the remainder of these tests.

Phase II: Calibration of the Alpha Systems AOA Stall Warning Legacy Electronic Display System

The Alpha Systems AOA Stall Warning Legacy Electronic Display System provided visual and audible indications as shown in Figure 1 and Table II below:

Figure 1

Alpha Systems AOA Stall Warning Legacy Electronic Display

Condition	Display Indication
Cruise	Blue Bar
Slow Cruise	Blue Bar and Amber Chevron
Very Fast	Amber Chevron
Fast	Amber Chevron and Lower Half of Green Donut (Three beeps audible at this indication)
Slightly Fast	Lower Half of Green Donut
On Speed (OAA)	Full Round Green Donut
Slightly Slow	Upper Half of Green Donut
Slow	Upper Half of Green Donut and Red Chevron
Very Slow	Red Chevron

Table II

Alpha Systems AOA Stall Warning Legacy Electronic Display System Indications

The Alpha Systems AOA Stall Warning Legacy Electronic Display System installed on the test aircraft had initially been calibrated for OAA at 90 MIAS. During the first of two test flights, the system's OAA green "donut" displayed in a range from 89 MIAS to 94 MIAS. As the actual wings-level stall speed at approximately 3,100 lbs. was 62 MIAS and 52 MIAS for the clean and dirty configurations respectively, the 90 MIAS OAA display was considered to be too fast, providing too much stall margin. As the Alpha systems AOA Stall Warning System is not biased for flap position, the decision was made to recalibrate the system in the clean configuration at 3,100 lbs. to an OAA equal to 1.3 V_S, or 81 MIAS. Recalibrating to the clean configuration V_S as opposed to the dirty configuration V_{SO} should provide ample (30%) stall margin in the clean configuration, and additional (more than 30%) stall margin in the dirty configuration. See Table III.

Clean Stall: V_S (MIAS)	**1.3 X V_S (MIAS)**	**Recalibrate OAA (MIAS)**
62	80.6	81

Table III

Recalibrated OAA

Recalibration of the OAA was accomplished in accordance with the Alpha Systems AOA Stall Warning Legacy Electronic Display System Installation Manual by first landing to calibrate the system's "zero airflow" point and refuel, and then returning to flight in the clean configuration at approximately 3,100 lbs. to calibrate the OAA at 81 MIAS.

Once recalibrated, the OAA displayed at a new range of airspeed from 81 MIAS to 87 MIAS.
See Table IV.

Optimum Alpha Angle (OAA)	**OAA Airspeed Range at 3,100 Lbs.**
1.3 V_S	81 MIAS to 87 MIAS

Table IV

Alpha Systems AOA Stall Warning Legacy OAA Range

At 81 MIAS, the full green donut was illuminated. Slowing slightly to 80 MIAS resulted in only the upper (slower airspeed) half of the green donut remaining illuminated. At 87 MIAS the full green donut was illuminated, but accelerating slightly to 88 MIAS resulted in just the lower (faster airspeed) half of the green donut remaining illuminated. This provided a range of 7 MIAS for OAA.

Phase III: Representative weight flight for Alpha Systems AOA Stall Warning system

Three representative configurations and two bank angle attitudes were flown on the second of two test flights to evaluate the usefulness of the Alpha Systems AOA Stall Warning Legacy Electronic Display System. A third flight operated at near-minimum gross weight, approximately 2,500 lbs. The results are presented in Table V below.

Configuration	Attitude (Deg. Bank)	Power (In. MP/Prop Pitch)	Weight (Lbs. approx.)	OAA Airspeed Range (MIAS)
Clean	0	Idle/Low	3,100	82-87
Clean	30	Idle/Low	3,100	82-87
Gear Up/Flaps Approach	0	15/Low	3,000	81-87
Gear Up/Flaps Approach	30	15/Low	3,000	80-87
Gear Down/Flaps Full	0	15/Low	3,000	80-86
Gear Down/Flaps Full	30	15/Low	3,000	81-87
Clean	0	Idle/Low	2,500	80-86
Clean	30	Idle/Low	2,500	81-86
Gear Up/Flaps Approach	0	15/Low	2,500	78-84
Gear Up/Flaps Approach	30	15/Low	2,500	80-84
Gear Down/Flaps Approach	0	15/Low	2,500	76-83
Gear Down/Flaps Approach	30	15/Low	2,500	79-83

Table V

OAA Speeds at Representative Configurations and Attitudes

With the Alpha Systems AOA Stall Warning Legacy Electronic Display System calibrated to an OAA of 81-87 MIAS at 3,100 Lbs., holding OAA in the various representative configurations and bank angles in Table V by reference to the Legacy AOA Display (full green donut) resulted in consistent OAA airspeeds in the 81-87 MIAS range. Later, the aircraft was flown in a very lightly loaded condition: a single pilot and minimum fuel. Within the scope of these tests, the Alpha Systems AOA Stall Warning Legacy Electronic Display System was useful as an additional tool to maintain optimum airspeed (1.3 X V_S) during a variety of maneuvering configurations and attitudes typical of General Aviation operations.

Phase IV: Operational scenario flights to determine usefulness of Alpha Systems AOA Stall Warning Legacy Electronic Display System

During the second of two 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 Legacy

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 Legacy Electronic Display System consistently provided adequate secondary indications of available stall margin.

The Legacy Display proved easy to learn and intuitive. It was clear in its information, unambiguous and easy to comprehend. The arrangement of the donut and chevrons in the display provided distinct information on proximity to stall and directive information that proved helpful at avoiding a near-stall condition considerably before the aircraft's normal audible stall warning system became effective.

There were a small number of deficiencies noted with the AOA Stall Warning System that were addressed rapidly by the manufacturer and most were completely resolved during the course of the flight test program.

During initial flights, bright sun interfered with the display at some flight attitudes and sun angles, making the display very difficult to read in those instances. By Flight No.3, a deep and long sun shade was incorporated that functioned well and resolved this problem.

Although an audible series of three beeps was heard when slowing from the very fast to the fast (Table II) AOA condition, the audible tones were somewhat subdued and lacked distinction and could be easily ignored and/or confused with other alerts and similar sounds in the aircraft. In addition, the three-beep audio sounded again as the aircraft accelerated from fast to very fast (Table II), an unnecessary and confusing application of the audible tone. By Flight 4 (after a short time-delay was added by the manufacturer) this alert became more useful, and was no longer annoying.

When slowing or accelerating through the range of indications on the Legacy Display, display segments tended to flicker, even in smooth air, as the display transitioned from one indication to the next. For example, when slowing from on-speed (OAA) to slightly slow, the lower half of the green donut flickered as it extinguished before leaving only the upper half of the green donut illuminated. This flickering tendency was present for all display segment transitions. During testing, we asked the manufacturer to incorporate a 300 Millisecond delay (and status re-sample) when changing a segment from ON to OFF or *vice versa* and that simple change made an annoying flicker into a desirable attention-getter.

Phase V: Free flight and unusual attitudes

Flight Maneuvering in attitudes exceeding those normally experienced in general aviation operations was investigated to determine the usefulness of the Alpha Systems AOA Stall Warning Legacy 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 OAA (Green Donut) on the AOA Stall Warning Legacy Display with airspeed reading well over 100 MIAS 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 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 (Table II) with the stall warning horn continuous. At that point, the nose of the aircraft was raised slightly further without stall proving that adequate stall margin still existed at OAA in this "unusual attitude".

Recommendations

1. Proceed with further testing as may be required to clarify and/or obtain FAA-approved guidance for installation of the Alpha Systems AOA Stall Warning Legacy Electronic Display System on certificated general aviation aircraft.
2. Collect and catalog completed Field Approvals (Form 337) and IA-approved logbook entries from previous installations of the Alpha Systems AOA Stall Warning Legacy Electronic Display System, so as to assist other aircraft owners/operators with the installation of the system in their aircraft.
3. Audio alert suggestion ONE: Redesign the audible three-beep tone that alerts when slowing from very fast to fast (Table II) to be a more attention-getting and distinctive tone, perhaps one similar to the Space Shuttle Master Warning tone.
4. Audio alert suggestion TWO: Add a female voice "Angle" audible annunciation to alert when slowing from slow to very slow (Table II) with a reasonable (300-500 millisecond) delay to avoid nuisance annunciations.
5. [Recommendation WITHDRAWN 4/10/2011. See Rev. 1, below] Consider the eventual addition of an affordable biasing of AOA display indications based on flap position between full up and full down to provide adequate stall margin in clean maneuvering flight as well as the slowest practical approach speeds with adequate stall margin for the safest possible approach to landing in the dirty configuration.

Qualitative Conclusion

From the Marine Aviator: "As I flew the approach to both landings, I "instinctively" flew based on AOA. Now remember, although I was experienced with AOA in the Marines, I haven't flown AOA since 1986…that's 24 years. Since leaving the Hornet in El Toro, CA, I've been an airspeed indicator pilot both privately in my Bonanza and commercially at American Airlines. In our commercial operation, we had a little booklet where each page was a different weight condition and we would reference that page as we set up for approach and landing to set our V- speeds including V_{ref} for final-flaps approach. In spite of the many years away from AOA flying, this Alpha Systems AOA Stall Warning Legacy Electronic Display System is so intuitive that I subconsciously and immediately reverted back to my much younger habit of flying AOA on both of my approaches. I think that says a lot for the usability of the Legacy System. However, it is important to remember that Airspeed must always be the primary reference."

From the Civilian Aviator: “I had a similar device (Safe Flight SC-100) displaying AOA on my Bonanza BE-36’s glareshield for over twenty years, and I always thought it was a wonderful reminder of the Bank v. G-Force curves that are so well known...but so easy to forget when pulling a turn just a bit too tight or a bank just a bit too steep. An Alpha Systems AOA Stall Warning Legacy Electronic Display System on the glareshield will stop those errors in airmanship because AOA is a constant -- unaffected by density altitude, cabin/fuel loadings or G-Force/ bank angle. It’s easy for me to appreciate this clear display of AOA up front and center on the glareshield. I am quite impressed with its simplicity of design, its high quality engineering, its low cost, and its genuine usefulness. I am exceedingly impressed by the rapid response of the Alpha Systems AOA manufacturer as they incorporated improvements to deal with our suggestions, made herein.

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

Revision 1 – Further observations

April 10, 2011

In February 2011, AlphaSystemsAOA delivered an upgraded version of the Legacy AOA for further evaluation. The manufacturer's primary effort in the upgrade was to address the flight test pilots' observations about the items that "could be improved" and to respond to subsequent feedback from the test pilots and other pilots who are flying their own Legacy AOA displays. Twenty or more evaluation flights were undertaken to see how the new features worked; comments were sent back to the manufacturer, and even newer software/hardware iterations were delivered, installed, calibrated, and re-evaluated. The most recent evaluations (Software Rev AJ) took place on March 20 and 24, 2011.

TONE/VOICE ALERTS: internal to the March 2011 version of the Alpha Systems AOA Stall Warning Legacy Electronic Display System 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 the new alerts to be 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.

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" 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 prevent 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" 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" 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 flights on November 3 and 10, 2010, the test pilots began to wonder if it would be possible to configure the system so that the Legacy segments would represent smaller ranges of airspeed. By example: the King Air was originally calibrated at Set Points of ZeroKIAS, 94KIAS, and with "AlphaSystems Cruise" at 180KIAS. That was changed to become ZeroKIAS, 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.

SUN SHIELD: A fitted deep-shadow sun shield, powder coated in black, is now included. A significant improvement in visibility of the display, when in direct bright sunlight, was noted.

AUTO-DIMMING of the Display: We observed several events in bright daylight in which the aircraft flew under a cloud shadow and the device auto-dimmed itself to Night mode—so much as to be unreadable. While this could be fairly blamed on the pilots' not setting the brightness levels correctly, it was also seen as a design that could be improved. Subsequently, the manufacturer redefined the switchover point between Light and Dark ambient light levels and significantly shifted that point towards dark. The latest software accepts much lower levels of ambient light before dimming the segments to night brightness…and it functions well.

FLAP BIAS – Is it needed…or not? After careful reconsideration, the test crew WITHDRAWS its Recommendation No. 5 (above) that flap bias be considered for the device. As we flew the display and came to understand it better, we realized that we had been thinking of AOA in the traditional way: as a dial-in system that can define a given-need target Alpha.

This AlphaSystemsAOA Legacy device is designed to accomplish an entirely different purpose: **Very Early Warning of impending aerodynamic stall**. To achieve that purpose reliably and repeatedly, flap bias is simply not needed.

It remains true that there are very small shifts in AOA/CL_{max} as flaps are deployed in the general aviation light aircraft fleet…but the differences and shifts only come into play at the very edge of stall. If the "Early Warning" is set for ~30 percent above stall, it really does not matter whether a warning comes at the 29 or 31 percent margin. **The "Early Warning" sounds off so early (so HELPFULLY early) that it's effective in any flap configuration**.

The "Last-Chance" warning is also far better than the factory stall warning as it sounds off **considerably prior to the factory stall warning**.

Qualitative Conclusions:

From the Marine Aviator: The latest version of the Alpha Systems AOA Legacy Device is nearly perfect. 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. The latest adjustment to the auto-dimming feature will help prevent loss of the AOA display when it is needed most in the landing pattern.

From the Civilian Aviator: 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. During one evaluation flight, I watched a CFII and a former AA 767 Check Airman fly the Legacy for his first time. He was new to this cockpit—flying downwind abeam the runway numbers, planning for two turns to landing and he was 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 slow, but wasn't even close to being at risk. The warning came early enough and he reported that it was really helpful.

From a Civilian King Air 350 pilot & CFII: I used to fly my Bonanza no slower than 120 knots during circling approaches because I was concerned about the possibility of an inadvertent stall. Now, with AOA displayed on my glareshield, I maneuver at about 85 knots (wings level) and dramatically shorten my turn radius and stay closer to the airport while circling because the AOA indicator lets me know I've got plenty of margin. After many years of flying this airplane, the AOA information has really changed the way I fly it.

By the time the stall warning horn comes on, it's too late; you've already arrived at the stall. The stall warning system doesn't show a progression. One moment the wing is flying, and then it's not. I have watched my students using the AOA in my Bonanza; the secure knowledge that their airplanes are flying safely well away from stall allows pilots with AOA indicators to avoid the trap of flying too fast on final approach.