FAA
Aviation Safety

SPECIAL AIRWORTHINESS INFORMATION BULLETIN

SAIB: 2024-07
SUBJ: STALL WARNING SYSTEM, Angle of Attack Alerting Systems **Date:** December 26, 2024

This is information only. Recommendations aren't mandatory.

Introduction

This Special Airworthiness Information Bulletin (SAIB) provides information to help **general aviation aircraft** owners and operators understand the importance and safety benefits of angle of attack (AOA) alerting systems on aircraft type certificated under title 14, Code of Federal Regulations (14 CFR) part 23 and operating under 14 CFR parts 121, 135, or 91. Increasing awareness of the benefits of these alerting systems may reduce the risk for loss-of-control (LOC) incidents and accidents. The SAIB Attachment contains more information on low airspeed alerting, AOA, and aircraft energy states.

At this time, the airworthiness concern is not an unsafe condition that would warrant airworthiness directive (AD) action under 14 CFR part 39.

Background

On February 12, 2009, a Colgan Air, Inc., Bombardier Model DHC-8-400 airplane crashed in Clarence Center, New York. Four crew members, 45 passengers, and one person on the ground were killed. The National Transportation Safety Board (NTSB) determined "the probable cause of this accident was the captain's inappropriate response to the activation of the stick shaker, which led to an aerodynamic stall from which the airplane did not recover. Contributing to the accident were (1) the flightcrew's failure to monitor airspeed in relation to the rising position of the low-speed cue, (2) the flightcrew's failure to adhere to sterile cockpit procedures, (3) the captain's failure to effectively manage the flight, and (4) Colgan Air's inadequate procedures for airspeed selection and management during approaches in icing conditions."[1]

As a result of its investigation, the NTSB issued several safety recommendations to the FAA to address the cause and contributing factors of the Colgan Air accident. Specifically, NTSB Safety Recommendation A-10-012 recommended the FAA require installation of low airspeed alerting systems that provide pilots with redundant aural and visual warnings of an impending hazardous low speed condition, on all airplanes operating under 14 CFR parts 121, 135, and 91, subpart K.

In lieu of rulemaking, the FAA is collaborating with the Commercial Aviation Safety Team (CAST) in development of Safety Enhancement 192, "Airplane State Awareness – Low Airspeed Alerting."[2] This safety enhancement would reduce the risk of LOC accidents by recommending operators implement low airspeed alerting on transport category airplanes that are type certificated under 14 CFR 25.1322, "Flightcrew alerting," at Amendment 25-38 (effective February 1, 1977). Transport category airplanes type certificated at current Amendment 25-131 (effective January 3, 2011) are equipped with low airspeed alerting systems and meet the objective of CAST Safety Enhancement 192.

---

[1] NTSB Accident Report NTSB/AAR-10-01, "Loss of Control on Approach, Colgan Air, Inc., Operating as Continental Connection Flight 3407, Bombardier DHC-8-400, N200WQ, Clarence Center, New York, February 12, 2000," dated February 10, 2010, https://www.ntsb.gov/investigations/accidentreports/reports/aar1001.pdf.

[2] https://skybrary.aero/articles/se192-airplane-state-awareness-low-airspeed-alerting

In addition, the FAA has developed this SAIB to advocate for the voluntary adoption of low airspeed alerting systems as standard equipment on new aircraft type certificated under 14 CFR part 23. The FAA has an extensive history of promoting low airspeed systems such as AOA systems. This SAIB summarizes the benefits of low airspeed alerting, including AOA indicators.

LOC Alerting Benefits and Limitations

Because stall speed changes with aerodynamic loads and the aircraft's configuration (e.g., position of flaps, slats, landing gear), the use of an AOA system can provide a more reliable indication of an impending stall than an airspeed indicator alone. In many cases, an approaching stall is not apparent to a pilot without considering AOA.

Audio or tactile alerting (e.g., stick shaker) that considers AOA, and is set to activate with sufficient margin to the stall, can significantly aid in capturing the pilot's attention.

Benefits of AOA Indicators

Research has shown AOA indicators assist pilots with stall margin awareness, stall prevention, and recovery from unusual attitudes or upset.[3] By providing the pilot with an indication of the wing's stall margin, regardless of g-loading, the pilot may be more likely to avoid a stall or upset. The pilot will also have a better indication of when the wing is flying again during recovery after exceeding the critical AOA. An AOA indicator may also be useful in emergency situations such as windshear or terrain avoidance maneuvers. An AOA indicator can allow the pilot to max perform the aircraft very near the critical AOA. In response to the controlled flight into terrain (CFIT) crash of American Airlines Flight 965[4], the NTSB recommended incorporating AOA indicators as an aid during emergency maneuvers. It was believed that an AOA indicator might have aided the flightcrew in achieving maximum climb performance during the attempt to avoid terrain.

Several studies have also indicated that AOA indicators could aid pilots in diagnosing problems with a pitot tube (used to indicate airspeed) or static port (used to indicate altitude).[5] For example, iced-over pitot tubes, or the pilot failing to remove a pitot tube cover, has caused fatal accidents. An AOA indicator would be a useful crosscheck to airspeed if a pitot-static system failure is suspected.

Faulty airspeed and pitot-static indications were the cause of the Northwest Airlines Flight 6231 accident.[6] The flightcrew failed to turn on the pitot tube heat, causing the pitot tube to ice over. The pressure within the pitot tube became constant, but static pressure continued to decrease during climb. As *indicated* airspeed continued to increase, the flightcrew continued to pull the nose up. When the overspeed warning horn sounded, the airplane was 30 degrees nose high. Ten seconds later, a stick shaker stall warning sounded. The airplane stalled, and the flightcrew lost control. This accident could have been prevented by an AOA indicator and proper pilot training in crosschecking airspeed and AOA.

Limitations

Although research and incident reports indicate AOA indicators can improve pilot performance and increase safety margins, there are limitations to using AOA indicators. Research found that without

---

[3] Ellis, 1977; Langdon, 1969; Odle, 1972. See Additional Resources in the attachment to this SAIB.

[4] https://www.faa.gov/sites/faa.gov/files/2022-11/NTSB_recommendations_3.pdf

[5] Karayanakis, 1982; Tucker & Gordon, 1959. See Additional Resources in the attachment to this SAIB.

[6] https://www.faa.gov/sites/faa.gov/files/2022-11/NWA6231_Accident_Report.pdf

training on how to use an AOA indicator, pilots were not able to effectively use the information provided.[7]

The wide differences in AOA display types create standardization challenges, including training problems. This poses the question of whether AOA presentation in the flight deck should be standardized. Whether AOA displays should be standardized and to what standard remain open questions.

To ensure accuracy, proper installation and calibration of AOA sensors and indicators is necessary. The location of the sensor and the airflow around the aircraft can introduce indication errors. The manufacturer's guidance should be followed to achieve the necessary accuracy.

Recommendations

The FAA recommends owners and operators of all airplanes type certificated under 14 CFR part 23 and operating under 14 CFR parts 121, 135, 91, or subpart K to part 91, and experimental amateur-built airplanes both certified and non-certified, do the following:

- Install and calibrate critical AOA alerting systems.
- Receive training on the use of AOA indicators and how to incorporate them in instrument scans.

For Further Information Contact

Kevin Gildea, Aerospace Engineer, FAA Mike Monroney Aeronautical Center, 6500 South MacArthur Boulevard, Oklahoma City, OK 73169; phone: (405) 954-7071; email: Kevin.Gildea@faa.gov.

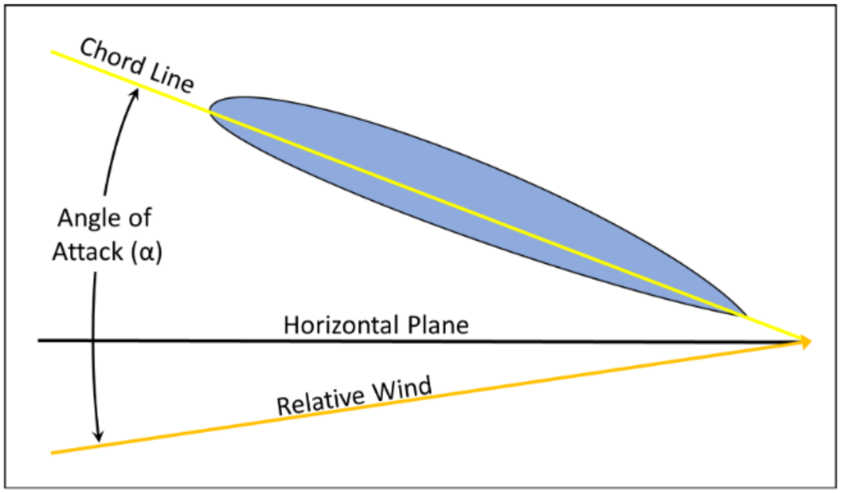
---

[7] DOT/FAA/TC-TN19/11, "A Review of Angle-of-Attack Display Research from 1958-2014," October 2019, https://rosap.ntl.bts.gov/view/dot/57876.

Definitions

Angle of attack (AOA): The angle between a chord reference line and the relative wind. See figure 1.

Figure 1 – Angle of Attack and Relative Wind[8]



Energy management: The process of planning, monitoring, and controlling altitude and airspeed targets in relation to the airplane's energy state in order to: (1) attain and maintain desired vertical flightpath-airspeed profiles; (2) detect, correct, and prevent unintentional altitude-airspeed deviations from the desired energy state; and (3) prevent irreversible deceleration and/or sink rate that results in a crash.[9]

Loss of Control Caused by Stall at Critical AOA

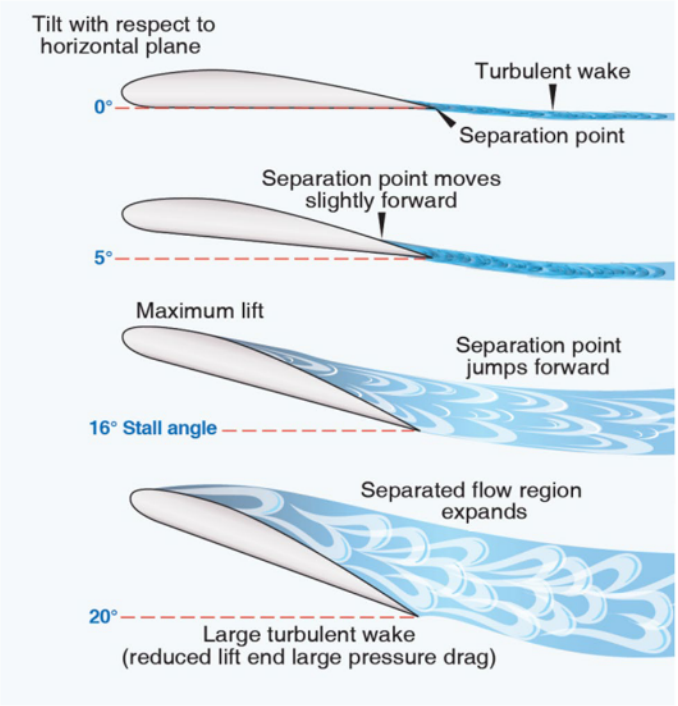
One key factor in preventing loss of control (LOC) is avoiding an airplane stall. An airplane can stall at any speed, but always stalls at the same AOA for a given airplane configuration and load factor (i.e., g-loading). The angle at which the stall occurs is referred to as the critical AOA, or stall AOA. When the AOA is low, the airflow over the upper wing surface remains smooth, generating lift with minimal drag. Increasing the AOA increases both lift and drag. As the airplane's AOA approaches the critical angle, the airflow begins to separate from the upper wing surface and becomes turbulent. See figure 2.

---

[8] https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/ifh_addendum.pdf

[9] Airplane Flying Handbook, FAA-H-8083-3C, Chapter 4, "Energy Management: Mastering Altitude and Airspeed Control," 2021, https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/airplane_handbook/05_afh_ch4.pdf.

Figure 2 – Illustration of Wing Stall at Critical AOA[10]



When the airplane's wing reaches the critical AOA, the wing lift decreases, drag increases, and the turbulent airflow may be felt through the flight controls or structure, which is referred to as buffet. This constitutes a stall, and if the AOA is not reduced, LOC and a significant loss of altitude may result. In a stall, the aircraft stability is degraded, and the resulting deterioration of handling qualities may result in abrupt motions (i.e., pitch down and roll off) and a LOC. Unless the stall is broken by reducing AOA and adding power, the loss of control and loss of altitude will continue until ground impact.

It is possible to exceed the critical (or stall) AOA regardless of airspeed, attitude, or power setting. If a pilot only references the stall speeds for a particular aircraft, unanticipated stalls may occur because those speeds are generally computed for a particular weight, a specified airplane configuration, and in straight-and-level, unaccelerated, 1G flight. Therefore, speed alone does not necessarily indicate how close the aircraft is to a stall. The actual stall speed will be affected by weight, flap setting, center of gravity, and load factor.

Pilots often associate pitch attitude with AOA. However, even with a constant pitch attitude, AOA can be changing with no indication to the pilot as the flight path angle and relative wind may be changing.

The aerodynamic load on a wing increases with bank angle in level flight. In level flight steep turns, the increased load places the wing closer to the critical AOA. In a steep turn, the indicated speed at the stall is higher than in straight-and-level (1G) flight. A pilot can be surprised by the stall at such a high airspeed.

---

[10] Airplane Flying Handbook, FAA-H-8083-3C, Chapter 1, "Introduction to Flight Training," 2021, https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/airplane_handbook/02_afh_ch1.pdf.

Energy Management

Pilots should always be aware of the airplane's altitude and speed (otherwise known as energy state) during various phases of flight. Maneuvering between energy states requires an understanding of excess power (the difference between power available and power required) and using it to affect climbs/descents or turns. A simple explanation of manipulating airspeed and vertical speed with power is provided in Plane and Pilot magazine (Wischmeyer, 2024).

Importance of energy management[11]

During the takeoff and landing phases-of-flight, the energy state is low, and mismanagement of that energy is unforgiving. Pilots need to honor speeds published in the flight manual and recognize that maneuvers that increase AOA will decrease the margin from stall.

During the descent phase-of-flight when a pilot reduces power to descend, they must remember to increase power when leveling off. Failure to increase power to maintain level flight will result in airspeed decaying, with AOA increasing and the potential to enter a stall. This particular descent scenario is especially dangerous when flown using a simple 2-axis autopilot with an altitude capture feature. Without an autothrottle, the autopilot will try to maintain level flight, but descent power may not be sufficient to hold altitude.

"Proper energy management is also critical to flight safety. Mistakes in managing the airplane's energy state can be deadly. Mismanagement of altitude and/or airspeed is a contributing factor to the three most common types of fatal accidents in aviation: loss of control in-flight (LOC-I), controlled flight into terrain (CFIT), and approach-and-landing accidents." (FAA-H-8083-3C)

There is an inextricable link between controlling AOA and managing energy.[11] This link is clear during maneuvering flight when the pilot makes inputs to alter or curve the flight path. Control inputs change the distribution of lift and drag on control surfaces, which changes the AOA. Maneuvers such as executing a go-around, entering a climb, and turning all require manipulation of AOA to curve the flight path and transition from one energy state to another. Of course, the throttle also plays a critical role in maneuvering flight that affects the AOA and the airplane's energy state. In maneuvers that require an increase in lift (and AOA), the questions are: what is the margin from critical AOA and does the airplane have enough airspeed, altitude, and excess power to complete the maneuver safely?

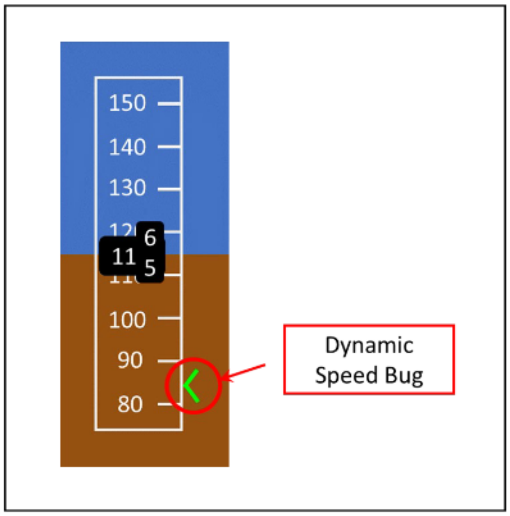
Types of AOA Indicators

There are several different ways that indicators can display the AOA. One of the more effective AOA presentations is a dynamic speed bug on the airspeed tape of an electronic Primary Flight Display. See figure 3. This symbol represents on-speed AOA for a given configuration. Typically, this is the speed corresponding to 1.3 x V_{so} (V_{ref}) on approach and indicates a safe speed regardless of configuration or g-loading during maneuvering flight. In this case, AOA is not presented in degrees but is normalized to speed and presented in the pilot's normal scan of airspeed. The benefit is that the pilot does not have to assimilate another AOA parameter in their scan but uses their normal scan of airspeed.

---

[11] Airplane Flying Handbook, FAA-H-8083-3C, Chapter 4, "Energy Management: Mastering Altitude and Airspeed Control," 2021, https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/airplane_handbook/05_afh_ch4.pdf.

Figure 3 – Dynamic Speed Bug



A more common method to display AOA is using a round dial. See figure 4. One of the most basic way is to present the actual degrees or the angle of the relative wind in relation to the chord reference line of the wing. Other scales use normalized units that range from "0" for zero AOA to "1" as the critical AOA.

Figure 4 – Basic AOA Indicator[12]

Another common way to communicate AOA to the pilot is using symbols, as shown in figure 5. This type of AOA indicator is often referred to as an AOA indexer.

Figure 5 – AOA Indexer[12]

---

[12] Source: DOT/FAA/TC-TN19/11

Additional Resources

- Adami, T.M., de Haag, M. U., Theunissen, E., Sizoo, D., &McGuire, R. (2014). An energy management display for general aviation safety enhancements. 2014 IEEE/AIAA 33rd Digital Avionics Systems Conference (DASC), Colorado Springs, CO, USA, 2014, pp. 2D1-1-2D1-11, doi: 10.1109/DASC.2014.6979430.
- Airplane Flying Handbook (FAA-H-8083-3C) Chapter 4: Energy Management.
- Amelink, M. H., Mulder, M., Van Paassen, M. M., & Flach, J. (2005). Theoretical foundations for a total energy-based perspective flight-path display. The International Journal of Aviation Psychology, 15, 205-231.
- Campbell, A. (2019). A review of angle-of-attack display research from 1958-2014. DOT/FAA/TC-TN19/11.
- Carlquist, R. (1960). Recommended angle of attack setting for various flight maneuvers; Report #1, final report. Naval Air Test Center, Patuxent River, Maryland.
- Cashman, J.E., Kelly, B.D., and Nield, B.N. (2000). Operational use of angle of attack on modern commercial jet airplanes. Boeing Commercial Aircraft Company. Aero Magazine, (4).
- Deters, J., LeSage, T., & Stevens, M. (2018). Cumulative system evaluation report of 10 commercial off-the-shelf angle-of-attack sensors and display systems. DOT/FAA/TC-18/19. https://www.tc.faa.gov/its/worldpac/techrpt/tc18-19.pdf.
- Dillman, B., et al. (2018). Angle of attack equipment in general aviation operations. DOT/FAA/TC-18/28. https://www.tc.faa.gov/its/worldpac/techrpt/tc18-28.pdf.
- Ellis, D.R. (1977). A study of lightplane stall avoidance and suppression (FAA-RD-77-25). Springfield, VA: National Technical Information Service.
- FAA (2015). Instrument Flying Handbook (FAA-H-8083-15B) Addendum: Angle of Attack Indicators. https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/ifh_addendum.pdf.
- FAA (2015). Stall prevention and recovery training. AC 120-109A. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_120-109A.pdf.
- FAA (2017). Vmc Training and Angle of Attack. https://www.faa.gov/newsroom/safety-briefing/vmc-training-and-angle-attack.
- FAA (2018). Low-cost accurate angle of attack system. DOT/FAA/TC-18/7. https://www.tc.faa.gov/its/worldpac/techrpt/tc18-7.pdf.
- FAA (2019). Angle of Attack Awareness. https://www.faasafety.gov/files/events/WP/WP07/2021/WP07104435/Angle_of_Attack_Awareness.pdf.
- FAA (2022). Flightpath management. AC 120-123. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_120-123.pdf.
- Fala, N. An Analysis of Fixed-Wing Stall-Type Accidents in the United States. Aerospace 2022, 9, 178. https://doi.org/10.3390/aerospace9040178.
- Forrest, F.G. (1969). Angle of attack presentation in pilot training (DS-69-6). Federal Aviation Administration. Washington, DC.
- Gee, S.W., Gaidsick, H.G., & Enevoldson, E.K. (1971) Flight evaluation of angle of attack as a control parameter in general-aviation aircraft. (NASA Document No. D-6210). National Aeronautics and Space Administration. Washington, DC.
- Karayanakis, N.M. (1982). Angle-of-attack feedback in manual aircraft control: Piloting techniques and some flight training implications (Doctoral dissertation). Available from ProQuest Dissertations and Theses database.
- Kish, B. A., et al., (2018). FAA part 23 methods of compliance for AOA warning/limiting systems. 2018 IEEE Aerospace Conference, Big Sky, MT, USA, 2018, pp. 1-13, doi: 10.1109/AERO.2018.8396441.

- Langdon, S.D. (1969) Fixed wing stability and control theory and flight test techniques (USNTPS-FTM-No. 103). Naval Air Test Center. Patuxent River, MD.
- Merkt, J. R. (2013). Flight energy management training: Promoting safety and efficiency. Journal of Aviation Technology and Engineering, 3(1), 24-36. doi:10.7771/2159-6670.1072.
- National Transportation Safety Board. 2010. Loss of Control on Approach, Colgan Air, Inc., Operating as Continental Connection Flight 3407, Bombardier DHC-8-400, N200WQ, Clarence Center, New York, February 12, 2009. NTSB/AAR-10/01. Washington, DC. https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR1001.pdf.
- Odle, M.L. (1972) ATC angle of attack training (AD-757 243). National Technical Information Service. U. S. Department of Commerce. Springfield, VA.
- Silver, I., Kish, B., & Wilde, M. (2022). Energy management displays and algorithms. DOT/FAA/TC-22/26. https://www.tc.faa.gov/its/worldpac/techrpt/tc22-26.pdf.
- Sizoo, D. (2014) AOA: More than just a display. FAA Safety Briefing May/June 2014, 25-26. https://www.faa.gov/newsroom/safety-briefing/faa-safety-briefing-mayjune-2014. Article was originally published in August of 2012 in Alaska "Transponder" Safety Magazine.
- Tucker, R.C., and Gordon, H.C. (1959). Evaluation of Kollsman and Specialties Inc. angle of attack presentation (AFFTC-TN-59-28). Arlington, VA: ASTIA Document Service Center.
- Valasek, J., et al. (2019). Characterization of derived angle-of-attack and flight path angle algorithms for general aviation platforms. DOT/FAA/TC-18/48. https://www.tc.faa.gov/its/worldpac/techrpt/tc18-48.pdf.
- Vaccaro, M., Lutz T., (2024). Accurate Pressure Derived Angle of Attack. Society of Experimental Test Pilots Annual Symposium, Anaheim, California. https://3c039af6-63d7-4703-82ff-4bf98735a5a3.usrfiles.com/ugd/3c039a_693616079c574a38a2129006b4a020b3.pptx.
- Wischmeyer, E. (2024, May). Airspeed and vertical speed. Plane and Pilot. https://www.planeandpilotmag.com/pilot-proficiency/airspeed-vertical-speed/.