

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."

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." 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 965⁴, 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). 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. 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

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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.

SAIB Attachment

Definitions

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

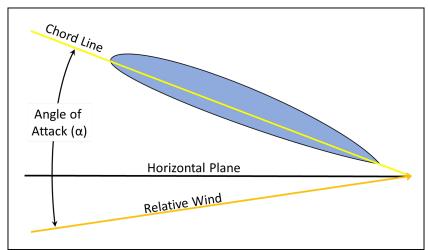


Figure 1 – Angle of Attack and Relative Wind⁸

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

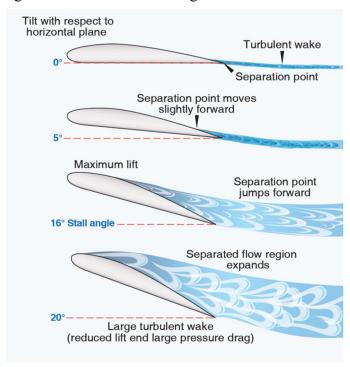
Loss of Control Caused by Stall at Critical AOA

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 AOA¹⁰



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 management¹¹

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)

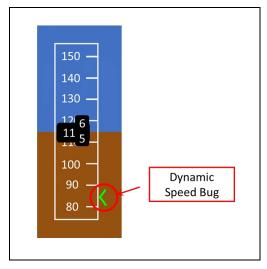
There is an inextricable link between controlling AOA and managing energy. ¹¹ This link is clear during maneuvering flight when the pilot makes inputs to alter or curve the flight path. Control inputs change the distribution of lift and drag on control surfaces, which changes the AOA. Maneuvers such 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 $1.3 \times V_{so}$ (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 Indicator¹²



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 Indexer¹²



¹² Source: DOT/FAA/TC-TN19/11

Additional Resources

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Memorandum

Date: February 5, 2014

To: See Distribution List

From: David W. Hempe, Manager, Aircraft Engineering Division, AIR-100D. Hempe

James D. Seipel, Manager, Production and Airworthiness Division, AIR-200

Subject: Approval of Non-Required Angle of Attack (AoA) Indicator Systems

Memo No.: AIR100-14-110-PM01

Regulatory Reference: Title 14 of the Code of Federal Regulations 21.8(d)

This memorandum establishes requirements and procedures for issuing a design and production approval to a United States (U.S.) manufacturer under Title 14 of the Code of Federal Regulations (14 CFR) 21.8(d) for a non-required/supplemental Angle of Attack (AoA) indicator system. This memo will expire in three years from the date of issuance, unless otherwise extended or incorporated into an order. Under this memo, all applications for AoA approval will be directed to the Chicago Aircraft Certification Office (ACO), Des Plaines, IL

Preventing loss of control in general aviation (GA) is a top focus area of the FAA and the GA community. Installation of an AoA system may aid in preventing loss of control accidents. Manufacturers have requested a streamlined method of design and production approval for non-required/supplemental systems. Since these systems provide only supplemental information to the pilot and are not required by regulation, the FAA has developed the following approval process under 14 CFR 21.8(d).

Applicability

This memo applies only to supplemental AoA system(s), not those required for type certification of the aircraft. Further, the word "system" refers to the AoA indicator and all of its associated parts and hardware allowing it to be installed and operated as an independent and stand-alone system. This memo applies only to systems installed in U.S.-registered aircraft, excluding commuter and transport category airplanes.

Procedure for Approving a Non-Required AoA Indicator System

1. Applicant Responsibilities.

- **a.** An applicant (i.e., AoA manufacturer) submits a request for a letter of approval (LOA) to the Chicago ACO. The letter should contain:
- (1) General information such as the applicant's address of the principle manufacturing facility that controls the design and quality of the article.
- (2) A description of the article, including part number, and any other information that provides a general overview of the article (e.g., design, performance, operation, etc.).
- (3) A statement of compliance certifying that the applicant's article meets the design requirements of ASTM F3011-13, and the applicant has met the requirements of this memo for the requested article. The statement of compliance will state: "I certify that we have complied with all applicable requirements, as identified in the memo no. AIR100-14-110-PM01, issued on 02/05/2014, and that the article is produced in accordance under the required quality system."
- **b.** If the submitted documents are deficient, the applicant is required, when requested by the FAA, to provide information necessary to show compliance with this memo.

2. AoA Design Requirements.

- **a.** A failure of the AoA system to perform its intended function or display erroneous indications must not adversely affect the safety of the aircraft, its occupants, or the proper functioning of equipment and systems that are required by the airworthiness standards or operating rules. At a minimum, a qualitative evaluation of the design is required to determine that neither its normal operation nor its failure will affect the safety of the aircraft or pilot workload. In most cases, a qualitative evaluation will be sufficient to satisfy the system safety assessment.
- **b.** When isolation between the AoA and aircraft required systems is provided by complex means, more detailed evaluation methods, such as System Safety Analysis (SSA), Functional Hazard Analysis (FHA), or Failure Modes and Effects Analysis (FMEA) may be necessary.
- **c.** The performance of the AoA system must meet ASTM F3011-13 and the following requirements:
- (1) The AoA system operating instructions must clearly state the accuracy of the AoA instrument (ref: F3011-13, section 5.1.2).
- (2) The AoA system calibration instructions must include a test that after calibration of the AoA system, the AoA does not provide information conflicting with the stall warning from a certified stall warning system, if the aircraft is so equipped.

- (3) The AoA system must be a stand-alone unit and must not interface with a certificated system (e.g., pitot-static system, stall warning, etc.) with the exception of supplying electrical power to the AoA unit and mounting requirements for the sensor and the display unit.
- (4) When properly installed and calibrated, the AoA system must not provide misleading information to the pilot (i.e., audible or visual cues that may conflict or interfere with the aircraft stall warning, if so equipped) (ref ASTM F3011-13, 5.2).
- (5) Marking and placards for the AoA system display must state the following: "Not for use as a primary instrument for flight."
- (6) The AoA system installation instructions must require that the installation of the AoA display will not interfere with the pilot's view of the primary flight instruments.
 - (7) The following statement below must be included in the installation instructions:
 - "This AOA system has not been determined to be suitable for installation in any specific aircraft by _____ (the AOA system manufacturer). It may be installed in a type-certificated aircraft, provided that it has been determined suitable for installation by an appropriately rated mechanic by means such as field approval or as a minor alteration."
- (8) A notice advising the installer that the AoA indicator cannot be placed in the cockpit in such a manner as to obstruct the pilot's view or cause distraction.
- (9) A notice advising the installer that installation of the AoA system in a commuter or transport category airplane is prohibited.
- (10) A notice advising that installation of the AoA system as a replacement for or modification to an existing approved stall warning system is prohibited.
- **3. Operating Limitations** The operating limitations (ref ASTM F3011-13, 4.3.3) must include the following:
- **a.** An advisory that the AoA system is non-required and is to be used only as supplemental information to the pilot. The AoA system may not be used as a substitution for the certified aircraft stall warning system.
- **b.** No operational credit may be taken for such items as reduced approach speed and shorter landing distances.
- **4. AoA Manufacturing Requirements.** The applicant is required to control both the design and quality of the article. To control the quality means the AoA system manufacturer must build the article in accordance with its approved design. This also means that each design change to the article or any of its components, features or functions is controlled by the manufacturer to ensure that after a change or modification to the article it still meets the specified requirements in this memo and the associated documents are updated accordingly. Applicants who hold a production approval under 14 CFR part 21 may produce a supplemental AoA system under their

existing quality system. Applicants who do not hold a part 21 production approval must have a quality system that contains the following elements:

Design data control	esign data control Document control	
Supplier control	Manufacturing process control	
Inspecting and testing	Inspection, measuring, and test equipment control	
Inspection and test status	Nonconforming product and article control	
Corrective and preventive actions	Handling and storage	
Control of quality records	Internal audits	
In-service feedback	Quality escapes	

5. ACO Responsibilities. Applicants must state in the application letter that their AoA system meets the design and quality control requirements of this memo. The ACO may rely on the applicant's certifying statement and issue a production approval under § 21.8(d) and provide a copy of the approval to the geographical manufacturing inspection district office (MIDO). A MIDO audit is not required. A template for the approval is provided below.

Distribution List:

All Aircraft Certification Directorates

All Aircraft Certification Offices

All Manufacturing Inspection Offices

All Manufacturing Inspection District Offices/Satellite Offices

All Certificate Management Offices/Units

All Flight Standards Divisions

All Flight Standards Field Offices

All Flight Standards International Field Offices

All Flight Standards Regional Offices

Designee Standardization Branch, AFS-640



Federal Aviation Administration

{ACO} {ACO address}

{Date}

{Name of applicant point of contact (POC)} {POC's title} {Name of company} {Street address} {City and zip code}

Dear {Mr. /Mrs. /Ms. Name of applicant POC}:

Subject: Angle of Attack System Approval {insert reference number}

This is in reply to your letter of *{enter date of application}*} requesting approval for the manufacture of your supplemental angle of attack system. We accept your statement certifying that your system meets the requirements of FAA memorandum number AIR-100-14-110xxxx.

All major components of the articles produced under this approval must be permanently and legibly marked with the authorization holder's name, or trademark, or symbol, part number and "21.8(d)."

You must allow the FAA to inspect your quality system, facilities, technical data, and any manufactured articles and witness any tests, including any inspections or tests at a supplier facility, necessary to determine compliance with this approval.

You must notify the FAA before making any changes to the location of any of your manufacturing facilities, company name or ownership.

This approval may not be transferred.

This approval, issued under 14 CFR 21.8(d), is effective until surrendered, withdrawn or otherwise terminated by the FAA.

Please note that technical data the FAA retains may be subject to Freedom of Information Act requests. This office will notify you of any requests pertaining to your data and give you the opportunity to protect the data from public disclosure. If you have any questions regarding this approval, contact *{enter FAA ACO contact and phone number.}*.

Sincerely,
{Name of ACO manager}
{Name of FAA ACO}
cc: AIR-112; {insert routing symbol of responsible MIDO}

NASA/TM-2014-218514



Review of Research on Angle-of-Attack Indicator Effectiveness

Lisa R. Le Vie Langley Research Center, Hampton, Virginia

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Table of Contents

1. In	ntroduction	2
	ngle-of-Attack	
	istorical Research	
4. A	oA in the Cockpit	10
	General Types	
4.2	* *	
4.3	Commercial Transport and Business Aircraft AoA Indicators	19
4.4	AoA on the HUD	22
4.5	General Aviation AoA Systems	24
5. A	oA Display Benefits	
	Energy State Awareness/Upset Recovery	
5.2	Detect/Diagnose Air Data System Failures	30
6. T	raining	32
7. C	oncluding Remarks	34
8. R	ecommendations	35
9. R	eferences	36

List of Figures

Figure 1: Aircraft Accident Statistics for Worldwide Commercial Fleet 2003-2012	2
Figure 2: Angle-of-Attack, Flight Path Angle and Pitch attitude	4
Figure 3: Lift at Angle of Attack	5
Figure 4: Different Pitch Attitudes and Stall AoA	5
Figure 5: Common AoA Sensor Types	10
Figure 6: Angle of Attack sensor on Embraer 145	11
Figure 7: Specialties AoA indicator displaying arbitrary numbers	
Figure 8: Teledyne Avionics Angle of Attack Indicator	12
Figure 9: AoA Indicator displaying degree units	12
Figure 10: Inset of Boeing AoA Gauge	
Figure 11: Specialties, Inc. B-2 Dial-type AoA Indicator	14
Figure 12: Specialties, Inc. AoA Approach Index Indicator	14
Figure 13: AoA Display and Key	15
Figure 14: AoA Indexer	16
Figure 15: T38 AoA System and Displays	17
Figure 16: Navy F/A-18 HUD display showing AoA and the AoA Bracket	18
Figure 17: Navy F/A-18 AoA Indexer	18
Figure 18: F-16 AoA Display System	19
Figure 19: Cessna AoA Indicator and Indexer	20
Figure 20: Optional Airbus AoA Indicator	20
Figure 21: Boeing AoA Gauge	21
Figure 22: Gulfstream PFD AoA Located Under Airspeed Tape	22
Figure 23: Rockwell Collins HGS6250 AoA Indicator	
Figure 24: Rockwell Collins HGS4200 AoA Indicator	24
Figure 25: Garmin GI 260 Angle of Attack Indicator	25
Figure 26: Garmin G3X AoA System	26
Figure 27: Alpha System AoA Griffin Chevron Display	
Figure 28: ICON A5 Light Sport Aircraft AoA indicator	27

Nomenclature

AAIU	Air Accident Investigation Unit
AFM	Airplane Flight Manual
AoA	Angle of Attack
BEA	Bureau d'Enquêtes et d'Analyses
CRJ	Canadair Regional Jet
FAA	Federal Aviation Administration
HGS	Head-up Guidance System
HUD	Head-Up Display
LOC-I	Loss-of-Control – In Flight
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NTSB	National Transportation Safety Board
PFD	Primary Flight Display
UPS	United Parcel Service
USAF	United States Air Force
VSST	Vehicle Systems Safety Technologies

Abstract

The National Aeronautics and Space Administration (NASA) conducted a literature review to determine the potential benefits of a display of angle-of-attack (AoA) on the flight deck of commercial transport that may aid a pilot in energy state awareness, upset recovery, and/or diagnosis of air data system failure. This literature review encompassed an exhaustive list of references available and includes studies on the benefits of displaying AoA information during all phases of flight. It also contains information and descriptions about various AoA indicators such as dial, vertical and horizontal types as well as AoA displays on the primary flight display and the head up display. Any training given on the use of an AoA indicator during the research studies or experiments is also included for review.

1. Introduction

Accidents resulting from Loss of Control – In Flight (LOC-I) continue to be the principal cause of commercial transport aviation fatalities worldwide (Figure 1). Between 2003 and 2012, 24 percent of fatal accidents, accounting for 39 percent of total aviation fatalities, were attributable to LOC-I. Of these, 59 percent occurred during the takeoff/initial climb and final approach/landing phases of flight (Boeing, 2013). In response to these findings, cooperative industry-government research into flight deck technologies, with the potential to minimize the problems and contributing factors of loss-of-energy state awareness, has been initiated.

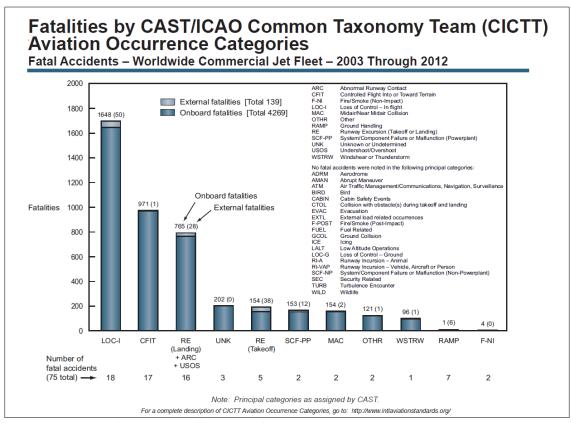


Figure 1: Aircraft Accident Statistics for Worldwide Commercial Fleet 2003-2012 (Boeing, 2013)

One technology that has been proposed to increase the pilot's ability to avoid, detect, and recover from situations that may lead to LOC-I is an angle-of-attack (AoA) display. This idea is motivated by the following: AoA information is considered most useful to the flight crew to show the margin to stall or stall warning, and AoA information may also be useful in the diagnosis of an air data system (e.g., pitot or static system) failure. An AoA indicator may further aid the pilot in recovering the aircraft from an upset situation.

An airplane upset occurs when an airplane unintentionally exceeds the normal flight parameters found in either line operations or training. They are unintentional in nature because the aircraft is not doing what it was commanded to do, and therefore is entering unsafe conditions. Upsets can be attributed to the environment, equipment and/or pilots (Upset Recovery Industry Team, 2008).

While each airplane model's specific value may vary, the following criteria are generally used to define an airplane upset situation (Upset Recovery Industry Team, 2008):

- Pitch attitude greater than 25 degrees, nose up;
- Pitch attitude greater than 10 degrees, nose down;
- Bank angle greater than 45 degrees;
- Within the above parameters, but flying at airspeeds inappropriate for the conditions.

The purpose of this research is to review literature from industry, academia and government agencies to evaluate past research on AoA displays and their effectiveness; review the types of AoA systems and their use; discuss the potential benefits of AoA displays to aid in energy state awareness, upset recovery and diagnosis of air data system failures; and review any previous training given or currently suggested regarding AoA indicators.

2. Angle-of-Attack

Angle-of-attack (AoA) is an aerodynamic parameter critical to understanding airplane stability, performance and control. AoA is the angle between a reference line on the airplane or wing and the relative wind or on-coming air.

Two other angles are more commonly referred to in reference to the fuselage (Figure 2). They are the pitch angle (attitude) and the flight path angle. The pitch angle is the angle between the fuselage and the horizon and is displayed on either the artificial horizon or the attitude indicator. The flight path angle, also referred to as the climb or descent angle, is calculated as the vertical angle between the velocity vector (i.e., where the airplane is going) and the Earth's horizon and can be displayed on the primary flight display as a flight path vector. In still air (i.e., no wind), AoA is the difference between the flight path angle and the pitch attitude (angle), assuming no wind (Cashman, Kelly, and Nield, 2005).

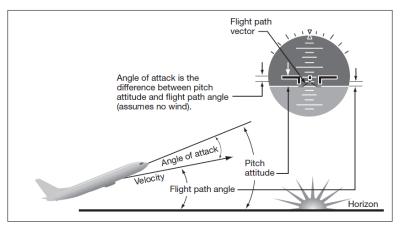


Figure 2: Angle-of-Attack, Flight Path Angle and Pitch attitude (Upset Recovery Industry Team, 2008)

A typical wing has a range of AoA over which it can function efficiently. With a typical cambered wing design, there is a small amount of lift at zero degrees of AoA (Figure 3). As the AoA increases, lift increases, until the air flowing over the wing will eventually separate from the upper surface, resulting in a loss of lift, or a stall. This stall condition can occur at any airspeed, altitude, or attitude (Figure 4), but will always occur at the critical angle of attack. Therefore, knowing when the wing is approaching this critical AoA is an important element of aircraft energy state awareness (Upset Recovery Industry Team, 2008).

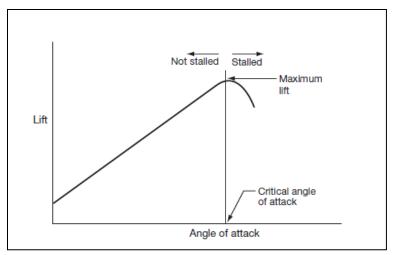


Figure 3: Lift at Angle of Attack (Upset Recovery Industry Team, 2008)

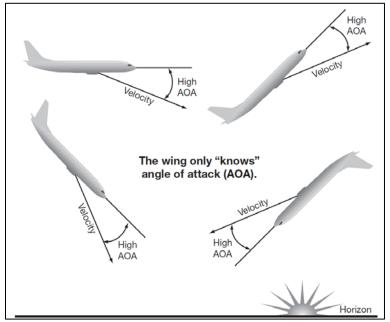


Figure 4: Different Pitch Attitudes and Stall AoA (Upset Recovery Industry Team, 2008)

3. Historical Research

The idea that usable AoA information can be gathered from a display already in the cockpit has persisted over the years. Cockpit displays, such as the stall margin on the airspeed tape and the pitch limit indicator on the primary attitude display, show AoA implicitly in the cockpit. Since AoA is a parameter that can't be sensed by pilots (Tucker and Gordon, 1959; Karayanakis, 1982), displayed AoA is beginning to be considered a valuable piece of information needed for many situations during flight; especially resolving upset recovery situations and detecting air data system failures. The following is a historical review of the studies done on AoA displays.

Svimonoff (1958) introduced the United States Air Force (USAF) Advanced Flight Instrument Panel that included an AoA indicator. This report detailed the evaluation of this system by various military, airframe and equipment test pilots as well as the implementation and recommended improvements of the overall system. At the time, AoA was an entirely new control parameter being displayed to the pilots. The large scale used on the indicator and the unstable characteristics during turbulence hindered the pilot's ability to develop a technique or use for the information presented. The AoA indicator developed for the test was only shown during the useful and well defined phases of flight: final approach, cruise and stall. No training on the use of the AoA indicator was given to the pilots beforehand. Pilots originally thought the AoA indicators were useless, but as they became familiar with and learned how to incorporate the information better, they understood the benefits and the resistance to the indicators subsided. The designers found that reducing the original scale factor of the AoA indicator and fixing the unreliable characteristics of the indicator in turbulent air helped increase acceptance and understanding by the pilots. There was a suggestion for further investigation on requirements for the display of AoA, as well as a training program that would allow pilots to take full advantage of the information.

Several other studies were done to test and judge the efficacy of AoA indicators. During flight studies to determine potential operating problems for the future of jet transports, Fishel, Butchart, Glenn, and Robinson (1958) investigated the relationship between 1g stall speed and stall characteristics that occurred during take-off and landing maneuvers. An AoA indicator was installed to give pilots a better indication of the aircraft's attitude during take-off. The pilots discovered that when the AoA indicator was used with other instruments (which the authors did not specify) they were able to achieve an optimal take-off attitude at speeds below the intended take-off speeds. This lessened the large AoAs and increased drag normally attributed to higher take-off speeds and over-rotation, and enabled the pilots to maintain proper aircraft attitude during take-off and climb-out.

Again in 1958, the Second Air Defense Command Safety Symposium (Orr, 1958), discussed flight safety issues in the terminal area and it was recommended that an AoA indicator be added near the airspeed indicator for future deliveries of their aircraft, and installed on the current inventory. This AoA indicator would be used in conjunction with a glideslope indicator to aid in establishing final approach sink rate.

Later, in 1963, during a presentation of 'lessons learned' from high speed supersonic transport flight operations, Barton (1963) stated that AoA indicators reduced pilot workload and allowed for more accurate control during the landing phase of flight. This increased control provided an additional margin of safety.

Several studies were done in the late 1960s through the 1970s. A study by Gee, Gaidsic, and Enevoldson (1971) evaluated whether AoA information was a useful addition to the General Aviation cockpit. The pilots, who did not receive any training with the display prior to flying in the experiment and varied widely in their piloting experience, appreciated the ease with which the AoA indicator allowed them to obtain trim and power settings. Piloting tasks that included take-offs, climbs, low speed maneuvers, approaches and landings were evaluated. The study found that an AoA indicator was a desired display to convey margin to stall as well as being a single reference point that allowed the pilot to select an approach trim condition which resulted in consistent flare and float characteristics regardless of weight or flap settings. It was concluded that displaying AoA was valuable during final approach as a way to maintain the flight path to the airport and in maneuvers to flare. Furthermore, it was found to be a desirable control parameter when used in conjunction with airspeed, attitude and other information.

In 1972, a conference was held by the Flight Mechanics Panel to discuss handling qualities criteria of aircraft within the North Atlantic Treaty Organization (NATO) countries. Twenty-one papers were presented and discussed to determine the direction that the panel should take in the future. In the comments section of the paper titled "Criteria for Stall and Post Stall Gyrations," (Lamar, 1972) several commenters mentioned the desire to have an AoA indicator included in the cockpit display and one commenter questioned "if the test pilot of an aircraft needed an angle of attack indicator to stay out of a stall, then shouldn't every aircraft have one?" Hancock (1972) stated that:

Fundamentally, and it has always been recognized as such, stall is a function of angle of attack, also rate of change of angle of attack, rather than speed. It would be more logical to express the safety margin in terms of angle of attack, especially from the point of view of accounting for atmospheric turbulence effects. However, the use of speed is more convenient and is by now well established; it is understood that the definition of the slow rate of decrease of speed is equivalent to a statement on the slow rate of increase in the angle of attack.

It was further proposed that AoA information would be valuable during the transition flight phase as well as during upsets caused by turbulence (Hancock, 1972).

Odle (1972) tasked with studying and evaluating an AoA system for use in the United States Air Force (USAF) Air Training Command's flight training program, found that AoA systems were most valuable in preventing stalls during the traffic pattern and landing phase. The study was used to determine which flying maneuvers could be flown using the AoA system and how, using AoA, those maneuvers should be flown. A large majority of the pilots in the study used AoA information and airspeed to control the

aircraft with greater confidence while flying traffic patterns and maneuvers requiring maximum performance. Further research was suggested to better understand other beneficial uses of an AoA indicator. Other studies cited in Karayanakis (1982) found that AoA feedback was useful during flight maneuvers such as: take-off, climb, turns, cruise, slow-flight, descent and landings. The AoA indicator gives the pilot a safe margin to stall that is independent of weight, bank angle, g-forces or density altitude variations.

The Navy evaluated AoA indicators to determine the optimum settings for the phases of flight where it determined it was most beneficial (Carlquist, 1960). They found that an AoA indicator provided useful information during steep turns, while gaining altitude where thrust was limited, maximum endurance flight at steady altitude, ground control approaches, normal field landings in smooth air, and carrier landings. It was impractical to use during cruise since the optimum AoA changed along with altitude, and it was difficult to use during times of turbulence. The AoA indicator was a primary reference during ground control approaches, stall warning, and smooth air landings and it was a secondary reference during other phases of flight. Following this study, it was recommended that AoA systems be installed according to military specifications. For the Navy, using AoA for low-speed control during carrier landings has shown a reduction in stall accidents and high energy landings (Forrest, 1969; Karayanakis, 1982). They also found that implementing the use of AoA on their other aircraft contributed to a substantial reduction in workload by providing a known margin to stall. This knowledge allowed pilots to achieve maximum aircraft performance during flight maneuvers. There was an almost complete elimination of early rotation during takeoff, and aircraft using AoA indicators were able to attain and maintain maximum range and endurance. Furthermore, AoA indicators were used to prevent stalls at high altitudes (above 40,000 feet) during high-g maneuvers. This led to significant improvements of all Navy jet operations. Forrest (1969) also believed that many of these advantages applied to commercial aircraft and anticipated the widespread use of AoA indicators in both jetliners and corporate jets.

Several studies, (Carlquist, 1960; Ellis, 1977; Gee, Gaidsic, and Enevoldson, 1971; Karayanakis 1982) noted that acceptance of AoA indicators varied with exposure. Most pilots have more experience and familiarity with the airspeed indicator and this may have had an influence on the perception of its usability. Pilots who were unfamiliar with AoA indicators needed practice with the instrument and an adjustment period to really understand the benefits. Carlquist (1960) found that acceptance by military pilots was varied due to factors which included: presentation, sensitivity, reliability, environmental conditions, aircraft maintenance procedures, individual pilot training and experience, and squadron policy and procedures.

Many of the previous studies called for further investigation into the actual requirements for an AoA display as well as further studies to better understand the full range of uses and benefits of displaying AoA in the cockpit. Studies of this nature were not found. In fact, research into displaying AoA information directly in the cockpit was primarily conducted prior to the 1980s. The research that was reviewed covered AoA use in

general aviation, military, and early transport aircraft; however, research using current general aviation, military and jet transport aircraft was not found.

4. AoA in the Cockpit

An AoA system contains all the components needed to calculate and display AoA in the cockpit. An AoA system typically contains these four components: sensors, transducers, indicators and stall-warning devices. Sensors can be either vane or probe types (Figure 5) which sense differential pressure through ports. One or more of these sensors are attached to either the wing or the forward fuselage (Figure 6) and sense the relative airflow. Transducers transform the sensor output to create a signal that is sent to the cockpit indicator. This signal can be sent directly or passed through an air data system (MacDonald, 2002). This signal must be corrected for flow effects across the aircraft nose and fuselage, position errors, and Mach number as well as other aerodynamic corrections to create an AoA measure relative to the aircraft wing. For commercial transport aircraft, these corrections can be significant (Cashman, Kelly, and Nield, 2005). AoA indicators include various display methods which may present the information implicitly (e.g., Pitch Limit Indicator, PLI, or 'barber pole' airspeed warnings) or explicitly indicating AoA using angles, normalized units, or symbols (e.g., indexers). Finally, stall-warning devices use AoA data to warn of impending stalls. Because AoA is critical for stall and stall margin awareness, the systems typically compute and display the critical AoA (stall AoA). For accuracy this computation must take into account how the critical AoA changes with the aircraft configuration (e.g., gear, flaps, spoilers, etc.), Mach number, and other aerodynamic effects (MacDonald, 2002).

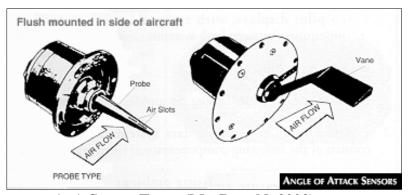


Figure 5: Common AoA Sensor Types (MacDonald, 2002)

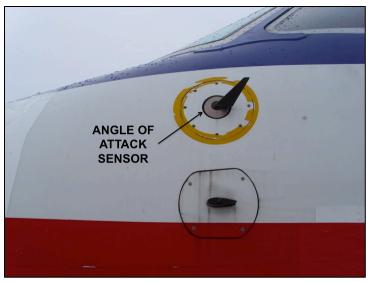


Figure 6: Angle of Attack sensor on Embraer 145 (Schock, 2014)

AoA is displayed in the cockpit in a variety of ways. Examples of AoA displays are taken from previous research as well as current AoA display options used in military, private and commercial aircraft. AoA indicators come in various stand-alone styles: circular/dial, horizontal, or vertical. They are also available on the primary flight display or head-up display as a dial, tape, or as a display of the calculated AoA value. Their size and position vary by manufacturer and aircraft. The scale on the indicator may display AoA in arbitrary units (Figure 7), normalized units (Figure 8), or actual degrees (Figure 9). The dial-type scale not only gives current AoA information, but it can also function as a rate-of-change indicator. This rate-of-change information can give the pilot an awareness of the situation that can keep the aircraft from entering a critical AoA state. AoA indexers, normally found in military aircraft, are also reviewed.

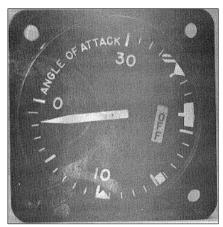


Figure 7: Specialties AoA indicator displaying arbitrary numbers (Carlquist, 1960)



Figure 8: Teledyne Avionics Angle of Attack Indicator (Starfleet Support, LLC, nd)

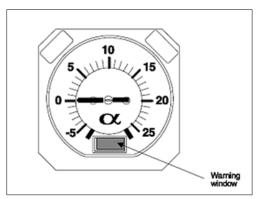


Figure 9: AoA Indicator displaying degree units (Airbus, 1995)

4.1 General Types

Normalized AoA indicators show a series of numbers between 0.0 and 1.0, where 0.6 is an AoA that is approximately 30 percent above margin to stall, taking into account the aircraft's current weight and configuration (Aarons, 2006). Since this stall AoA is dependent upon aircraft configuration, among other things, the normalization factor would need to change if a normalized AoA value of 1.0 is to always indicate the critical AoA. Furthermore, using normalized AoA indicators on commercial jet aircraft would require that the AoA calculation include Mach number which would inhibit the indicator from being used as a cross-check of a possible pitot or static system failure (Cashman, Kelly, and Nield, 2005). Color wedges can be added on a dial indicator to further situation awareness. As an example, a green wedge from 0.0 to 0.6, a yellow wedge from 0.6 to 0.8 and a red wedge from 0.8 to stall. Staying in the green should keep the pilot out of harm's way. The green-yellow border, which is still within the 30 percent margin to stall, is best for low-speed, maximum lift maneuvers that typically occur directly after takeoff or during final approach. At 0.8, the stall warning devices normally activate (Aarons, 2006).

With a non-normalized design, the AoA read-out reflects only the sensed AoA (Figure 10). In a pitot or static failure situation, the marks indicating stall warning, stick shaker and the speed tape bands may act erratically, but the needle and numerical read-out of AoA will remain stable and usable. This also enables non-normalized indicators to be used as a backup for an unreliable airspeed reading (Cashman, Kelly, Nield, 2000).

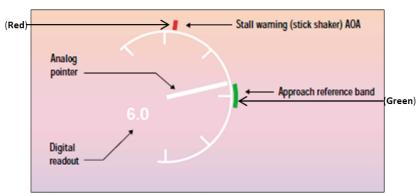


Figure 10: Inset of Boeing AoA Gauge (Cashman, Kelly, Nield, 2000)

Two types of early AoA indicators (not depicted), the Kollsman airspeed/AoA indicator and the Specialties Inc. AoA indicator were evaluated by Tucker and Gordon (1959) at the Air Force Flight Test Center. Thirty-two flights, primarily testing power approach problems, were flown. Secondary considerations included maximum range and endurance, as well as recovering from stalls and engine flame-outs during approach. The Kollsman airspeed/AoA indicator presented AoA indirectly on the airspeed indicator using a "marked ring which travels the circumference of the indicator. Aligning the airspeed needle with the appropriate AoA index, the airplane will be flown at the optimum airspeed for that condition at essentially all the gross weights and bank angles." (Tucker and Gordon, 1959) Because there were two moving reference points, the information provided was not useable rate information until the aircraft's airspeed and AoA was close to optimum. The movable reference points also made it unsuitable for measuring closeness to the desired AoA. The presentation allowed the pilots to reference either airspeed or AoA independently. The Specialties, Inc. gauge provided a direct indication of AoA, but it was done in arbitrary units that the pilots had no experience interpreting. Pilots in the Tucker and Gordon (1959) study preferred the Kollsman system over the Specialties, Inc. AoA system. Both indicators were evaluated and while it was discovered that both were good for optimizing cruise, neither was recommended for inclusion into the USAF's F-106 or F-102 fleet because they were not believed to aid in the approach problems for which they were tested. The study did find that both systems would be useful in the event of a pitot-static system failure.

In a 1960 study looking to determine optimum AoA settings for all applicable phases of flight, the Navy studied two (of which only one system is pictured below) dial-type indicators with a pointer that moved counterclockwise in increasing value of AoA, in units from 0-30 (Figure 11) (Carlquist, 1960). This movement better matched the movement of both the airspeed indicator and aircraft pitch attitude. Three movable index markers rotated within the face. The marker with a hashed area at 25-27 units indicated

the point of the stall warning while the other two movable markers could mark other desired pre-determined values. A fixed marker at the 3 o'clock position marked the optimum approach AoA.

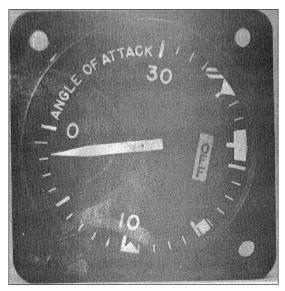


Figure 11: Specialties, Inc. B-2 Dial-type AoA Indicator (Carlquist, 1960)

The study also included an AoA approach index indicator (Figure 12). The center circle was lit to indicate the optimum approach angle and the chevrons lit up to give the direction of correction needed to maintain the optimum approach angle (Carlquist, 1960).

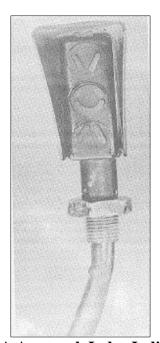


Figure 12: Specialties, Inc. AoA Approach Index Indicator (Carlquist, 1960)

In 1969, Forrest wrote a report for the FAA which studied whether using AoA information as well as other required instruments would "enhance the process of learning

to pilot an airplane". They found that most of the benefit of using AoA came while flying steep ascent and descent. However, it was determined that AoA displays may be more beneficial to instrument rated pilots, since most beginning pilots use visual cues to fly. The researchers felt that one limitation to their study was the presentation of AoA. Sixty percent of the instructor pilots felt that a different presentation of AoA may have improved its use by the subject pilots during flight. The instrument used was a dial-type indicator that used arbitrary reference units, graduated in thirty units. Certain reference units applied to certain maneuvers, and it was the pilot's job to know which reference unit correlated to which maneuver. Recommendations for further research into using an AoA indicator in instrument flight training were made since there are many benefits to using AoA that may be better realized at the instrument pilot level (Forrest, 1969).

The AoA indicator used on a twin engine general aviation airplane for a 1971 study conducted by Gee, et al., was a horizontal display, mounted above the instrument panel on the left side of the cockpit (Figure 13), to enable it to be within the pilot's field-of-view as he looked through the windscreen. The regions were color coded to simplify understanding of the information.

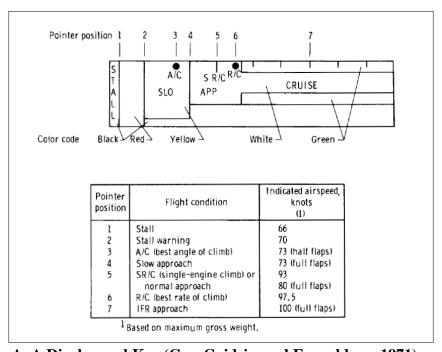


Figure 13: AoA Display and Key (Gee, Gaidsic, and Enevoldson, 1971)

Pilots in Odle's 1972 study, which looked at AoA use in various flight maneuvers for the USAF's Air Training Command's Instrument Flight Center, stated a desire for AoA to be displayed as the percent of lift available. They felt that displaying the percent of lift available led to better understanding and easier application of the AoA information. Additionally, displaying AoA as a percentage of lift available was appropriate and desired due to the fact that when the display read 0.8, the pilots knew that there was 20 percent lift available, whereas when an indicator showing available AoA read 0.8, this corresponded to 20 percent of available AoA left. While similar, the differences are

significant. The pilots felt that displaying AoA as a percentage of lift available was more direct and transferable across aircraft. The study also recommended that a standardization of AoA displays and symbology across airframes be implemented (Odle, 1972).

For Odle's (1972) study, a Bendix Standardized AoA System was used that included an AoA indicator and a head-up indexer. The Bendix indicator (not pictured) is a round dial which displayed the percentage of available AoA. The scale ranged from zero lift angle (0) through the stall angle (1.1), where 1.0 represents a stall. The approach index is set at 0.60, while maximum endurance is set at 0.30. The approach to stall is shown with amber coloring and begins at 0.90, while the stall area is shown with red coloring and begins at 1.0 (Odle, 1972).

The head-up indexer (Figure 14) was mounted directly in front of the pilot and used trend information to indicate high, slightly high, on approach, slightly low or low AoA flight information. The indexers were unanimously accepted by the study pilots who found them to be an effective cue of the direction of pitch attitude correction needed to maintain an optimum AoA. Furthermore, it allowed the pilot to fly 'heads up' with better aircraft control and more accuracy during the traffic pattern and landing phase (Odle, 1972).

Light		Meaning
11	Red	High AOA, low airspeed
N	Red Green	Slightly high AOA, slightly low airspeed
0	Green	On approach AOA, on approach speed
© /\!\	Green Amber	Slightly low AOA, slightly high airspeed
11	Amber	Low AOA, high airspeed

Figure 14: AoA Indexer (Odle, 1972)

Odle (1972), Egan and Goodson (1978) looked at AoA displays in military aircraft and suggested a standardization of the system and the symbology across the military to reduce confusion and aid in skill and knowledge transfer when switching between different aircraft.

In Ellis' Light Plane Stall Avoidance and Suppression study (1977), pilots evaluated three styles of AoA indicators: a dial-type indicator with a normalized scale of zero to one, which presented percent of maximum lift available; a vertical indexer with chevrons and a 'donut' indicating optimum angle of attack; and a slow-fast meter that was horizontally mounted. It was noted that with familiarity and practice that any of the three styles could be used effectively as an AoA indicator (Ellis, 1977). The study did not mention whether the pilots had any preference towards any particular display style sampled.

4.2 Military AoA Systems

The AoA system for the T-38 (Figure 15) includes a dial indicator for each pilot that displays AoA as a percentage of maximum lift during all phases of flight as well as an AoA indexer which operates and illuminates when the aircraft is configured for landing or when flaps are extended 5 percent or more with the landing gear up (USAF, 1978). The dial is calibrated counterclockwise in increments of 0.1, with each increment from 0 to 1.1, representing approximately 10 percent of aircraft lift. It has two colored arcs, yellow to represent buffet warning and red to represent stall warning. Furthermore, the AoA indicator contained three white indices at 0.18 to denote maximum range, 0.3 to denote maximum endurance, and 0.6 to denote optimum final approach at 1g flight. The indexer will illuminate the chevrons and circle independently or in combination to indicate different AoA conditions such as red for low speed, green for on speed, and yellow for high speed.

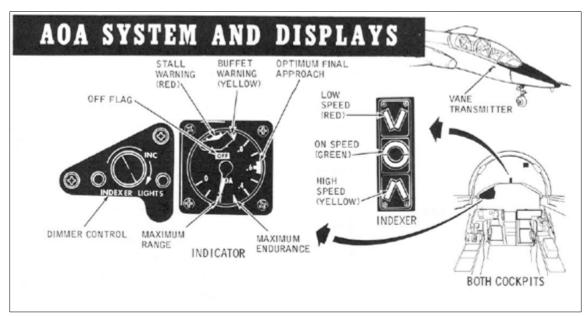


Figure 15: T38 AoA System and Displays (USAF, 1978)

The Navy F/A-18 displays true AoA in degrees in the Head-Up Display (HUD) (Figure 16). When the landing gear is down, an AoA bracket appears. The bracket moves with respect to the velocity vector and the center of this bracket indicates the optimum approach AoA. The pilot also has an AoA indexer mounted to the left of the HUD which operates when the landing gear is down and locked during flight (Figure 17). The chevrons and the circle light up in different combinations to give the pilot a visual indication of the aircraft's airspeed and AoA during landing. The true airspeed and AoA can be referenced on the HUD as described above (United States Navy, 2008).

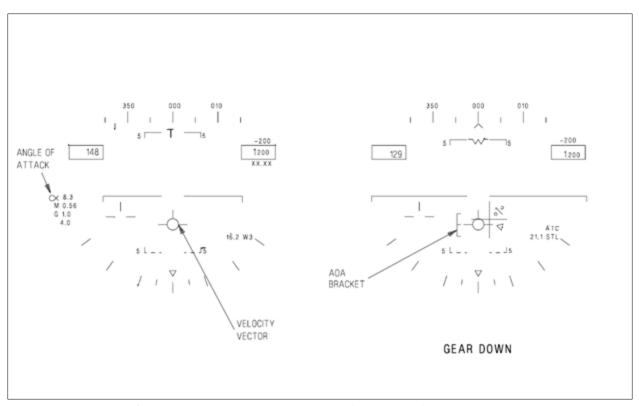


Figure 16: Navy F/A-18 HUD display showing AoA and the AoA Bracket (United States Navy, 2008)

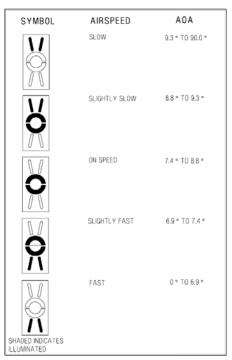


Figure 17: Navy F/A-18 AoA Indexer (United States Navy, 2008)

The F-16 AoA system (United States Air Force, 2002) consists of an indicator located on the instrument panel, an indexer located on the top left side of the glareshield and the HUD AoA display (Figure 18). The AoA indicator displays AoA in true degrees on a vertically moving tape indicating -5 to +32 degrees. Color coding from 9 to 17 degrees corresponds to the color coding on the AoA indexer. The AoA indexer provides a visual indication of aircraft AoA by illuminating either one of the chevrons or the circle. The indexer operates continuously with the landing gear handle up or down. The HUD display uses an AoA bracket when the landing gear is lowered. When the flightpath marker is even with the top of the bracket, the AoA of the aircraft is 11 degrees. When the flightpath marker is in the middle of the bracket, the AoA of the aircraft is 13 degrees and when the flight path marker is even with the bottom of the bracket, the AoA of the aircraft is 15 degrees.

INDICATOR	INDEXER	HUD DISPLAY	ATTITUDE
\$\frac{2}{2} \\ \frac{2}{15} \\ \frac{1}{15} \	(RED)		SLOW HIGH AOA
13 (SREEN)		ON SPEED OPTIMUM AOA
11 (A	MBER)		LOW AOA

Figure 18: F-16 AoA Display System (United States Air Force, 2002)

4.3 Commercial Transport and Business Aircraft AoA Indicators

Cessna offers an optional AoA indicator and indexer on their Citation X Model 750 (Figure 19). The indicator is standardized from 0 to 1.0, and contains colored arcs (Cessna, year unknown). The green arc, located from 0 to 0.60, represents normal operation. The yellow arc, located between 0.60 and 0.80, represents the area where the aircraft may be approaching the critical AoA. The yellow arc also contains a symbol between 0.55 and 0.65 and represents the optimum landing approach airspeed. The red arc, from 0.80 to 1.0, represents where low speed buffet may occur and if uncorrected, could continue on to a full stall. The stick-shaker activates around 0.83 +/-0.02. This information is valid for all aircraft configurations and weights. The Cessna approach indexer is mounted on the pilot's glareshield and uses three lighted symbols to indicate one of five AoA conditions. When lit, the top chevron, colored red, indicates a high AoA. This chevron points down to indicate that the AoA should be decreased. A slightly

high AoA is indicated when the top chevron and the green circle are lit. Only the green circle lights up when the AoA is on the optimal approach reference. A slightly low AoA is indicated when the circle and bottom chevron, colored yellow, are lit. The bottom chevron lights up when the AoA is low. This chevron points up to indicate that the AoA should be increased.

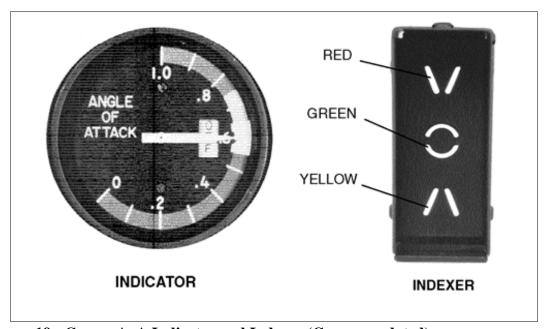


Figure 19: Cessna AoA Indicator and Indexer (Cessna, undated)

Airbus offers an optional AoA indicator on the A340 that provides the crew the true AoA between -5 and +25 degrees (Figure 20). There is an indicator on both the Captain and First Officer side; they are fed directly from the air data inertial reference unit on the corresponding side. In the event of failure of the AoA system, the pointer is positioned at the lower stop and an amber warning flag appears (Airbus, 1995).

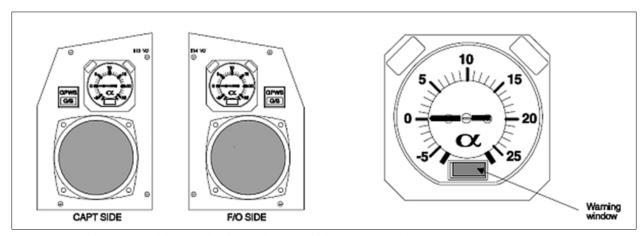


Figure 20: Optional Airbus AoA Indicator (Airbus, 1995)

Boeing offers an optional, non-normalized AoA indicator on its 737-600/-700/-800/-900, 767-400, and 777 flight displays (Figure 21). The indicator combines a digital readout, showing body AoA in degrees, and an analog pointer with a red tick mark indicating the stall warning AoA. In addition, an approach reference band in green is shown whenever landing flaps are being used. Because the displayed value of AoA is non-normalized, it can be used as a backup when there is a suspected pitot or static source blockage or failure. This indicator can also be used to determine margin to stall during upset recovery (Cashman, Kelly & Nield, 2000).

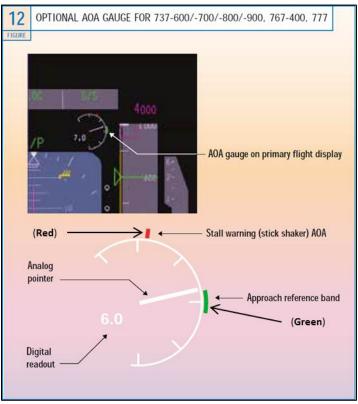


Figure 21: Boeing AoA Gauge (Cashman, Kelly, Nield, 2000)

Other aircraft manufacturers are also offering AoA indicators. Gulfstream displays AoA as a computed, normalized value ranging from 0.00 to 1.10 with 0.00 corresponding to zero lift, while 1.00 is the stick pusher activation threshold. This normalized AoA information is displayed on the primary flight display (PFD) below the airspeed tape (Figure 22). The AoA number can change color from white, during normal operations, to amber for approach to stall, and to red to indicate a stall. When used together with the airspeed tape, pilots can use these as indications of low speed and/or high AoA situations (Gulfstream, 2003).



Figure 22: Gulfstream PFD AoA Located Under Airspeed Tape (Gulfstream, 2003)

4.4 AoA on the HUD

The Rockwell Collins HGS6250 is a Head-up Guidance System that has an AoA indicator (Figure 23) for the HUD. It displays both an analog and a digital readout of AoA. It contains 6 index marks representing from -5 degrees to +20 degrees, and markers that show an approach reference band, a stick-shaker threshold and a maximum lift-over-drag reference (FedEx, 2012).

Angle-of-Attack Scale and Indicator	The Angle-of-Attack (AOA) Scale and Indicator shows on the upper right side of the Combiner display in a fixed position, and provide an analog and digital indication of the current AOA of the aircraft.
2.0	The AOA digital value shows in horizontal, small- size numbers displayed within the AOA scale.
	The AOA Scale includes 6 index marks representing -5 degrees (6 o'clock position) to +20 degrees (10 o'clock position) on the scale.
	The AOA pointer provides a graphical representation of the current AOA with respect to the AOA scale. The pointer is centered within the scale and rotates counterclockwise for an increasing AOA and clockwise for a decreasing AOA.
AOA Approach Reference Band	The AOA Approach Reference Band is an empty rectangle that rotates around the AOA Scale to indicate the desired AOA for approach.
	The Approach Reference Band is displayed when normal or engine-out landing flaps (20, 25, 30) are selected and indicates the appropriate range of approach AOA for VREF+15 knots. The ban adjusts for each flap position and is approximately 1.5 degrees wide. It is not displayed during takeoff or initial climb.
AOA Stick Shaker Trip Point	The AOA Stick Shaker Trip Point is an empty triangle that rotates around the AOA Scale to indicate the AOA in which the stick shaker will be activated. AOA Stick Shaker Trip Point appears as the AOA pointer approaches stick shaker AOA (within 3 degrees).
AOA Max L/D Symbol	The AOA Max Lift/Drag (L/D) symbol is an empty circle with reference to the AOA scale to indicate the AOA Max L/D for a given flight condition. Max L/D is only displayed with a clean wing configuration.

Figure 23: Rockwell Collins HGS6250 AoA Indicator (Fed Ex, 2012)

Another option by Rockwell Collins (Figure 24) shows the approach reference band, (which is variable in accordance with flap settings), and a stick-shaker point which indicates the point at which stick-shaker occurs. The area past the stick-shaker pointer is the "stay-out zone" and is represented by groups of hashed lines (Rockwell Collins, 2002)

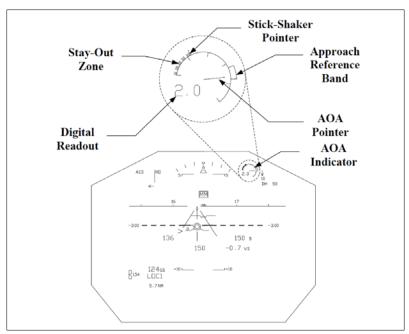


Figure 24: Rockwell Collins HGS4200 AoA Indicator (Rockwell Collins, 2002)

The styles and types of AoA indicators reviewed are diverse and varied. Most of the studies involving AoA indicators sampled only one indicator and did not compare types of indicators. In those that sampled more than one type, there was little mention by the researchers of any pilot preferences between those sampled. The following research did mention indicator type/style preferences. Tucker and Gordon (1959) stated that the Kollsman system of presenting AoA indirectly on the airspeed indicator was preferred over the Specialties, Inc. AoA indicator displaying arbitrary units. Sixty percent of the instructor pilots in the FAA report *Angle of Attack Presentation in Pilot Training* (Forrest, 1969) felt that a different presentation, other than displaying arbitrary units matched with certain maneuvers, would have been more beneficial. Another pilot preference mentioned in the literature was that AoA be displayed as a percentage of lift available (Odle, 1972). Many studies suggested designing a standardized AoA display to ease acceptance and understanding across aircraft; further studies into this were not found.

4.5 General Aviation AoA Systems

In May 2013, the FAA Fact Sheet for General Aviation Safety stated that AoA indicators are one of the technologies that have the highest possibility of significantly enhancing safety and reducing fatalities. According to the FAA, an AoA indicator gives the pilot a visual aid during critical phases of flight that helps to prevent Loss of Control. The approval of AoA indicators for GA aircraft has been streamlined by the FAA as the Administration works towards encouraging the retrofitting of the entire GA fleet (FAA, Dugette & Dorr, 2013). American Society for Testing and Materials (ASTM) International has published functional operation and minimum performance requirements for an AoA system in support of this effort (ASTM, 2013). More recently, in February 2014, the FAA released a memorandum that simplified the design and production

approval of AoA systems. Manufacturers, using the functional operation and minimum performance standards published by ASTM International, can apply for FAA approval via a letter certifying that the system meets those standards. This AoA system is a non-required/supplemental system that is to be installed and operated as a standalone/independent system. It must not interface with any certificated system (i.e., pitot static, stall warning, etc.) except to draw electrical power needed to run the AoA unit and any sensor or display unit mounting requirements. To keep policy interpretation consistent, the FAA's Chicago Aircraft Certification Office will be the only office to process the manufacturer's application of their AoA system for market (FAA, Dorr & Cory, 2014; FAA, Hempe & Seipel, 2014).

Several manufactures offer AoA systems for general aviation aircraft. Garmin offers a normalized AoA indicator (Figure 25) which uses a combination of chevrons and colors to enable the pilot to easily understand the information. The green bars on the bottom show the minimum visible AoA and build towards the calibrated AoA approach target, the small green circle. Increasing the AoA beyond the target is indicated by yellow bars and further by yellow chevrons pointing down. If the AoA increases and exceeds the critical AoA, red chevrons, pointing down, illuminate and begin to flash. There is also an audible alert that begins to beep once the first red chevron is illuminated and increases in intensity and speed until it reaches a constant tone as the top chevron illuminates and flashes, indicating a stall condition (Garmin, 2014).

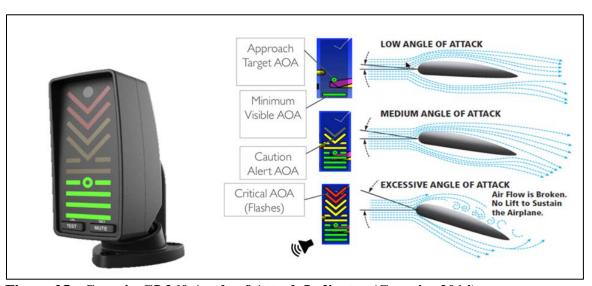


Figure 25: Garmin GI 260 Angle of Attack Indicator (Garmin, 2014)

Garmin also offers the same AoA indicator displayed on the PFD using the above color and audio features (Figure 26).

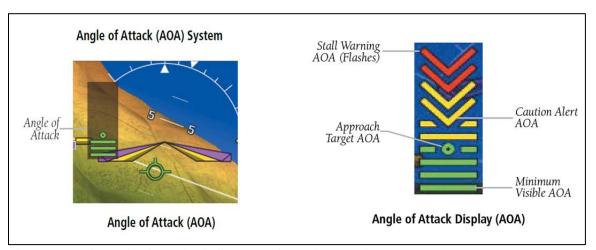


Figure 26: Garmin G3X AoA System (Garmin, 2014)

Alpha Systems has a chevron Style AoA display (Figure 27) that will display a green bar to indicate normal operations for cruise and that AoA is low, and no action is required. A blue donut lights up to indicate "Optimum Alpha Angle" which is a 30 percent margin above stall. A yellow chevron lights up indicating a relatively high AoA and the need to take action to reduce AoA. And finally, a red chevron indicates an AoA that is too high; immediate action is required to reduce the AoA and stall recovery procedures should be performed. The display also has sixteen different brightness levels and four different audio options. Each AoA display is calibrated to the aircrafts specific lift curve (Alpha Systems, 2014).

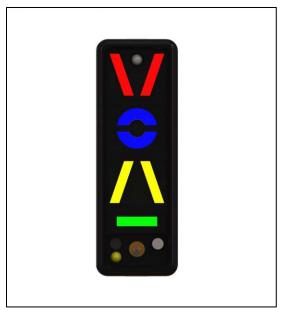


Figure 27: Alpha System AoA Griffin Chevron Display (Alpha Systems, 2014)

ICON Aircraft offers an AoA system on its A5 Light Sport Aircraft (Figure 28) that is currently in production. It is an analog display that gives graphical information about how much lift is available from the wing before it stalls. The indicator uses green, yellow, and red sectors to give a direct indication of the performance of the wing in real time (ICON, 2013).



Figure 28: ICON A5 Light Sport Aircraft AoA indicator (ICON, 2013)

These examples are just a sampling of the many different types of General Aviation AoA indicators currently on the market. This was not meant to be a complete list and peer-reviewed research was not found on any current AoA indicators on the market.

5. AoA Display Benefits

5.1 Energy State Awareness/Upset Recovery

During low speed conditions and/or upset recovery situations, presenting a visual cue of AoA information in the cockpit can allow the pilot to gather independent verification of how the wing is flying and whether the aircraft's AoA is increasing, decreasing or holding steady. This information may be useful when a pilot is disoriented and cannot trust vestibular cues or their own seat-of-the-pants intuition (Ellis, 1977; Langdon, 1969; Odle, 1972). The literature is reviewed to evaluate evidence that the display of AoA in the cockpit has been useful for energy awareness, stall awareness, and stall and upset recovery.

AC 120-09 from the FAA (2012) states that any transport category airplane must have one or more natural or synthetic indications of an approach to stall. These may include: aerodynamic buffeting (some airplanes will buffet more than others), reduced roll stability and aileron effectiveness, visual or aural cues and warnings, reduced elevator (pitch) authority, inability to maintain altitude or arrest rate of descent, and/or stick shaker activation (if installed) (FAA, 2012).

AoA information may drive one or several of these indications and the visual display of AoA may complement the stall warning systems already in place. Binary stall warning systems (i.e., stall horns, stick shakers) provide a fixed margin to stall. These systems typically do not provide information leading up to that activation, nor does it provide information between the stall warning and the aerodynamic stall. An airspeed indicator provides information across the entire range of the flight envelope, but is only accurate for stall prediction in un-accelerated flight. An AoA indicator provides information across the same flight envelope range as an airspeed indicator, but remains accurate under accelerated G loads. The AOA indicator can keep the pilot from entering into a situation where binary stall warning systems activate and can also provide information between the warning activation and actual aerodynamic stall, depending on the format and resolution of the display. An AoA indicator adds a margin of safety to low speed maneuvers by providing information about how the wing is flying and enables the pilot to keep the aircraft in the air. For example, when flying a holding pattern, an increase in AoA can be an indication of wing icing. The extra wing loading due to turns at low speed can induce a stall quickly, even on a "clean" wing (Air Safety Week, 1999).

When stall warning systems are misunderstood, as in Air France Flight 447 (Bureau d'Enquêtes et d'Analyses, 2012), an AoA indicator can be a single point of reference where the pilot can see the margin to stall and determine whether the aircraft is in a stall. An AoA indicator would have given the pilot knowledge of how the wing was flying. This knowledge can be crucial in the first few seconds of an emergency and can give vital information that assists the pilot in recovering the aircraft. In Air France 447, the accident report noted that the crew inadvertently entered an upset situation after an autopilot disconnect. The destabilization of the flight resulted in a sustained stall, which the crew never formally identified or recovered from. The instantaneous feedback of an AoA indicator can give the pilot key information quickly that can be used to assess the

flight condition and keep the aircraft in the air. This information may allow better comprehension of what is happening which can increase their situation and energy state awareness (Ellis, 1977).

While pitch attitude - the angle between the aircraft body reference and the horizon - can typically be recognized by pilots, this is not the case when pilots attempt to determine AoA. Trubshaw, as quoted in Karayanakis (1982) believes that, from the pilot's standpoint, the rate of change of AoA while approaching a stall is a significant piece of information that should be displayed. Furthermore, Hancock (1972) stated that a pilot can believe that the aircraft has recovered from a stall, based on pitch attitude, their vestibular system and/or other clues, but still be at a critical AoA which can lead to a secondary stall.

AoA information can give the pilot the ability to reliably use the aircraft's maximum climb performance, which is necessary to effectively travel through severe wind shear. However, this is rarely directly displayed in the cockpit. Therefore, in a 1983 report it was suggested that AoA indicators be installed as part of the cockpit instrumentation displayed to the pilot. These indicators are considered to be "simple instruments" that can accurately inform a pilot how best to fly their aircraft (Townsend, 1983).

The investigation of a fatal December 1995 accident of American Airlines Flight 965 in Cali, Columbia found that after the Ground Proximity Warning System sounded, the first officer repeatedly increased pitch attitude until the stick-shaker activated and then reduced pitch until the stick-shaker warning ended. The first officer may have been using the stick-shaker activation as an indication of the aircraft's maximum AoA that would enable him to gain the maximum available thrust and altitude. Without an actual AoA indicator, the pilot could not keep the pitch attitude in the stick-shaker region because he had no idea how much lift was still available or how close the aircraft was to a stall. The report showed that if he had held the AoA at stick-shaker activation steadily during his recovery, the aircraft may have cleared the first collision site (NTSB, 1996). As a result of these findings, the National Transportation Safety Board (NTSB) issued Safety Recommendation A-96-094. It reads:

TO THE FEDERAL AVIATION ADMINISTRATION (FAA): Require that all transport-category aircraft present pilots with angle-of-attack info in a visual format, and that all air carriers train their pilots to use the info to obtain maximum possible airplane climb performance. (NTSB, 1996)

This recommendation was reiterated again after a fatal December 1996 accident of an Airborne Express DC-8 in Narrows, Virginia. In this report the NTSB also states that "a display of angle of attack on the flight deck would have maintained the flightcrew's awareness of the stall condition and it would have provided direct indication of the pitch attitudes required for recovery throughout the attempted stall recovery sequence." The NTSB also believed that the accident may have been prevented if a direct indication of AoA was presented to the flightcrew (NTSB, 1997).

The FAA evaluated the NTSB's recommendation A-96-094 and found that using ground proximity warning systems would reduce the occurrence of ground proximity escape maneuvers by enabling the pilot to determine a terrain threat well before any maximum climb maneuver would be needed. The NTSB mentioned in a later response to the FAA that there were several other scenarios where AoA information would have been beneficial to the flightcrew. These included erroneous airspeed, blocked static ports, and improperly entered fuel weight. The FAA believed that these scenarios and the accidents they caused were not related to the original need for maximum climb performance, but instead could be addressed without requiring AoA indicators. The FAA further stated that pilots can reference the predetermined pitch and power settings to accomplish continued flight and landing in such incidents. The NTSB stated in 2001 that an AoA indicator is a single point of reference that gives a quick indication of the margin to stall and is more accessible than the charts providing recommended pitch and power setting for each scenario (NTSB, 2001). While the issues brought up in the discussion between the NTSB and the FAA have been addressed by incorporating terrain avoidance systems and better defined procedures and training in those systems, there is still a missing component, one that may improve all of the systems already in use, a cockpit display of AoA.

Ellis (1977), Langdon (1969) and Odle (1972) believed using AoA in low speed situations may be useful as an aid to upset recovery. The aircraft incidents described above are included as they contain recommendations that may prevent those same situations from happening again. Current studies researching the use of AoA indicators as an aid in airplane energy state awareness or upset recovery were not found.

5.2 Detect/Diagnose Air Data System Failures

An AoA indicator may be effective as an additional independent or redundant information source in the event of a pitot static system failure. AoA may be a useable indication of airspeed during recovery as both airspeed and AoA offer the same accuracy in low speed operations (Carlquist, 1960; Odle, 1972). The literature is reviewed to assess the efficacy of AoA in detection, diagnosis, or recovery in the event of air data system failures.

In 1996, both a Birgenair 757 and an AeroPeru 757 crashed due to blocked pitot systems. In these accidents, the airspeed and altitude indicators gave conflicting and erroneous readings and the pilots were without a secondary system to use as a cross check. An AoA indicator could be used to detect and diagnose air data system failures. In the event of pitot tube blockage, an AoA indicator can serve as a secondary source of information to confirm the suspected issue and prevent an inadvertent loss of control, thereby assisting the pilot in keeping the aircraft in the air. (Air Safety Week, 1999).

Following an incident involving a UPS 747-200 freighter with unreliable readings of both altitude and airspeed, due to open static port drain lines, UPS asked that their response be included in the final report of the Irish Air Accident Investigation Unit (AAIU). It is as follows:

An additional option that should be addressed is the inclusion of an Angle of Attack (AoA) presentation in the cockpit. The AoA provides immediate reference for stall protection in the event that there is a failure of both airspeed indicators. The information presented by the AoA is immediate and continuous as opposed to the task of referencing charts in manuals. It is also more accurate than using Target Pitch and Thrust Settings. Additionally, in cases where the Captain's and the First Officer's airspeed indicators do not agree, the AoA would provide a reference source to the flight crew to help determine which airspeed indicator is reading correctly (AIUU, 2000).

The AIUU's lead investigator for the case, Graham Liddy, stated that an AoA indicator is a single point of reference that is simple and easier than looking for pitch and thrust information from books and graphics during an emerging situation. Having AoA information readily accessible can keep the crews from becoming distracted and allow for a quicker diagnosis and recovery (Air Safety Week, 2004).

As part of its investigation into the Air France accident of Flight 447 on June 1, 2009, due to blocked pitot tubes, the Bureau d'Enquêtes et d'Analyses (BEA) stated that "only a direct readout of the angle of attack could enable crews to rapidly identify the aerodynamic situation of the aeroplane and take actions that may be required." (Bureau d'Enquêtes et d'Analyses, 2012) One of the many factors that are believed to be a contributing cause of this accident is the crew not identifying or reacting to the stall warning. This may be because of a combination of factors, one of which is that there was not any visual indication available to confirm the approach to stall given by the aural stall warning (Bureau d'Enquêtes et d'Analyses, 2012).

Most of the recommendations for using AoA indicators as a backup for pitot static system failure were written in response to incidents that occurred. Current research into the use of AoA as a verification for pitot static system failure was not found.

6. Training

The display of AoA as discussed in Section 2 has been shown to provide beneficial information to the flight crew. As part of the cost-benefit trade-off, the question of the training and proficiency requirements for various indicators must be considered. In this section, the literature was reviewed to identify training provided prior to the various research studies and any remarks about either provided or suggested training.

In some of the studies reviewed, little to no training was given to pilots before using the AoA indicators (Gordon & Tucker, 1959; Ellis, 1977). While there was also not any training done for the AoA portion of Svimonoff's 1958 *Air Force Integrated Fight Instrument* report, it was recommended that a training program be created to allow the Air Force to take full advantage of the new AoA system (Svimonoff, 1958).

Forrest (1969) studied the impact of presenting AoA instrumentation training during initial private pilot training. He also looked into determining when to present AoA during instruction so that it would have the biggest impact on learning. This study was carried out in the initial phases of flight instruction and ground school for student pilots. Training for both groups was identical except the experimental group's instruction contained the addition of AoA indicator instruction. Of the ten instructors, seven felt that incorporation of an AoA indicator during commercial and instrument training would improve the attainment of pilot skills enough to warrant installing an AoA indicator in general aviation aircraft. It was found that some of the student pilots in the experimental group seemed, at times, confused by the AoA indicator. The original idea that incorporating an AoA indicator into pilot training would simplify the process of learning to fly was only accomplished once the student pilot had enough knowledge to properly utilize the instrument. Once this occurred, the experimental pilot group obtained an 8.32% increase in their final check ride performance over the 20 hour check ride scores, while the control group only achieved a 1.54% increase in their performance. Some flight instructors and examiners involved in the study offered the opinion that teaching the use of an AoA indicator during instrument flight training would better utilize the full potential of the indicator. The study concluded that there was no significant difference in flying performance or apparent maneuvering skills between those students trained on the use of an AoA indicator and those trained without. This led to the recommendation that there be no further consideration given to adding AoA training at the private pilot level. There was a suggestion that a project be considered to determine the advantage of adding AoA indicator training during instrument flight training.

In Gee, Gaidsick, and Enevoldson's 1971 evaluation study, no formal training on how to use the provided AoA indicator was given. The safety pilot did direct the participating pilots to develop a technique to use for the study, but each pilot was encouraged to develop his own technique in using the information displayed.

In the 1972 military study to determine which flying maneuvers could be flown using an AoA indicator and how the information should be used during those maneuvers, the test pilots were given a thorough briefing before flight to ensure familiarity with the AoA

system (Odle, 1972). At the conclusion of the study, it was recommended that AoA training be available for instructor pilots at each base as soon as AoA equipped aircraft became available. Furthermore, it was recommended that a training film be made detailing the procedures, techniques, and uses and of an AoA indicator in the cockpit.

Boeing (Cashman, Kelly, Nield, 2000) stated that using an AoA indicator can be a way to increase understanding of the physics of flight as well as aid in a crew's situation awareness of their aircraft's wing during normal and non-normal flight conditions. While the AoA indicator is considered unambiguous, its use and reliability as a secondary backup indicator is dependent on each individual airline's training scenarios and procedures. Training should focus on emphasizing the use of an AoA indicator as a cross-check/back-up to airspeed and Mach indicators, as well as the understanding that AoA information is most useful during low speed, high AoA flight to aid in stall prevention and upset recovery. Furthermore, the green approach band on the Boeing AoA indicator can be used as a cross-check for configuration, reference speed calculation, and/or gross weight errors. However, staying within this green band during the approach phase of the flight, without taking into consideration the regulatory requirements that lead to normal variations of AoA measurement, can lead to inappropriate approach speeds.

Conclusive studies involving research into whether training on the use of an AoA indicator made a difference in its use was not found. The literature reviewed contained limited information on whether training was given or not, with little description to the type of training offered. Suggestions for training found in Cashman, et al. (2000) provide the only detailed discussion of training needs for large transport airplanes.

7. Concluding Remarks

This work collected and reviewed literature to assess the state-of-the-science with respect to the benefits of using various forms of AoA displays to aid in energy state awareness, upset recovery, and diagnosis of air data system failure. Different styles and types of AoA indicators and displays were discussed with descriptions of each.

AoA indicators have been shown to give pilots more accurate control and knowledge of the aircraft's performance and aerodynamics, which is especially useful as the aircraft approaches a stall. In addition, some studies have shown that AoA indicators are effective in reducing pilot workload. The most beneficial use of an AoA display may be as an aid in upset prevention/recovery situations and the detection of pitot or static system failures. However, definitive works quantifying these benefits were not found. The literature did show that AoA can be a beneficial display and may be used in the following phases of flight: take-off, climb, turning, maximizing cruise, descent, final approach, low speed maneuvers, maneuvers to flare, landing, as well as high g turns, approach to stall, and identifying and recovering from stalls at low and high altitudes. However, definitive works that determine the requirements for an AoA display were not found.

Training was offered in some studies, while others allowed the subject pilots to attain their own techniques for the use of AoA indicators in flight. Definitive works to determine the requirements for training for and with AoA information were not identified in this review. This work concludes with the recommendation that two lines of research be pursued for further investigation of appropriate AoA indicator design and training.

8. Recommendations

Based on the literature review, the benefits of an AoA display have been touted - that is, it can provide a direct indication of the airflow angle relative to the wing, which can be especially beneficial for stall margin awareness, and it may also be useful in detecting air data failures. However, most of the literature concerning the benefits in these areas is conjecture based on the information available from an AoA display and how it may be used by a pilot/crew.

Further, the lack of AoA research since about the late 1970s warrants further studies. In particular, two lines of research are recommended:

- Current research into the display of AoA is needed. Research should be conducted into how to best display AoA and when it should be used during commercial transport aircraft operations. The effectiveness of AoA, or any parameter for that matter, is significantly influenced by where and how the information is presented and how it can be integrated and used in the intended operation.
- Very little data was found on how pilots should be trained to use AoA and how a
 training program can best transfer its utility and benefits to the users. Future
 research must also consider the extent of training and training methods for
 dedicated AoA indicators.

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14. ABSTRACT

The National Aeronautics and Space Administration (NASA) conducted a literature review to determine the potential benefits of a display of angle-of-attack (AoA) on the flight deck of commercial transport that may aid a pilot in energy state awareness, upset recovery, and/or diagnosis of air data system failure. This literature review encompassed an exhaustive list of references available and includes studies on the benefits of displaying AoA information during all phases of flight. It also contains information and descriptions about various AoA indicators such as dial, vertical and horizontal types as well as AoA displays on the primary flight display and the head up display. Any training given on the use of an AoA indicator during the research studies or experiments is also included for review.

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16. Abstract

Throughout history, although piloting an aircraft has remained essentially the same, the information that the pilot must interpret and the interface through which control must be accomplished have changed dramatically. Examples including autopilots, flight directors, glass cockpits, and Flight Management Systems, to name a few, have necessitated that pilots interface with their aircraft in a way that was not foreseen when flight was first accomplished. Despite all these technology advancements, many of which are designed to help with aircraft control, a loss of control due to stall/spin encounters continues to be a primary cause of fatal accidents in both general and commercial aviation. The use of an angle of attack (AOA) indicator was assessed during this project to determine if the stability of the approach was impacted by varying levels of exposure to an AOA display, and education on the concepts of AOA and the mechanisms by which the display for this study illustrate the AOA during various phases of flight. Four groups participated in the study from three different universities, with three different aircraft flown. One group received education on the use of the AOA display and was granted access to the display during the data-collection phase. One group was only provided education on the use of the AOA display but was allowed access to the display during data collection. Another group neither received education nor was allowed access to the display during data collection.

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TABLE OF CONTENTS

			Page
EXE	CUTIV	E SUMMARY	X
1.	INTE	RODUCTION	1
2.	MET	THODOLGY AND EXPERIMENTAL DESIGN	2
	2.1 2.2	1 3	
		2.2.1 Research Questions	5
	2.3	Experiment Approach and Procedures	5
		 2.3.1 Condition A—Group 1 2.3.2 Condition B—Group 2 2.3.3 Condition C—Group 3 2.3.4 Condition D—Group 4 2.3.5 Pilot Participant Requirements 2.3.6 Flight Scenario 2.3.7 AOA Equipment Configuration and Installation 2.3.8 Flight Parameter Data Collection 2.3.9 Flight Instructor/Safety Pilot Training 2.3.10 Pre-Experiment Dry Run 2.3.11 Experiment 2.3.12 Definition of Stabilized Approach 	6 7 7 7 8 9 12 13 13 14
3.	EXP	ERIMENT PROCEDURE	18
	3.1 3.2 3.3 3.4	Research Participant Consent Form Pre-Experiment Questionnaire Pre-Experiment Briefing Post-Experiment Questionnaires	18 19 19 19
4.	EXP	ERIMENTAL RESULTS	20
	4.1 4.2 4.3	Pilot Characteristics Observers' Assessment of Pilot Pilot's Self-Assessment	20 21 21
		4.3.1 Pre-Test 4.3.2 Post-Test	21 22
	4.4	Effects of AOA display on Pilot Procedures	23

		4.4.1	Pilot Use of AOA Display	24		
		4.4.2	Pilot Flight-Control Actions, Based on AOA	24		
	4.5		Results from Analysis of Best Practices and Development of Education Materials			
	4.6	Attitud	de Awareness Enhancement	25		
	4.7	Stabili	ized Approach Analysis	25		
		4.7.1	Tailwind Considerations	42		
		4.7.2	Conclusions for Experimental Hypothesis	44		
		4.7.3	Conclusions for Research Questions	45		
	4.8	Cost/E	Benefit/Risks Assessment	49		
		4.8.1	Cost Summary	49		
		4.8.2	Benefit Summary	50		
5.	RECO	MMEN	NDATIONS FOR FUTURE EXPERIMENTS	51		
6.	REFE	RENCE	ES	52		
APPE	NDICE	S				
	A—SI	MALL	AIRCRAFT DIRECTORATE LETTER			
		HECKL				
			LIBRATION PROCEDURE			
	D—IR	B CON	ISENT FORMS			
	E—PI	LOT Q	UESTIONNAIRES			
	F—OS	SU SAF	ETY PILOT REFERENCE GUIDE			
			OURE FOR FPA ANALYSIS			
			RGANIZATION			
			ELEVATIONS AND LAYOUTS			
			ECORDER ASSESSMENT			
			VICE DIAGRAMS			
	L—Al	TRUA	CH ANALYSIS FACTORS, RESULTANTS, AND CODES			

LIST OF FIGURES

Figure		Page
1	Alpha Systems AOA displays	2
2	AOA display	10
3	AOA display installed in Piper Arrow and Warrior aircraft	10
4	AOA probe on Piper Arrow aircraft	11
5	FPA analysis	17
6	Participant flight-hour experience	21
7	Post-test question	22
8	Plot of the residuals for all universities	26
9	University A plot of the residuals	28
10	University B plot of the residuals	28
11	University C plot of the residuals	29
12	Overhead image of approaches at KMLB	42
13	Measurements of overshoot beyond extended runway centerline	43
14	Overhead image of approaches at KCFJ	44
15	Two-bar VASI system (AIM, 2014)	48
16	PAPI (AIM, 2014)	49

LIST OF TABLES

Table		Page
1	Experimental design matrix	3
2	Smart Box recorded parameters	13
3	Composition of approaches analyzed for all groups	20
4	Tests of fixed effects	27
5	Breakdown of approaches analyzed for three universities	27
6	University A simplest model	29
7	University B simplest model	29
8	University C simplest model	29
9	University A fixed-effects model	30
10	University B fixed-effects model	30
11	University C fixed-effects model	30
12	University C fixed-effects model	31
13	University A—Final model	32
14	University B—Final model	32
15	University C—Final model	32
16	Breakdown of approaches analyzed in power-on an power-off conditions for AOA display	33
17	University A—EvalGRP comparisons for power on	34
18	University A—EvalGRP comparisons for power off	35
19	University A—Estimates and contrast for power off	35
20	University B—EvalGRP comparisons for power on	36
21	University B—Estimates and contrast for power on	37
22	University B—EvalGRP comparisons for power off	37
23	University B—Estimates and contrast for power off	38
24	University C—EvalGRP comparisons for power on	38
25	University C—EvalGRP comparisons for power off	39
26	University C—Estimates and contrast for power off	39
27	University C—Approaches analyzed for VASI condition	40
28	University C—EvalGRP comparisons for VASI	40
29	University C—EvalGRP comparisons for no VASI	41

30	University C—Estimates and contrast for no VASI	41
31	Estimated cost for a typical AOA in GA aircraft	50

LIST OF ACRONYMS

AIM Aeronautical Information Manual

AOA Angle of attack

AOPA Aircraft Owners and Pilots Association

CAA Critical angle of attack
CFI Certified Flight Instructor
EvalGRP Evaluation Group (1-4)
FDR Flight data recorder

FIT Florida Institute of Technology FOQA Flight Operational Quality Assurance

FPA Flight path angle

FSF Flight Safety Foundation

GA General aviation

GA-JSC General Aviation Joint Steering Committee

IRB Institutional Review Board

LED Light-emitting diode

LOC-WG Loss of Control Working Group

NOTAM Notice to airmen

PAPI Precision approach path indicator

PEGASAS Partnership to Enhance General Aviation Safety, Accessibility and Sustainability

SAT Safety Analysis Team SME Subject-matter expert

SumFPA Sum of the flight path angle variation

TDZE Touchdown zone elevation
VASI Visual approach slope indicator

Vspeed Definitions

V_{S0}: Stall speed in landing configuration

This is the stalling speed of an aircraft when flaps and gear are extended and the aircraft is configured for landing.

V_{S1} (V_{STALL}): Stall speed in normal configuration

This is the stalling speed of an aircraft when it is configured for cruise flight—flaps and gear are retracted.

V_A: Maneuvering speed

An aircraft flying at or below maneuvering speed will stall before it exceeds its maximum load factor and its structure is damaged. Maneuvering speed is the maximum speed at which abrupt control inputs may be applied without the risk of structural damage.

EXECUTIVE SUMMARY

The ultimate aim of this research project is to determine if the use of an angle of attack (AOA) display can provide a pilot with additional information necessary to increase the stability of an approach. This research project centered around four core aspects as outlined below:

1. Analysis of Best Practices and Development of Educational Materials

This research analyzed current best practices provided by AOA display manufacturers, groups, and individuals that advocate the use of AOA displays. A comprehensive analysis of the devices available for installation, the ease of operation, the information provided, and the mechanism with which this information can be used to understand the flight dynamics of the given aircraft in operation would be a logical next step.

2. Attitude-Awareness Enhancement

With the introduction of AOA displays, it has become possible to incorporate the relationship between the current AOA and the desired phase of flight. As such, the potential for a more precise approach path during the approach and landing phase has been suggested.

3. Stabilized Approach Analysis

Whereas the primary objective of an AOA display is to provide an understanding of the current AOA and its proximity to the critical AOA to prevent unintentional aerodynamic stalls, other benefits and additional insights can potentially be provided to the pilot. The primary objective of this study will be to conduct a comparative analysis of a pilot's ability to conduct a stabilized approach both with and without AOA displays.

4. Cost/Benefit/Risks

The benefits associated with AOA displays (e.g., the necessary cost for acquisition, installation, and training) and the mitigation of associated risks will all need to be clearly identified, addressed, and communicated in a clear and consistent manner to the general aviation (GA) flying community.

Participants were recruited from both the local GA population and the flight schools of the three participating universities. A predominant number of participants were from the flight schools and therefore have experience within a highly structured curriculum and a consistent and stable degree of proficiency. The requirements for the pilots were that they must have their private pilot certificate, 50–200 total flight hours, and did not possess commercial or instructor certificates.

Once selected, participants were randomly placed in one of four groups as follows:

- Group 1 received training and had access to the AOA display.
- Group 2 received training but did not have access to the AOA display.
- Group 3 did not receive training but had access to the AOA display.
- Group 4 did not receive training and did not have access to the AOA display.

Stabilized Approach

Within the GA environment, the targeted outcome of a given approach is determined by the individual pilot and can vary depending on the landing airport, aircraft used, environment, and other factors. For this reason, the approach stability within this project was measured by the variability of the flight path angle at each second for the last 30 seconds of each approach and was added together to arrive at a sum of the flight path angle variation (SumFPA) that was then compared among the various groups.

For instances in which the approach for landing was conducted under traditionally normal circumstances for the participants, the use of the AOA system did not significantly impact the stability of the approach for any of the experimental or control groups.

Differences in the SumFPA were discovered for instances in which the AOA system could replace information that is normally present but was absent for a given approach. These include a lack of a visual guidance system at the landing airport and unfamiliarity with the aircraft being used. It was discovered that there were differences among the groups, and the more AOA information the pilot had received (in both education and AOA access), the more stable the approach.

During instances in which a simulated engine-out approach was conducted, it was anticipated that the AOA system could be used as a tool for approach stability for the participants. However, it was determined that participants for two universities did not have differences in the stability of the approach in a simulated engine-failure situation; one university showed that participants not trained on the use of the AOA system but allowed to utilize the AOA display performed less-stable approaches than the other groups. This result was not anticipated, but the highly structured programs within the collegiate environment and the level of proficiency present in practicing emergency and abnormal situations might be a contributing factor because the participants were experienced in the scenarios that were presented and might have relied on their previous experience to conduct as stable an approach as possible.

In summary, there were three notable instances for which there was a difference in approach stability among the groups:

- Results from one university showed that participants who were allowed access to the AOA display flew more stable approaches when power was allowed to be controlled by the pilot (as opposed to the "simulated engine failure" power-off landing).
 - Two universities did not show any statistical difference in approach stability, whether power was on or off, when comparing approaches with access to an AOA display versus ones that did not have access to an AOA device. However, participants at one university revealed a statistically significant result when power-on approaches with AOA access were compared to those without access to the AOA display.
- Results from one university showed that participants who had both received education
 and were allowed access to the AOA display flew more stable approaches when a visualapproach system was not available for use.

- When looking at the differences in group performance, Group 1 performed better than the rest of the groups. Group 4 performed better than Groups 2 and 3. A conclusion can be drawn that with both AOA education and access to AOA displays, approaches are more stable. For instances in which either just AOA access or just AOA education are provided and a pilot is attempting an approach without visual guidance, the approaches are more stable when the pilot has not been influenced by an AOA device. This indicates that proper education and proper usage are important to the stability of an approach when conducted to runways without visual guidance information.
- Results from one university showed that participants who did not receive education but were allowed access to the AOA display flew approaches that were less stable than the other participants during approaches in which engine power was placed at idle in the traffic pattern abeam to the touchdown point.
 - Group 3 at one university had the most variation in the SumFPA during power-off approaches. Group 3 did not receive any training on the AOA display indications and had the potential for the display to be a distracter in the completion of the power-off landing, which could explain why their performance was the most unstable.

Because of the nature of conducting research studies in real-world environments where not all of the variables are directly controllable by the researchers, it is possible that there are hidden factors present that cannot be sorted out within the scope of this study. This situation is potentially present because the results were not consistent across all the universities. Factors such as weather and other environmental conditions, pilot capabilities, pilot proficiency (overall and aircraft-specific), pilot currency, mental workload, and airport familiarity will need to be evaluated further to understand the entirety of the potential benefits of an AOA device as a mitigation strategy for loss of control accidents. To determine the impact of these factors, additional data would need to be collected to determine the exact circumstances in which AOA education and displays could have the maximum impact.

There are subject matter experts in the aviation industry who promote the use of AOA as a mitigation strategy for the reduction of loss of control accidents during the landing phase of flight. The qualitative feedback that was received from the participants and the statistical results that were obtained indicate there is merit in the promotion of the use of AOA displays. At this time, there is insufficient information to draw conclusions as to exactly who would benefit most from the usage of AOA devices and the exact circumstances under which this mitigation strategy would be the most effective. Additional research is required to identify those characteristics, and one of the study universities is including AOA exposure for their flight students in their training curriculum for single-engine commercial candidates.

1. INTRODUCTION

The General Aviation Joint Steering Committee (GA-JSC) is a joint FAA and aviation industry group established with the goal of improving safety in general aviation (GA). The GA-JSC's technical arm, the Safety Analysis Team (SAT), identifies safety issues and develops mitigation solutions and strategies for the GA-JSC to implement in GA. In April 2011, the GA-JSC chartered the SAT to conduct a review of fatal GA accidents from 2001 through 2010. The SAT reviewed 2472 fatal GA accidents based on Commercial Aviation Safety Team/International Civil Aviation Organization Common Taxonomy Team categories and identified Loss of Control—In-flight accidents as the most prevalent accident type with 1259 fatal. Industry and government have agreed to propose a data-driven approach to identifying high-priority safety initiatives for GA and jointly agreed to work toward the mitigation of accident causes. The Loss of Control Working Group (LOC-WG) was formed by the FAA and GA industry to review GA accidents related to LOC and to recommend safety enhancements. Some of the safety enhancements recommended by the LOC-WG pertain to the usage of angle of attack (AOA) systems in GA aircraft.

The AOA is the angle formed by the chord¹ of the airfoil and the flight path of an aircraft. As the AOA increases, so does lift up to a point referred to as the critical angle of attack (CAA). Beyond this angle, there is a subsequent loss of lift and the airfoil is now considered to be stalled. As a mitigation strategy, it has been proposed that the use of an AOA indicator in an aircraft will keep the pilot informed of the AOA related to the aircraft performance and margin from the CAA. This would allow the pilot to reduce the risk of an inadvertent stall resulting in a loss of control. It is important to note that although this technology is readily available, AOA systems are not required equipment and are not widely used in the GA community. There has been evaluative work concerning the awareness of AOA and potential stall conditions by groups such as the American Bonanza Society, Aircraft Owners and Pilots Association (AOPA), The Boeing Company, and others when utilizing AOA displays for AOA awareness. Pilots that have adopted AOA displays verbalize the benefit to be gained in understanding the complete picture that is presented when AOA displays are utilized as a crosschecking tool with airspeed indicators and attitude indicators. Aviation practitioners have reported the ease with which pilots can intuitively understand the AOA of the aircraft during a given phase of flight and understand the proximity to the stalling angle during critical situations, such as takeoff and landing. AOA displays also assist in the approach phase by compensating for factors that sole references to airspeed cannot.

Whereas the objective of an AOA display is to provide input to the pilots as a crosscheck mechanism for standard instrumentation like any other flight deck instrument, its proximity to the primary instrument scan and primary field of view, and therefore the ease of interpretation, could play a factor in the utilization of this information. Although there are numerous choices from manufacturers as to the basic design and functionality of AOA indicators, the displays in figure 1 (from Alpha Systems AOA) are representative of the majority seen in the market place. This type of instrumentation is available as an add-on technology with relatively little maintenance intervention. In a letter published by the Small Aircraft Directorate (Appendix A), AOA systems such as the one displayed in figure 1 are considered a minor alteration to the aircraft for installation. Because of the cost of adding equipment using a FAA Form 337 or a Supplemental Type

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¹ The chord of an airfoil is an imaginary line drawn between the leading edge of an airfoil to the trailing edge of that same airfoil.

Certificate, this would be an important consideration for aircraft owners considering the purchase of non-required additional flight instrumentation, affecting not only the decision to purchase but also from which manufacturer.







Figure 1. Alpha Systems AOA displays

However, the method of interpretation and analysis, especially as a crosscheck mechanism for instrumentation displays, may vary substantially, depending on the aircraft avionics suite and the AOA display that is installed.

In collaboration with pilot advocacy and industry groups, such as AOPA, the Experimental Aircraft Association, and the General Aviation Manufacturers Association, this research will study the possible benefits and incentives for the installation and usage of AOA systems in the GA environment, specifically focused on their applicability towards a stabilized approach.

2. METHODOLGY AND EXPERIMENTAL DESIGN

Participants were recruited from both the local GA population and the flight schools of the three participating universities. Many participants were from the flight schools and had experience within a highly structured curriculum and a consistent and stable degree of proficiency. Additionally, participants were recruited from the GA population at each university; most of those recruited were flight students taking part in the professional aviation programs at Purdue University, Ohio State University, and The Florida Institute of Technology (FIT). The requirements for the pilots were that they must have their private pilot certificates, have 50–200 total flight hours, and have no commercial certificates or instructor certificates. The reason for the 200-hour maximum was the theory that a student enrolled in the professional pilot program in the university would no longer be representative of the GA population after that amount of training in the program.

Once selected, participants were randomly placed in one of four groups, one of which was a control group. The three experimental groups were designed to analyze any potential comparative differences. The control group served the purpose of a baseline comparison and, as such, did not receive any guidance or have access to AOA displays during visual approaches.

The first of the three experimental groups received guidance on the usage of AOA displays and were encouraged to use the AOA displays while executing the visual approaches.

The second group received specific guidance on the usage of AOA displays but was prohibited from using the displays during the approach conditions. This group will help to establish whether it is the combination of educational materials and the technology that establishes any distinguishable differences between the groups versus the AOA technology alone. The third group did not receive any specific guidance on the usage of AOA displays but was not prohibited from using the displays during the approach conditions.

The design matrix for the stabilized approach comparative analysis was a 2x2 design, as shown in table 1. This design allowed the researchers to determine the degree to which each of the treatments played a role in the accuracy of the approach segment for each condition. In summary, four test conditions were created to which participants were randomly assigned for participation.

- Group 1 received training and had access to the AOA display.
- Group 2 received training but did not have access to the AOA display.
- Group 3 did not receive training but had access to the AOA display.
- Group 4 did not receive training and did not have access to the AOA display.

		Education		
		None	AOA Ground Instruction	
splays	No Access	30 Participants	30 Participants	
AOA Displays	AOA Display Access	30 Participants	30 Participants	

Table 1. Experimental design matrix

When considering the need to generalize the findings of the comparative analysis, the researchers conducted the analysis using a single AOA display in a variety of aircraft types and avionics platforms. The aircraft used were a Cirrus SR-20 with a Garmin G1000® Perspective avionics platform, a Piper Warrior with an Avidyne avionics platform, and a Piper Arrow with an Avidyne avionics platform and retractable landing gear, which added a degree of complexity to the landing approach.

2.1 EXPERIMENTAL OBJECTIVES

The ultimate aim of this research is to provide pilots and instructors with information that could give additional assistance to interpret the flight path and aircraft attitude relationship. This focus will be accomplished by the advancement of the following outcomes:

1. Analysis of Best Practices and Development of Educational Materials

With the wide variety of AOA indicators available, there is a vast amount of subjective opinions that could wrongly influence operators who seek to enhance the pilot's understanding of current flight attitude. This research analyzed current best practices that are provided by AOA display manufacturers, and groups and individuals who advocate the use of AOA displays. A comprehensive analysis of the AOA devices available for installation, including the ease of operation, the information provided, and the mechanism with which this information can be used to understand the flight dynamics of the given aircraft in operation, will be conducted.

2. Attitude Awareness Enhancement

During flight training, pilots are generally required to demonstrate knowledge, recognition, and recovery from stalled situations and knowledge of spin entry, spins, and spin-recovery techniques. Following demonstration of this ability, there is no requirement for pilots to incorporate AOA concepts into what would be considered "normal" flying. With the introduction of AOA displays, it has become possible to incorporate the relationship between the current AOA and the desired phase of flight. As such, the potential for a more precise approach path during the approach and landing phase has been suggested.

3. Stabilized Approach Analysis

Whereas the primary objective of an AOA display is to provide an understanding of the current AOA and its proximity to the critical AOA to prevent unintentional aerodynamic stalls, there are potentially other benefits and additional insights that can be provided to the pilot. For example, the AOA can be used to execute more precise flight during phases such as approach and landing. A primary objective of this study will be to conduct a comparative analysis for pilots to conduct a stabilized approach both with and without AOA displays.

4. Cost/Benefit/Risks

The challenges, both financial and otherwise, for aircraft owners and fleet operators alike are of concern in the decision-making process for continued safety improvements. Upgrading avionics platforms, standalone tablet and hand-held devices, and advanced training all compete for the scarce financial and time resources available. The benefits associated with AOA displays; the necessary cost for acquisition, installation, and training; and the mitigation of associated risks will all need to be clearly identified, addressed, and communicated in a clear and consistent manner to the GA flying community.

2.2 HYPOTHESES

Hypothesis 1—Training related to AOA, the use and operation of an AOA system, and the use of the AOA system in flight will allow GA pilots to conduct a more stable approach to landing.

Hypothesis 2—Training related to AOA and the use and operation of an AOA system will allow GA pilots to conduct a more stable approach to landing, even without the use of an AOA system in flight.

Hypothesis 3—The use of an AOA system in flight will allow GA pilots to conduct a more stable approach to landing, even without training on the use of an AOA system.

2.2.1 Research Questions

Research Question 1: Of the groups evaluated, which pilots had a more stable approach?

Research Question 2: What difference does it make on approach stability whether AOA training occurs?

Research Question 3: What difference does it make on approach stability whether AOA is visible?

Research Question 4: What difference does it make on approach stability between the different aircraft?

Research Question 5: What difference does it make on approach stability during "normal" versus "engine-off" approaches?

Research Question 6: What difference does it make if visual guidance (visual approach slope indicator [VASI] or precision approach path indicator [PAPI]) is available for each of the groups?

2.3 EXPERIMENT APPROACH AND PROCEDURES

Because of practical, legal, and procedural concerns, it was important to have the study participants fly with a trained observer who was also credentialed as a Certified Flight Instructor (CFI). To fill this requirement safety pilots from the flight instructor staff at each university were recruited. They were trained in the objectives of the experiment, how to provide the participant consent forms to the participants, provided the ground training to those participants that were selected for the ground training, and completed the training and evaluation flights.

All participants for the study were recruited from the student and local GA populations in the area of each three universities. Participants were then randomly assigned to one of the four different condition groups. The participants and safety pilots were contacted by the researchers so that they could schedule their study participation.

After scheduling was complete, the safety pilots provided the participant consent forms, pre-flight surveys, and training (if appropriate for the participant).

The training for the participants who obtained ground and flight training was based on viewing a video developed and created by the research team and peer reviewed by Rich Stowell, a Master Flight Instructor. Mr. Stowell is well known in the aviation industry for training in unusual attitude and upset recovery. Changes to the training video suggested by Mr. Stowell were incorporated before the final training video was released for use.

The participants randomized into groups requiring training started their experience by watching the educational video before commencing flight training. This training flight included various

maneuvers and the normal stall sequence of approach to landing, takeoff, departure, and accelerated stalls to observe the operation of the AOA display. Additionally, the training flight also included landings and takeoffs at three separate airports—two outlying airports, and the primary airport used by each university for training. The participants performed two takeoffs and landings at each airport. It was decided that the outlying airports should be included to provide participants with some unfamiliar air traffic pattern and landmarks.

Regardless of their assigned groups, there was an evaluation flight for all participants that did or did not allow the use of the AOA display, depending on the condition group for which they were assigned. (See table 1 in section 2.) The evaluation flight was designed to include a takeoff from the primary airport, flight to a satellite airport for two landings and takeoffs, then a flight to a second satellite airport for two landings and takeoffs—where the second landing would be a power-off landing—then back to the primary airport for two landings.

After the evaluation flight, the participants completed a post-flight survey, which can be found in Appendix E.

During the experiment, for both the training and evaluation flights and to ensure both consistency and completed items were accomplished within the instructor group, the safety pilots had checklists to guide them on the specifics of the participants' assigned groups. Additionally, the safety pilot had an evaluation form to fill out for both the training and evaluation flights. The guidance material, checklists, and evaluation forms are included in appendices B and F.

2.3.1 Condition A—Group 1

During condition A, the participants were trained on the use of AOA displays and had access to AOA displays during approach and landing demonstrations.

Condition A provided a participant grouping that allowed both experimental conditions to be applied. In this scenario, designated as Group 1, pilots were given ground training on the use of the AOA display by watching a video prepared by the research team. In addition, participants in Group 1 also received in-flight training on the use of the AOA device from the instructor/safety pilot administering the AOA research encounter. Following completion of the training, participants were evaluated during a second flight in which they had access to the AOA device. This evaluation flight consisted of no instruction, but only observation by the flight instructor/safety pilot during the six approaches to landing. The safety pilot noted basic qualitative data about the flight while the flight data recorder (FDR) saved specific flight parameters for further analysis.

2.3.2 Condition B—Group 2

During condition B, the participants were trained on the use of AOA displays but did not have access to AOA displays during approach and landing demonstrations.

Condition B is one of two conditions that only had partial experimental treatment applied. Similar to condition A, this grouping, also known as Group 2, had a training flight and an evaluation flight. As with Group 1, pilot participants watched the AOA training video and completed the training flight that consisted of instructional use on the AOA device in an identical manner as Group 1. However, during the evaluation flight, the AOA device remained off and the participant had no

access to AOA information, whereas the flight instructor/safety pilot served as a safety pilot to record observational information about the flight as the FDR saved specific flight parameters for further analysis. The condition-B design evaluated educational transfer of the AOA training. The research team's primary focus for this group was to determine the effect AOA training had on pilots when they were tasked with going back to flying without access to the AOA display.

2.3.3 Condition C—Group 3

During condition C, the participants were not trained on the use of AOA displays but did have access to AOA displays during approach and landing demonstrations.

Condition C, labeled as Group 3, also applied a partial experimental treatment design. Participants in this group did not receive any AOA training but performed a single evaluation flight with access to the AOA display. Like all four conditions, pilots completed the six approaches to landing while undergoing evaluation from the flight instructor/safety pilot as the FDR saved specific flight parameters for further analysis. The safety pilots were not permitted to give any guidance to the participant on the use of the AOA indicator. Researchers designed this group to simulate a pilot who either rents or flies an aircraft with an AOA device or purchases an AOA device for a personal aircraft but does not receive any specific training regarding operation of the device before using it during flight. From an experimental standpoint, this group helps to establish whether AOA training combined with access to the AOA device produces results that differ from use of the AOA by itself.

2.3.4 Condition D—Group 4

During condition D, the participants were not trained on the use of AOA displays and did not have access to AOA displays during approach and landing demonstrations.

Condition D, labeled as Group 4, served as the control group for the experimental design. During this condition, pilots did not have access to the AOA display nor were participants given instruction or education on the use of the AOA device. Researchers conducted a single evaluation flight consisting of the required six approaches to landing while the AOA device remained off, simulating how the aircraft would normally be flown without any AOA device installed. During the evaluation flight, quantitative flight data from the FDR and qualitative comments were recorded by the safety pilot for comparison against the other experimental groups.

2.3.5 Pilot Participant Requirements

For this project, the research team required that participant pilots hold only a private pilot certificate and have 50–200 hours of total flight experience to be eligible for recruitment into the study. An instrument rating was not considered for the purpose of recruiting participants. The reason for the 200-hour maximum was the theory that a student enrolled in the professional pilot program in the university would no longer be representative of the GA population after that amount of training.

The study design had a fairly narrow window of allowable flight time, which was designed to simulate the typical experience of the private pilot. Because many pilots recruited to the study fly on a regular basis, it was noted that those pilots were close to the maximum allowable flight hours

and, as such, were scheduled as soon as possible. However, despite these efforts, participant attrition was expected because some pilots might gain more than 200 hours of flight time or a commercial pilot certificate between the moment of recruitment and the actual first flight as part of the experiment. It was also conceivable that for pilots assigned to an approach group with two flights, one or both of the recruitment parameters may be exceeded between the training flight and the evaluation flight. To keep participant attrition as low as possible, those pilots who had less than 200 hours during recruitment were allowed to continue as participants in the project. Pilots who earned commercial certificates before the first flight were not allowed to participate, but if the commercial certificate was earned between the first and second flight, the pilots were allowed to complete participation in the study. Because of the short duration of the data-collection portion of the study, researchers surmised that, although pilots may have exceeded the recruitment criteria before the first flight or between flights, their overall abilities as pilots would not change in a brief period of time and were judged to be acceptable.

Whereas pilots ranging from low-time new student pilots to Air Transport Pilots with several thousand hours of flight time were available to participate, the researchers determined that the study needed to focus on a select group of GA pilots with similar experience and certification to provide both a better representational cohort and a proper statistical analysis. Additionally, allowing a wider range of participant experience would have forced a high number of approaches to be evaluated, thereby exceeding both the budgetary and time limitations.

2.3.6 Flight Scenario

There are three flights to describe for the experiment—one is a training flight for those participants who obtain ground and flight training; another is for those participants who have access to the AOA display; and another is for those participants who do not have access to the AOA display.

The participants who were provided ground and flight training were given a training flight that provided information about the display and how it responds to varying phases of flight. The safety pilots had the participant take off from the primary airport and perform a slow flight and a stall sequence that includes an approach to landing stall, a takeoff and departure stall, and an accelerated stall. The participant then conducted two landings and takeoffs at the first of two outlier airports. After completion, the participant flew to a second outlier airport and performed two landings and takeoffs. Finally, the participant flew to the primary airport and performed two landings at that location before commencing a full stop, thereby ending the flight portion of the research.

There are two types of evaluation flights, one where the participant had access to the AOA display and one where they did not. Other than the display access, the flight procedures were the same and are described below.

The evaluation flights are very similar to the training flights, but do not include the slow flight and stall sequence because they were only exposed to those maneuvers to better understand AOA functionality. The participant flew to the first outlier airport, performed two landings and takeoffs, then proceeded to the second outlier airport and performed two landings and takeoffs. During the second landing, the safety pilot pulled the power to idle, and the participant performed a landing with engine power at idle. If the landing resulted in a go-around instead of a landing, the participant performed a second landing, after which the participant flew to the primary airport and performed

two landings, followed by a full stop. Airport diagrams for airports that were used during the study can be found in Appendix I.

2.3.7 AOA Equipment Configuration and Installation

There are several manufacturers of AOA equipment that could have been used for this experiment. Unfortunately, at the time of equipment purchase, the only manufacturer that had a letter allowing installation without a lengthy Supplemental Type Certificate or other FAA approval paperwork was Alpha Systems. Most manufacturers of off-the-shelf AOA displays now have the letter from the FAA Small Airplane Directorate that allows installation as a minor alteration if the manufacturer's installation instructions are followed. See Appendix A for an example of the approval letter.

Alpha Systems provides an installation and operator's manual for the Alpha Systems AOA system. The version of the Alpha Systems equipment chosen for this experiment was their legacy system and is described below. Although Alpha Systems manufactures and sells various types of display formats, this one was chosen because it almost exclusively represents the type of unit sold to the GA community. (Since the purchase of the equipment used for the experiment, Alpha Systems has redesigned the displays used in their system. The researchers determined that changing the display in the middle of the experiment would insert undue complexity in the research and could affect the results.)

Alpha Systems' AOA Legacy chevron-styled, light-emitting diode (LED) driven AOA system is 2.5 inches long by .860 inch wide by 1.250 inches deep and weighs .300 lb with the electronic cable. Other components considered part of the design include an interface module, tubing, an external probe, and an associated mounting plate. The display can be mounted anywhere in the cockpit and comes with angle brackets when needed for instrument panel mounting. Other optional mounting kits are available for glare shield mounting, vertical dash mounting, or vertical swivel flush mounting for the aircraft that has a sloping glare shield, allowing positioning of the display so that it can be seen in the pilot's peripheral vision. The AOA display is mounted in the top middle of the instrument panel on the Cirrus SR-20 aircraft and on the top of the glare shield to the left on the Piper Arrow and Piper Warrior aircraft.

Figure 2 shows the center two LEDs on the display as green. When the current installation took place, the system was sold using a green LED for the center LEDs and blue for the bottom or cruise indicator. The systems are currently sold reversing the colors on the display. This change was at the request of the FAA to standardize the color schemes for AOA systems.

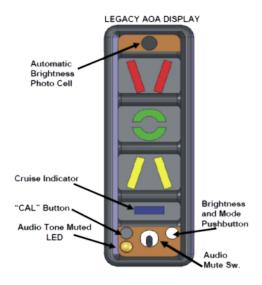


Figure 2. AOA display

Figure 3 shows the installation of the AOA display in the Piper Arrow and Warrior aircraft.

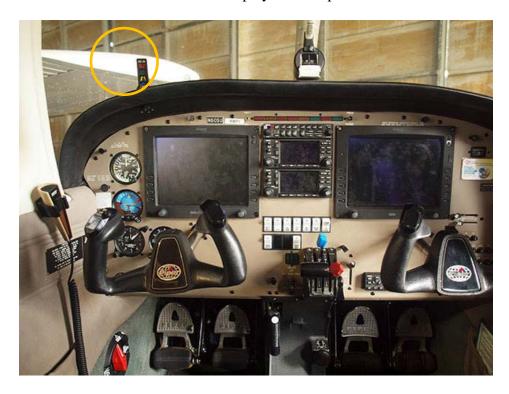


Figure 3. AOA display installed in Piper Arrow and Warrior aircraft

There is an AOA computer or interface module and a probe with the appropriate tubing and wiring for installation in addition to the display. The installation instructions provide a general description for the installation of all components so wiring and tubing will not interfere with any control cables, pushrods, or other wiring and a general positioning of the AOA probe. The probe is

normally positioned where it can be mounted solidly to the aircraft in clean air flow (undisturbed air), a minimum of 2 feet outside the prop arc; typically mounted at least 6 inches back from leading edge, and at least 6 inches up from the trailing edge, so at any attitude, slip, or skid, nothing should disrupt the air into the AOA probe. Figure 4 shows an AOA probe installed on the Piper Arrow aircraft. Additional information concerning installation and additional Alpha Systems specifications for the Legacy system can be found in Appendix K.



Figure 4. AOA probe on Piper Arrow aircraft

The installation manual also provides detailed information on power requirements and instructions on installation for power to the system, and instructions on how to install the optional probe heat capability if desired. After installation, the system must be calibrated, and detailed instructions are provided. The specific process for calibration can be found in Appendix C. In summary, the system must go through a three-part calibration in which there is a ground calibration with zero airflow to the probe, a calibration in the air while flying the aircraft at $1.3V_{\rm stall}$, and a calibration at cruise flight. There are also means to set the display brightness and a capability for providing different audio tones and voice warnings to the pilot. The systems in the research aircraft for all three universities are set for maximum brightness and the use of both tone and voice warnings.

With a successful calibration, the system will determine the AOA in any weight or configuration that provides proper information to be provided to the pilot through the AOA display. The calculation of AOA is completed by measuring the differential of air pressure between two ports on the probe. One port is facing forward, similar to the pitot tube for the airspeed system on the aircraft, but this system does not calculate airspeed. The other port is on the bottom of the probe and provides a different air pressure measurement but is not a static port as commonly designed on similar looking airspeed probes. The Alpha Systems electronic AOA system measures pressure

at these two points on the AOA probe and transmits those pressures via AOA sense lines to the AOA interface module. The AOA interface module converts those pressures into an electronic signal that is transmitted to the display. The display interprets the signal and turns on the appropriate colored bars to convey the AOA information to the pilot.

A general description of the LED indications and audio warnings is as follows:

- Blue bar: Indicates normal operations calibrated at a weight-adjusted V_A value and lower AOA. Alpha Systems calls that set point CRUISE. The AOA is low, and there is a high margin of lift from stall.
- Yellow segments: Indicate approaching caution; the AOA is starting to transition. If not intentional, take action to reduce the AOA. When the system begins to show the yellow segments and the bottom of the green doughnut, there will be an audio tone and a voice that says "getting slow."
- Complete green doughnut: Is the set point that identifies optimum alpha angle, calibrated at a weight adjusted 1.3 V_{STALL} (see definition). The system can illuminate both arcs, just the top arc, or just the bottom arc to give a display just above or just below the set point.
- Red segments: Indicates the AOA is too high. Take immediate action to reduce the AOA, such as performing a stall-recovery procedure. When the red segments appear, there will be an audio tone and a voice that says "too slow, too slow."

The indication of the green doughnut is the calibrated AOA that provides the pilot with an indication that she/he is flying at $1.3~V_{\tiny STALL}$. This is the indication that should be showing when on final approach to land the aircraft.

2.3.8 Flight Parameter Data Collection

The system used to capture data during the evaluation flights was provided by an AvConnect Smart BoxTM. The Smart Box is a standalone data recorder that is mounted into the aircraft on the longitudinal axis and is powered either through the auxiliary electrical panel or through a 12-volt portable power supply.

The FDR unit captures the parameters shown in table 2.

Table 2. Smart Box recorded parameters

LAT—Latitude	HDG—Heading	LON_G—Longitudinal G
LON—Longitude	PITCH—Pitch	MIN_LON_G—Min Longitudinal G
GS—Groundspeed	ROLL—Roll	MAX_LON_G—Max Longitudinal G
TRK—Track	LAT_G—Lateral G	VERT_G—Vertical G
VSI—Calculated VSI	MIN_LAT_G—Min Lateral G	MIN_VERT_G—Min Vertical G
ALT—GPS Altitude	MAX_LAT_G—Max Lateral G	MAX_VERT_G—Max Vertical G

For the purposes of this study, GS, VSI, ALT, PITCH, ROLL, and VERT_G were used to calculate a flight path angle (FPA) for each second of the approach from 615 feet above the touchdown zone elevation (TDZE) of each runway down to 15 feet above the TDZE. The traditional altitude on completing the base leg and initiating the final leg of the traffic pattern (base to final turn) is 400 feet above the ground. By capturing the data starting at 615 feet above the TDZE, it was intended that the base to final turn was also captured.

Further information concerning the calculation of the FPA can be found in Appendix G.

Further information concerning the collection of data used for the statistical analysis can be found in Appendix H.

Further information concerning the use of the Smart Box versus the Garmin or Avidyne data information can be found in Appendix J.

2.3.9 Flight Instructor/Safety Pilot Training

All safety pilots recruited into the project held current CFI certificates and received training on the administration of the AOA experiments. Group or personal meetings with a member of the research team served to introduce the instructors to their roles in the project as safety pilots and to do walkthroughs of the necessary steps to help a participant from each approach group complete the experiment. All project materials—including forms, instructions, checklists, and the video—were provided with any related supplemental information. Instructors also watched the AOA training video and were permitted to use the AOA device when flying equipped aircraft to familiarize themselves with the technology prior to administering the experiment.

Before instructors could participate in the study, they were required to sign a consent agreement similar to the one signed by participants. In addition, instructors were required to sign a confidentiality agreement to ensure the confidentiality of the project participants and the data they would be collecting.

2.3.10 Pre-Experiment Dry Run

During the development of the materials for the experiment, all three universities shared information concerning the consent forms, data-collection forms, participant-recruiting materials, and pre-test and post-test questions to facilitate consistency across the delivery of the experiment.

On completion of the materials development, FIT performed a dry run for the experiment. An experienced flight instructor was used to review and fill out the participant consent form, the preflight survey, the training video, the four different participant checklists, the post-flight checklist, the two post-flight surveys, and the training and study flights.

There were few changes needed for the experiment procedures, but there were some minor changes to add airport identifier information and aircraft registration numbers to the checklists.

Avidyne Primary Flight Display and Multi-Function Display data were downloaded and sent to Avidyne for post-download processing. The researcher at FIT determined that a checklist was needed for downloading the Avidyne data. This checklist was developed and has been in use since the dry run.

Smart Box data were downloaded and sent to CAPACG, LLC for verification. There have been several software upgrades to the Smart Box since the beginning of the project that have simplified the download process and improved data download and upload reliability.

2.3.11 Experiment

The participants were assigned to a flight instructor/safety pilot trained on the administration of the AOA experiment, and a mutual time was agreed on to conduct the experiment. Occasionally, the time of the experiment was changed because of a scheduling conflict or an aircraft maintenance issue. However, at all times, both training and experimental flights were conducted under day Visual Flight Rules conditions, and, therefore, the experiment was subject to rescheduling under adverse weather conditions.

If the pilot was assigned to an approach group that was to receive AOA education—Condition A (Group 1), or Condition B (Group 2)—the participant proceeded to watch the AOA training video and complete an AOA training flight. Participants assigned to Condition C (Group 3) or Condition D (Group 4) did not receive any AOA education and proceeded directly to the evaluation portion of the experiment after receiving a briefing from the instructor on the anticipated plan for the flight.

For participants assigned to an approach group with training, a 38-minute video was shown to brief an overview of AOA concepts and AOA technology. It also included several video segments of in-flight demonstrations of the AOA display during stalls and approaches, which was a real-time recording of a principal investigator demonstrating the device's functionality in a university aircraft. Finally, the video briefed the flight portion of the experiment for the participant and outlined what maneuvers and situations the participant would encounter during the experiment. The exact same video was shown to all participating pilots who received training regardless of the university conducting the training, ensuring standardized content of the AOA ground-training portion of the experiment.

After watching the training video, the pilot and instructor proceeded to the aircraft for the in-flight training portion of the experiment. During this flight, the participant had the opportunity to do a sequence of various maneuvers and aerodynamic stalls, and completed six approaches to landing at three different airports (two at each) while using the AOA technology. Specifically, the training consisted of cruise flight, slow flight, power-off stall, power-on stall, and an accelerated stall (either demonstrated by the safety pilot or performed by the participant, depending on school

policy). In addition, participants were given the opportunity to do six approaches to landing at three different airports (two at each) for further demonstration of the AOA technology. These were the same airports used for the evaluation portion of the experiment. Data for the purpose of final experiment analysis were not gathered during training flights.

The final portion of the experiment consisted of an evaluation flight for all participants. The evaluation flight consisted of six approaches to landing at three different airports (two at each airport). During the second approach to landing at the second airport, the flight instructor/safety pilot pulled power to idle to have the participant perform a power-off approach. If this approach resulted in a go-around, the participant was then allowed to remain in the pattern to conduct a second landing at this airport. All participants completed an evaluation flight; however, only Condition A (Group 1) and Condition C (Group 3) had access to the AOA display during the evaluation. The other two groups, Condition B (Group 2) and Condition D (Group 4), flew the evaluation flight with the AOA display in the off mode and were not allowed to reference the AOA technology. Instruction or training was never given during an evaluation flight; therefore, the instructor primarily served the purpose of a safety pilot and also recorded pilot behavior for later analysis by the research team. All evaluation flights were monitored by the SmartboxTM FDR that recorded numerous aircraft parameters to be used later for statistical analysis.

2.3.12 Definition of Stabilized Approach

Worldwide runway overruns continue to be a leading cause of accidents in aircraft of all sizes and types of operation (e.g., air carrier and GA), and post-accident investigations into these events have revealed several commonalities. As such, the aviation industry has focused on these factors in an effort to reduce the incidence or at least the severity of these overrun events. These factors have been analyzed and developed into a list of criteria that pilots can consider or, in some cases, are required to follow (e.g., air carrier flight operations) in determining if their approach is considered stable, and, therefore, they have a very low probability of a runway overrun. Worldwide, both regulators and individual operators alike have promoted or adopted the criteria established by the Flight Safety Foundation (FSF) in whole or in part to reduce these events.

Typically, the accepted criteria for defining stabilized approaches include almost a dozen specific objectives that must be met at either 500 feet visual meteorological conditions or 1000 feet instrument meteorological conditions above runway elevation before an approach can be considered stable and, therefore, continued. However, some of these required goals are dependent on the type of equipment available and the type of operation being flown.

While designing this study and considering the definition of a stabilized approach, the criteria for stabilized approaches were influenced by the less complex aircraft types being used, as compared to transport category aircraft, and the type of data that were captured. In this consideration, both cost and timeline were factored. Because of these inherit limitations, the definition of a stabilized approach is less restrictive as the original FSF criteria. Furthermore, it is important to understand that the primary research goals did not include determining which flights were considered stable and which were not, but instead to examine across the four experimental groups and capture which appeared to be more stable than others. Therefore, when analyzing the quantitative aspect of the data, parameters such as speed, descent rate, roll, pitch, and FPA were all considered. The values collected aided in this determination.

For the purposes of this experiment, the definition of a stabilized approach is: a consistent glide path with no more than 1000 fpm descent and with a stabilized speed and controlled bank with coordinated turns and a rectangular-shaped pattern. In an effort to capture as accurate of a measure of the stability of the approach as possible, the team decided to use a different measure of stability than has traditionally been used in Flight Operational Quality Assurance (FOQA) programs. In a traditional FOQA program, the system is set up with thresholds of measurements based on one or more measures. It could be a measurement of airspeed, vertical speed, roll rate, pitch rate, g-forces, or a combination of individual measures and the FPA. It is common for a FOQA program to establish "gates" along a flight path where flight parameters and aircraft configuration have to be within predetermined thresholds or a missed approach/go-around is warranted. If the aircraft goes beyond the boundaries of the FPA or exceeds the limits at an individual gate, then an exceedance is recorded. These exceedances are traditionally recorded on the aggregate, and the organization follows up with a mitigation strategy to reduce the number of exceedances and continues to monitor the trends within the system. Looking at figure 5, the framework of this system can be seen in a representation for approaches to an example runway. Looking at the blue line that represents the flight path, it can be seen that figure 5a stays relatively close to the center line, and figure 5b varies along the flight path but never exceeds the outer boundaries. If the aircraft had met the criteria at the given "gates," then the FOQA system might not have recorded either approach as an exceedance, even though the aircraft in figure 5a was more stable. For the purposes of this study, it is important to measure the stability of the approach and not just a measure established within boundaries, as in a traditional FOQA program.

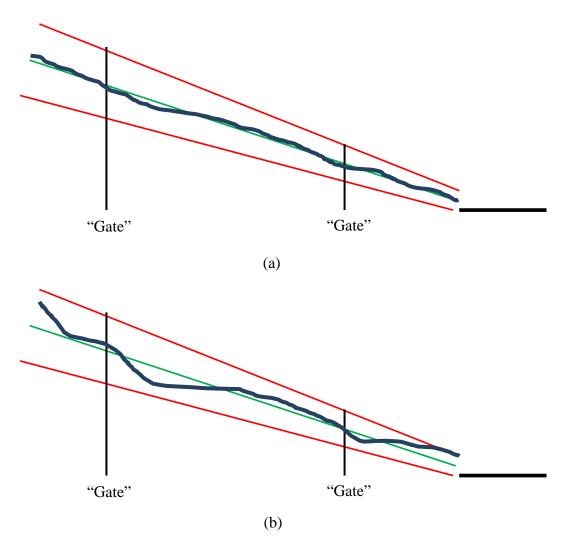


Figure 5. FPA analysis

To accomplish this task, the FPA was measured at 1-second intervals along the approach, the absolute value of the difference between a given second and its subsequent second value was calculated, and the sum of the variations in the FPAs for the last 30 seconds was calculated. An approach that maintained a perfectly consistent FPA would have no difference in the FPAs at each second interval, and then the sum of the variations in the FPAs for the last 30 seconds would equal zero. An approach that had a lot of variation would end up with a larger sum of the variation in the FPAs for the last 30 seconds. It is this measure that was then compared among the groups.

The decision to capture the last 30 seconds of the approach was based on the length of time it took for participants to complete the approach at each airport. Thirty seconds was the maximum length of time able to be captured to retain the maximum number of approaches to be considered for analysis. If a timeframe that was longer than 30 seconds was selected, then data would have to be eliminated from the analysis.

3. EXPERIMENT PROCEDURE

All participants in each group completed an informed consent form, pre-experiment survey, evaluation flight, and post-experiment survey. Additionally, half of the participants also received education on the use of AOA technology. To ensure proper flow for the approach groups, each university developed a specific checklist to ensure conformity with the experimental procedure within each approach grouping.

All participants were given informed consent prior to beginning any segment of the experiment and were required to sign a Research Participant Consent Form. After agreeing to the informed consent, all participants were also asked to complete a pre-experiment questionnaire to determine pilot experience and AOA knowledge and principles. Following completion of the first two tasks, participants continued on one of the two paths through the experiment. Half of the pilots received AOA education (video and flight training) and an additional evaluation flight; the other half of the participants only completed an evaluation flight. Prior to any flying, participants were given a chance to review aircraft procedures and limitations, and the instructor and pilot worked together to obtain proper pre-flight briefings for weather and Notices to Airmen (NOTAMs) for the airports and airspace that was expected. Outside the AOA training portion for two of the experimental groups, instructors were allowed to provide only specific aircraft instruction for those not familiar with the specific aircraft being used. For example, University B used a Piper Arrow, and several of the participants had never flown a complex aircraft. Those participants were allowed some flight instruction for proper approach speeds and power settings.

Completion of a post-flight questionnaire was the final portion of the experiment. This survey differed based on the participants' approach group assignments, and, therefore, there are two versions of the post-flight questionnaire: one for pilots with access to AOA technology during evaluation and another for pilots who did not have access to the AOA during the evaluation flight. After completion of the final survey, pilots were able to ask any final questions they had about the research encounter and fill out any required forms to be compensated for their time as a participant in the experiment.

3.1 RESEARCH PARTICIPANT CONSENT FORM

The consent form required for human-in-the-loop experiments is a necessary part of the system to ensure that all participants are aware of their rights while participating in any type of experimental research. The consent used in the study varied slightly as each university involved in this study submitted university-specific consent forms to its respective Institutional Review Board (IRB) for approval.

The consent form explains the purpose of the study; the activity the participant will be conducting during the study; the possible length of the participant's activity; any possible risks or discomforts; possible benefits, payments, and incentives; and potential costs to the participant. The consent form also provides the participants with assurance of confidentiality and of how their confidentiality will be assured. The form also provides participants with contact information allowing them the ability to contact the principal investigator, researchers, and the information of the IRB chairperson if they have any questions regarding the study or their confidentiality and rights. The form must be signed by the participant and one of the study researchers before any

experimental activities can take place. There are copies of each university's consent forms in Appendix D.

3.2 PRE-EXPERIMENT QUESTIONNAIRE

The pre-experiment survey had several purposes: to verify pilot demographic and experience information, to determine the participant's pre-experiment knowledge of AOA technology, and to establish the pilot's knowledge of AOA principles. This information served as a benchmark to compare the post-experiment surveys and to assist in determining how AOA training or usage changed a participant's understanding of AOA technology and AOA principles.

Many participants had not been exposed to the AOA technology, but it was important for the research team to conduct a pre-experiment questionnaire to establish if any participants previously encountered AOA technology in literature or any aircraft they had flown. The survey also established the understanding each pilot had of AOA principles and, in particular, the relationship of AOA to aerodynamic stalls and approach to landing. The requirement for participation, as outlined in section 2.3.5, focused only on total flight time and pilot certification level. Prior exposure to AOA technology did not preclude pilots from participating in the experiment. Prior exposure to AOA technology was assessed during the pre-experiment questionnaire.

3.3 PRE-EXPERIMENT BRIEFING

Following completion of the pre-experiment questionnaire, participants were briefed on the expected maneuvers for the upcoming flight. This was done one of two ways. For participants watching the AOA training video, a brief of the flight was included as part of the video. Approach groups not watching the video were briefed regarding what to expect during the evaluation flight. For pilots not familiar with the aircraft, the instructor serving as the safety pilot was permitted to give basic information about aircraft procedures, speeds, and operating limitations.

Providing a streamlined process to each participant was important to ensure that pilots were given the proper experimental treatment for their assigned approach group. As such, the research team at each university created internal checklists to be used to standardize the flow of each participant through the experiment for each approach group. The checklists were used to remind instructors administering the research of each step involved in completing an AOA study flight. Beginning with verifying the approach group, type of flight (education or evaluation), and participant information, the checklist served as a guide throughout the preflight process. Items on the checklist included the following: whether to watch the training video, brief the flight with the participant, complete required preflight tasks, such as a weather briefing, and a check of the NOTAMs at airports to be used for the flight. The checklist also reminded instructors to ensure the battery pack that powered the Smartbox FDR was powered on and to determine whether to turn on the AOA display for the flight.

3.4 POST-EXPERIMENT QUESTIONNAIRES

On completion of the evaluation flight, all participants were asked to complete a post-experiment questionnaire based on their approach group assignment. The post-flight survey for those with AOA access sought to determine if AOA education had any effect on the stability of the approaches during landing. The survey also asked questions regarding the participant's experience with the

AOA technology by requiring pilots to respond with their opinions about how they used the technology, and what benefits or issues a participant encountered while using the AOA device. Group 1 and Group 3 had access to AOA technology during evaluation; however, only pilots in Group 1 received the AOA education. Therefore, this survey was designed as an important step in determining whether the AOA education was beneficial to the participant's understanding and use of the AOA device.

For participants without AOA access during evaluation, a different survey asked pilots about their knowledge of AOA technology. It also sought information about their current methods for ensuring a stabilized approach and provided space for any other feedback about experiences as a participant in the study. This survey for participants without AOA access was given to Groups 2 and 4. Group 2 received AOA education, and Group 4 was the control approach group. Therefore, this questionnaire focused on the effectiveness of the AOA education and recognizing if any education transfer from the AOA training assisted the participant in completing the evaluation approaches.

4. EXPERIMENTAL RESULTS

There were 84 participants that completed evaluation flights in which data were captured and collected for analysis. To center the discussion on the effect of the AOA, the labels "University A, B, and C" are used at various points in the discussion that follows. University A had 33 participants complete the evaluation flights in which data were captured and collected for analysis. University B had 14 participants complete the evaluation flights in which data were captured and collected for analysis. University C had 38 participants complete the evaluation flights in which data were captured and collected for analysis.

The approaches analyzed for all universities combined are shown in table 3.

Table 3. Composition of approaches analyzed for all groups

Group 1	133
Group 2	124
Group 3	124
Group 4	126
Total	507

4.1 PILOT CHARACTERISTICS

Participants were predominantly young adult male private pilots. The responses were 90% from males, 87% from 18–22 year olds, and 93% from private pilots.

Total flight hour experience level varied among the breakdown groups of <50, 50–99, 100–149, 150–199, 200–249, and >250 hours (see figure 6).

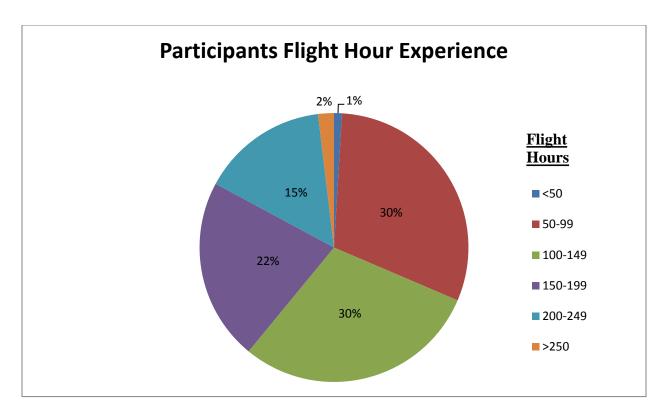


Figure 6. Participant flight-hour experience

4.2 OBSERVERS' ASSESSMENT OF PILOT

The safety pilots are collecting information for the purposes of the study regarding the following areas:

- the manner in which the participant used the device
- the performance of the student on the simulated engine failure (power-off) landing
- the frequency of usage of the device

The collected data were used in the statistical analysis of the approach stability found in section 4.7.

4.3 PILOT'S SELF-ASSESSMENT

4.3.1 Pre-Test

When participants described what causes a wing to stall, nearly all responses were similar to the example "exceeding the critical angle of attack." They all included such keywords as critical angle of attack, wing, enough, and lift.

When the pilots were asked to describe an accelerated stall, however, the answers varied considerably. Some respondents were able to provide a detailed description of an accelerated stall whereas other replies were more vague, such as describing the stall as "caused by increased load factor" or "rapid back pressure causing the aircraft to lose vertical lift."

There was a consensus when describing AOA, such as, "the angle between the chord line and relative wind." Most participants responded using keywords like angle, wing, relative wind, and chord line.

Only one participant had used an AOA device before. Most participants did not know how an AOA device works. Some of the responses included "I'm assuming it measures/approximates the AOA and informs you whether you are flying at a high AOA," and "possibly indicates when a wing is approaching its critical AOA on a display so that a stall can be avoided. With regards to how it works, maybe it takes into account G forces and airspeed."

4.3.2 Post-Test

Question: "Do you find that the angle of attack device helped with your approach to landing?"

This question was asked of those participants that had access to the AOA display during the approaches and the result is shown in figure 7. The majority of the positive responses were from those participants who had access to the AOA display and received training on its usage. For those participants who answered "Yes," the display was most helpful on the final phase of the approach.

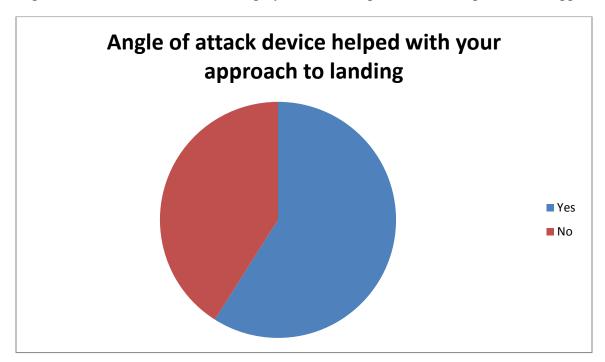


Figure 7. Post-test question

There were many different kinds of responses to the question about how the device assisted the participant's approach. Many included keywords like airspeed, better, red, green, centered, and angle. For example, "I used the green section as a sort of guide on setting up for the approach to get a good airspeed and rate of decent; also I tried to avoid red whenever possible," and "Pretty much as an extra reference of landing angle."

When asked "Do you believe that angle of attack devices would be useful in the cockpit of all aircraft?" all participants but six said "yes." The ones who said "no" either were not familiar with the device or thought it would be ineffective and too distracting. The participants who said yes were very pleased with its usage. For example, "Yes because especially in beginner pilots, awareness about the critical angle of attack can help teach students where a stall is most likely to occur and help avoid dangerous situations," and "Yes because of its ease to operate and learn. A leading factor in a lot of crashes is exceeding the critical angle of attack so it only makes sense to have a device that shows what your angle of attack is."

Answers to the question, "What could be better about the device?" varied significantly. The common responses were:

- If I knew what the lights meant.
- A mute function.
- Less auditory warnings.
- Brightness of device.
- "Too slow" voice is irritating.
- Having it integrated into glass cockpit.
- Having to reset circuit breaker because it was a bit buggy.
- Randomly turned off all the time.
- "The voice that kept reminding me that I was losing airspeed became slightly annoying when setting up for an approach or in situations where I intended to lose airspeed."
- Potentially distracting to a new pilot.

Answers to the question, "Do you find the angle of attack device to be distracting?" also varied significantly. Common responses were:

- The voice saying slow when in fairly normal flight around the pattern.
- During cruise it would occasionally flash.
- When it kept telling me too slow on final.
- When the device was telling me to do something that I did not think was right, it distracted me while I was trying to focus on my landing.
- At night, lights could prove a little distracting.

The answers to the question, "Could the device be better positioned in the cockpit?" revealed that only four participants indicated that it could be part of the avionics display or PFD.

4.4 EFFECTS OF AOA DISPLAY ON PILOT PROCEDURES

The addition of an AOA indicator in the GA cockpit altered the procedures used by the participants to successfully land the aircraft. Depending on the recency of experience and level of education provided on the subjects of stalls and the Alpha Systems product, participants varied in their use of information from the display.

4.4.1 Pilot Use of AOA Display

Participants involved in the study with University B flew in the Piper Arrow, a complex aircraft with which many participants were unfamiliar. Being the first flight behind the controls of this type of aircraft for most of them, the indicator played an advisory role for some and no role at all for others. Participants who flew less than the average participant seemed more concerned with keeping up with the pace of the complex aircraft than focusing on flying a very stable approach, leading to minimal use of the indicator. The use of the indicator decreased even further when the participant received neither education nor maneuvers training. Conversely, participants who flew more often or received education used the indicator more, but not to a level at which they relied on it for a majority of pitch and airspeed change cues. Those who had seen the indicator display its lights in the educational video and in flight during maneuvers became more familiar with the pattern of lights and audio cues, but again did not rely on the indicator for a majority of their information.

4.4.2 Pilot Flight-Control Actions, Based on AOA

For University A participants, six individuals encountered a situation in which the AOA device prevented a stall situation.

For University B participants, even for those who learned before stepping in the airplane that the green doughnut should be displayed on a stabilized approach, the use of the indicator for clues on adjusting pitch and power was not as great as the use of the information gathered from the instruments and outside references. At most, participants would use the indicator to back up or confirm the information presented to them on the PFD.

For University C participants, four individuals encountered a situation in which the AOA device prevented a stall situation.

4.5 RESULTS FROM ANALYSIS OF BEST PRACTICES AND DEVELOPMENT OF EDUCATIONAL MATERIALS

An initial task mandated by this project was to conduct a review of material available to determine the quantity and quality of existing best practices and education material related to AOA, with the goal of developing a comprehensive recommendation on the development of future literature and training materials. The review sought out many sources of information about AOA technology, including industry periodicals, journal proceedings, and Internet or blog posts. The research team also reached out to aviation interest or advocacy groups and the manufacturers of AOA devices. Ultimately, the reviewers concluded that basic literature is available, but the depth of information currently available to users of AOA technology is limited.

Many of the sources reviewed consisted of anecdotal evidence of the benefits of AOA devices and called for further investigation into the benefits of promoting the use of AOA technology, similar to this project's design. Unfortunately, excluding the AOA manufacturer's specific device user manuals, the research team was unable to find any overall guidance on the use of AOA devices. The predominant feature of the literature was a basic overview by a subject-matter expert (SME), usually found in a trade publication that was not subject to peer review. Although a majority of the

literature was SME opinion, the research team did find common themes throughout many of the publications.

An overwhelming amount of the literature promoted the use of AOA in GA operations and found a necessary interest in investigation of the technology. Many of the authors had personally used the AOA display in their personal flying and recounted the experience for the reader as a version of some best practices. The best practices included exact display indications for particular flight segments (especially approach to landing) and a how-to on performing consistent stabilized approaches, both of which are goals of this study. However, all of these best practices were of a personal opinion by the SME and not subject to a broad review by users of AOA technology.

4.6 ATTITUDE AWARENESS ENHANCEMENT

The goal of the AOA display was to aid the participant's understanding of the aircraft's AOA at any given time in the flight. Given the numerous lighting configurations of the Legacy display, a pilot can ascertain whether the aircraft has an AOA representative of a departure, cruise, or approach phase of flight (i.e., how close the wings are to a stall condition). As part of the system's design and the alerting functionality, the Legacy system provides the aural alert of "Getting Slow" at a predetermined proximity to the calibration point established during initial display setup.

A majority of participants indicated that the AOA indicator provided them with a better understanding of the aircraft's AOA, and they would use the display to their advantage as a secondary instrument during the approach phase of flight. In response to questions on the post-flight survey, participants indicated several ways that the equipment could be improved to better achieve the overall goal and provide pilots with even better attitude awareness. Responses also suggested that those participants with access to AOA education before the data-collection flight felt as though the device was much more useful because they were able to use it throughout the entire data-collection flight, as opposed to those who had no training and needed to determine on their own what information the lighting configurations meant.

The completion of this study not only provides great insight into the usefulness of AOA indicators in GA cockpits and the value of education on said systems but also intelligent feedback on the equipment by real-world users. The suggestions provided by the participants should be taken into account when designing future AOA equipment or enhancing current models.

4.7 STABILIZED APPROACH ANALYSIS

There are many ways that the data can be analyzed for the purposes of this study. Each method carries with it a degree of statistical strength based on the available data. Efforts have been focused on having an equal representation of data for each university within the study and for each group within the university. This effort is dedicated to maintaining a dataset that will allow for the analysis of the degree of effect for each condition within the experiment. Measuring the effect size of an AOA on the stability of an approach using statistical methods is enhanced when there is equal representation from each group being analyzed. This type of analysis is not desirable with the current dataset because there is an unequal representation in each of the groups. To analyze the data, a mixed procedure ANOVA was conducted with SAS statistical software using a Kenward-Roger method for fixed effects and degrees of freedom calculations.

To analyze the data and determine what affects the stability of an approach and how each of the participant groups performed when compared against each other, a best-fit model was developed to determine an estimate for the stability of the FPA. Within the dataset are 24 factors and 1 resultant that were used to develop this model. Sum of the Flight Path Angle Variation (SumFPA) is the resultant of the model and the other items are factors combined to estimate the resultant. The point at which each factor is added is based on operational experiences of the researchers as to which factors are likely to affect the SumFPA from greatest to least. The Evaluation Group (EvalGRP) will be added at the beginning, then the factor likely to have the greatest effect on the SumFPA will be added next. Each factor was added from greatest to least in sequential order. The table in Appendix L captures these factors and the resultant.

Before analysis was started, it was necessary to check the data assumptions for normalized data. The plots of the residuals of the SumFPA (see figure 8) show that the assumptions have been checked.

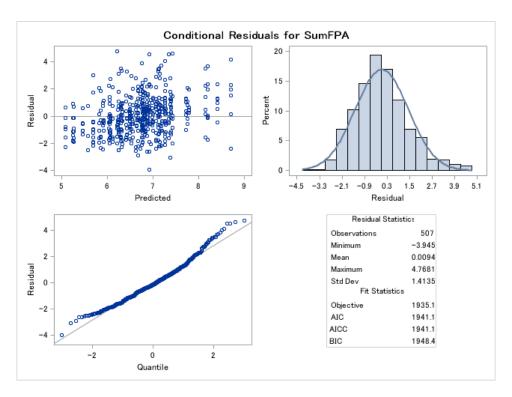


Figure 8. Plot of the residuals for all universities

Before the analysis of the entire dataset began, a check for an effect for the university factor needed to be conducted to determine if the data could be analyzed as an entire set or if the analysis would need to be conducted individually for each university. Table 4 shows the result of this analysis.

Table 4. Tests of fixed effects

Type 3 Tests of Fixed Effects						
Effect Num DF Den DF F Value Pr > F						
EvalGRP 3 80.5 0.39 0.7637						
University	2	81.1	13.38	<.0001		

With a *p*-value of <.0001, this shows that there is an effect on the SumFPA depending on at which university the participant completed the study. This will require that the analysis be conducted individually among the universities so that an effect of one of the factors does not get bunched together in the university factor. To center the discussion on the effect of the AOA, the labels "University A, B, and C" will be used throughout the remainder of the analysis.

The approaches analyzed for individual universities are shown in table 5:

Table 5. Breakdown of approaches analyzed for three universities

University A		University B		University C	
Group 1	62	Group 1	12	Group 1	59
Group 2	40	Group 2	24	Group 2	60
Group 3	54	Group 3	15	Group 3	55
Group 4	51	Group 4	29	Group 4	46
Total	207	Total	80	Total	220

Because the data are being separated out, the assumptions need to be verified again for normalized data.

Figures 9–11 show the assumptions check for all datasets for each of the three universities.

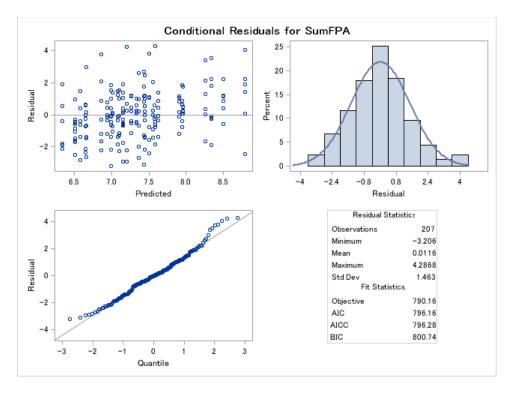


Figure 9. University A plot of the residuals

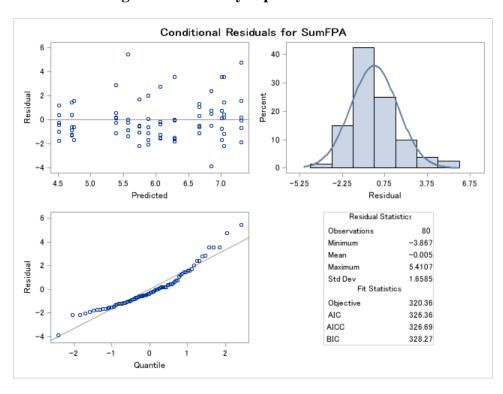


Figure 10. University B plot of the residuals

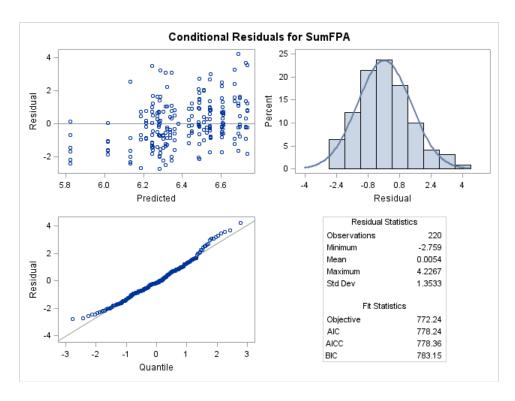


Figure 11. University C plot of the residuals

To start the analysis, the simplest model was initiated first and was comprised of the EvalGRP being the sole factor used to estimate the SumFPA. Tables 6–8 show the fit of this model for each university.

Table 6. University A simplest model

Type 3 Tests of Fixed Effects						
Effect	Effect Num DF Den DF F Value Pr > F					
EvalGRP	EvalGRP 3 30.1 0.30 0.8280					

Table 7. University B simplest model

Type 3 Tests of Fixed Effects					
Effect Num DF Den DF F Value Pr > F					
EvalGRP 3 10.3 2.26 0.1426					

Table 8. University C simplest model

Type 3 Tests of Fixed Effects					
Effect Num DF Den DF F Value Pr > F					
EvalGRP 3 34.4 0.26 0.8568					

In the models above, universities A and C have *p*-values of 0.8280 and 0.8568, respectively; this shows us that EvalGRP alone is not a good estimator of the SumFPA in those cases. University B, however, has a substantially lower *p*-value of 0.1426. This factor will need to be monitored as additional factors are added to the model to determine if the effect of EvalGRP on SumFPA gets stronger, weaker, or remains constant.

Depending on the willingness of an organization to be wrong in their assertion of the accuracy of the estimators, the p-value would need to get substantially lower. A p-value less than 0.1000 would be sufficient for the purposes of this study. A p-value greater than 0.1000 would need to be assessed for practical significance to determine if it is worth additional inquiry.

The next model that was evaluated incorporated the Pwr factor to see if having power on or off during the approach and an inclusion of an interaction with the EvalGRP has an effect on the SumFPA. Tables 9–11 show the fit of this model for each university.

Table 9. University A fixed-effects model

Type 3 Tests of Fixed Effects						
Effect Num DF Den DF F Value Pr > F						
EvalGRP	3	41.1	0.57	0.6405		
Pwr	1	165	17.33	<.0001		
EvalGRP*Pwr	3	164	2.95	0.0345		

Table 10. University B fixed-effects model

Type 3 Tests of Fixed Effects					
Effect Num DF Den DF F Value Pr > F					
EvalGRP	3	14.6	2.61	0.0906	
Pwr	1	62.5	37.69	<.0001	
EvalGRP*Pwr	3	62.3	0.25	0.8628	

Table 11. University C fixed-effects model

Type 3 Tests of Fixed Effects					
Effect Num DF Den DF F Value Pr > F					
EvalGRP	3	62.9	1.09	0.3613	
Pwr	1	146	8.80	0.0035	
EvalGRP*Pwr	3	146	1.62	0.1874	

With *p*-values of 0.6405 and 0.3613 for universities A and C, respectively, for EvalGRP and a *p*-value of 0.1874 for the interaction between EvalGRP and Pwr for University C, this shows us that neither of these effects are good estimators of the SumFPA. The interaction for EvalGRP and Pwr for University A is significant at a *p*-value of 0.0345. This tells us that the EvalGRPs for University

A do not perform the same during an approach with Pwr On versus Pwr Off. This interaction will need to be analyzed further to understand the impact of this interaction for University A.

Additionally, two universities have a *p*-value <0.0001, and one has a *p*-value of 0.0035 for the factor Pwr alone. This indicates that Pwr is a good estimator of the SumFPA. This should be no surprise. Most pilots are intuitively aware that in the event of an engine failure, the stability of the approach path is highly likely to be affected. It is also interesting to note that the effect of EvalGRP for University B is strengthened from a *p*-value of 0.1426 to 0.0906 when Pwr is added to the model.

The next evaluated model incorporated the VASI effect to the model and included an interaction effect between EvalGRP and VASI. Only University C conducted approaches at an airport where one or more of the runways did not have some sort of visual guidance available. Table 12 shows the fit of this model for University C.

Type 3 Tests of Fixed Effects					
Effect Num DF Den DF F Value Pr > F					
EvalGRP	3	62	0.94	0.4273	
VASI	1	146	2.02	0.1571	
Pwr	1	150	5.43	0.0212	
EvalGRP*VASI	3	145	3.18	0.0258	
EvalGRP*Pwr	3	150	2.48	0.0632	

Table 12. University C fixed-effects model

Similar to the effect of Pwr on SumFPA, the interaction between EvalGRP and VASI is significant at a *p*-value of 0.0632. This tells us that the EvalGRPs for University C do not perform the same during an approach with visual guidance or without visual guidance. This interaction will need to be analyzed further to understand the impact of this interaction for University C. It's also interesting to note that the strength of the effect of the interaction of EvalGRP and Pwr is increased when VASI is added to the model.

This process is continued throughout all of the potential factors that were recorded in the data-collection process. Any factor that does not have a *p*-value of less than 0.1000 is removed from the model unless the interaction between that factor and EvalGRP is less than 0.1000, in which case it must remain in the model because of the interaction. On completion of this process, the models in the following tables were achieved for each university.

Tables 13–15 indicate that the evaluation groups do not have a significant effect on the stability of an approach for universities A, B, or C at the 0.1000 level. At *p*-values of 0.6405 and 0.4273 for universities A and C, respectively, it is not significant enough to indicate the there is an effect outside of a random occurrence. The *p*-value for EvalGRP for University B is worth further inquiry to determine if there is an effect among specific groups when AOA education or use is evaluated. Further inquiry into the effect of the interaction of EvalGRP and Pwr for University A, the effect of EvalGRP for University B, the effect of the interaction of EvalGRP, and Pwr and EvalGRP and VASI for University C, should be evaluated.

Table 13. University A—Final model

Type 3 Tests of Fixed Effects							
Effect	Num DF	Den DF	F Value Pr > F				
EvalGRP	3	41.1	0.57	0.6405			
Pwr	1	165	17.33	<.0001			
EvalGRP*Pwr	3	164	2.95	0.0345			

Table 14. University B—Final model

Type 3 Tests of Fixed Effects						
Effect	Num DF	Den DF	F Value	Pr > F		
EvalGRP	3	10.1	2.56	0.1130		
Pwr	1	65.5	46.12	<.0001		

Table 15. University C—Final model

Type 3 Tests of Fixed Effects							
Effect	Num DF	Den DF	F Value	Pr > F			
EvalGRP	3	62	0.94	0.4273			
Pwr	1	150	5.43	0.0212			
VASI	1	146	2.02	0.1571			
EvalGRP*Pwr	3	150	2.48	0.0632			
EvalGRP*VASI	3	145	3.18	0.0258			

To analyze the data for the individual situations at each university, an analysis was conducted providing separation of data for various factors. For the cases in which there was an interaction between Pwr and EvalGRP, all EvalGRPs in a Pwr On situation were analyzed without the Pwr Off approaches included in the data. This would be considered a separation of data for Pwr Off. An analysis was then conducted in the Pwr Off situation with a separation of data for Pwr On. The analysis for each situation for each university could then be compared to better understand the information presented in the data.

The approaches analyzed for individual universities in the power-on and power-off conditions are shown in table 16.

Table 16. Breakdown of approaches analyzed in power-on an power-off conditions for AOA display

University A Power On		Universi Power	-	University C Power On	
Group 1	49	Group 1 10		Group 1	49
Group 2	31	Group 2	20	Group 2	50
Group 3	45	Group 3	12	Group 3	47
Group 4	41	Group 4	24	Group 4	38
Total	166	Total	66	Total	184

University A Power Off		Universi Power	•	University C Power Off		
Group 1	13	Group 1	2	Group 1	10	
Group 2	9	Group 2	4	Group 2	10	
Group 3	9	Group 3	3	Group 3	8	
Group 4	10	Group 4	5	Group 4	8	
Total	41	Total	14	Total	36	

Table 17 provides a comparison of the estimates of the SumFPA for the various situations in the title row for the various combinations. The estimate provided is a comparison of the mean (average) estimates of the various combinations. The *t*-value and Adj P show the statistical comparison of the two estimates and determines if they are statistically different. Even though they are actually different numbers, the difference may not be statistically significant, and the *t*-values and Adj P help to determine the comparison. If the *t*-value is sufficient enough, the associated *p*-value and Adj P of the comparison will be a low number (less than 0.1000 for statistical significance for the purposes of this study), which would indicate that it is more than a random occurrence for the difference in the mean estimates of the SumFPA for each combination.

Table 17. University A—EvalGRP comparisons for power on

Differences of Least Squares Means									
				Standard					
Effect	EvalGRP	_EvalGRP	Estimate	Error	DF	t Value	Pr > t	Adjustment	Adj P
EvalGRP	1	2	0.1017	0.5626	30.8	0.18	0.8577	Tukey- Kramer	0.9979
EvalGRP	1	3	0.4985	0.5116	29.4	0.97	0.3378	Tukey- Kramer	0.7649
EvalGRP	1	4	0.4623	0.5267	29	0.88	0.3873	Tukey- Kramer	0.8163
EvalGRP	2	3	0.3968	0.5738	30.5	0.69	0.4945	Tukey- Kramer	0.8995
EvalGRP	2	4	0.3605	0.5872	30.1	0.61	0.5439	Tukey- Kramer	0.9268
EvalGRP	3	4	-0.03623	0.5386	28.7	-0.07	0.9468	Tukey- Kramer	0.9999

For example, in row 1, EvalGRP 1 is compared with EvalGRP 2. The estimate in this graph is the difference in the mean estimates of SumFPA of EvalGRP 1 and EvalGRP 2. The mean SumFPA for the group in column 3 is subtracted from the mean SumFPA for the group in column 2, and the result is provided in the Estimate column. Because the number in the Estimate column is a positive number, that indicates that the mean SumFPA for EvalGRP 2 was a lower number, which would indicate that EvalGRP 1 performed worse (higher fluctuation of FPA, which resulted in a higher mean SumFPA). Even though EvalGRP 1 performed worse, the *p*-value is not low enough to indicate that it is enough to be considered a result that is something other than random. In looking at the *p*-values of the comparisons in this condition, it can be seen that none of the relationships between any of the groups for University A in the Pwr On situation are statistically significant.

Table 18 shows the comparison of the evaluation groups for University A in the power-off situation and the differences starting to develop. In the second row, EvalGRP 1 is compared with EvalGRP 3. Because the number in the Estimate column is negative, it indicates that the mean SumFPA for EvalGRP 3 is a higher number, which would indicate that EvalGRP 1 performed better (lower fluctuation of FPA, which resulted in a lower mean SumFPA). When looking at the basic t-test in the analysis, it can be seen that the relationship is statistically significant, but when it is adjusted for the type of statistical analysis that was conducted, it moves outside of statistical significance. There are other relationships worth noting. EvalGRP 2 and 4 do better than EvalGRP 3 in a similar relationship as EvalGRPs 1 and 3. To further understand this relationship and to determine if it was the AOA education, the AOA usage, or a combination of both, a contrast statement was run to compare the combinations of various groups. Because EvalGRP 1 and 2 both received AOA education, that could be a contributing effect to their performance on the approach. Likewise, EvalGRPs 1 and 3 were both allowed access to the AOA display during the evaluation flights. A contrast analysis will compare the effect of AOA education, the effect of AOA usage, and the effect of the combination of AOA usage and education.

Table 18. University A—EvalGRP comparisons for power off

			Difference	s of Least Sc	quares M	Ieans			
				Standard					
Effect	EvalGRP	_EvalGRP	Estimate	Error	DF	t Value	Pr > t	Adjustment	Adj P
EvalGRP	1	2	-0.9805	0.6199	6.48	-1.58	0.1612	Tukey- Kramer	0.4321
EvalGRP	1	3	-1.6372	0.7406	35.6	-2.21	0.0336	Tukey- Kramer	0.1889
EvalGRP	1	4	-0.01975	0.5710	5.67	-0.03	0.9736	Tukey- Kramer	1.0000
EvalGRP	2	3	-0.6567	0.7857	32.2	-0.84	0.4094	Tukey- Kramer	0.8364
EvalGRP	2	4	0.9608	0.6283	5.89	1.53	0.1780	Tukey- Kramer	0.4590
EvalGRP	3	4	1.6174	0.7477	33.4	2.16	0.0378	Tukey- Kramer	0.2021

Table 19 shows that the effects of the combination of AOA education and AOA access during a power-off situation are statistically significant. Based on the earlier comparisons of the groups, it can be determined that EvalGRP 3 had the most variation in the SumFPA. One possibility for this effect is the level of proficiency of the participants in this analysis. A power-off accuracy landing is conducted on a routine basis in training. For EvalGRPs 2 and 4, the performance of the power-off approach and the lack of an AOA display would be familiar to this group. EvalGRP 1 had the most familiarity with the AOA displays and, therefore, could use the information to assist in the performance of the maneuver. EvalGRP 3 did not receive any training on the AOA display indications and had the potential for the display to be a distracter in the completion of the power-off landing, which could explain why its performance was the most unstable.

Table 19. University A—Estimates and contrast for power off

Estimates										
Label	Estimate	Standard Error	DF	t Value	Pr > t					
Education-No Education	-0.6764	0.9713	18.7	-0.70	0.4947					
AOA–No AOA	0.6369	0.9713	18.7	0.66	0.5200					
Education*AOA	-2.5980	0.9713	18.7	-2.67	0.0151					

Contrasts										
Label	Num DF	Den DF	F Value	Pr > F						
Education-No Education	1	18.7	0.49	0.4947						
AOA–No AOA	1	18.7	0.43	0.5200						
Education*AOA	1	18.7	7.15	0.0151						

When looking at the comparison of the evaluation groups for University B in the power-on situation, as shown in table 20, some differences can be seen among the various groups. In rows 1, 3, 4, and 6, the relationships among the groups reflect statistical significance based on a basic t-test, with weakening significance in the Adj P measure. It appears that EvalGRPs 1 and 3 tend to do better than EvalGRPs 2 and 4, but to confirm this possibility, a contrast statement will help show the dynamics.

Table 20. University B—EvalGRP comparisons for power on

			Difference	s of Least S	quares I	Means			
Effect	EvalGRP	_EvalGRP	Estimate	Standard Error	DF	t Value	Pr > t	Adjustment	Adj P
EvalGRP	1	2	-1.3452	0.7584	9.52	-1.77	0.1080	Tukey- Kramer	0.3390
EvalGRP	1	3	0.1557	0.8281	10.3	0.19	0.8545	Tukey- Kramer	0.9975
EvalGRP	1	4	-1.4352	0.7354	9.63	-1.95	0.0806	Tukey- Kramer	0.2674
EvalGRP	2	3	1.5010	0.7028	10.7	2.14	0.0568	Tukey- Kramer	0.2064
EvalGRP	2	4	-0.09001	0.5908	9.69	-0.15	0.8820	Tukey- Kramer	0.9987
EvalGRP	3	4	-1.5910	0.6779	10.9	-2.35	0.0389	Tukey- Kramer	0.1511

The estimates in table 21 show that the use of AOA resulted in a lower estimate for the SumFPA versus not having the use of the AOA. This would indicate that there is an effect for University B when having access to an AOA device.

Table 21. University B—Estimates and contrast for power on

Estimates										
Label	Estimate	Standard Error	DF	t Value	Pr > t					
Education-No Education	0.06571	1.0172	10.1	0.06	0.9498					
AOA–No AOA	-2.9362	1.0172	10.1	-2.89	0.0161					
Education*AOA	0.2457	1.0172	10.1	0.24	0.8140					

Contrasts										
Label	Num DF	Den DF	F Value	Pr > F						
Education-No Education	1	10.1	0.00	0.9498						
AOA–No AOA	1	10.1	8.33	0.0161						
Education*AOA	1	10.1	0.06	0.8140						

When comparing the EvalGRPs for University B in the power-off condition, table 22 shows that although there are differences among the estimates for the SumFPA for the various groups, none of them are statistically significant enough to indicate an occurrence beyond random effects.

Table 22. University B—EvalGRP comparisons for power off

			Differences	of Least Squ	uares I	Means			
Effect	EvalGRP	_EvalGRP	Estimate	Standard Error	DF	t Value	Pr > t	Adjustment	Adj P
EvalGRP	1	2	-1.1492	2.2512	10	-0.51	0.6208	Tukey- Kramer	0.9547
EvalGRP	1	3	1.0499	2.3730	10	0.44	0.6676	Tukey- Kramer	0.9696
EvalGRP	1	4	-1.6271	2.1749	10	-0.75	0.4716	Tukey- Kramer	0.8754
EvalGRP	2	3	2.1991	1.9854	10	1.11	0.2939	Tukey- Kramer	0.6932
EvalGRP	2	4	-0.4780	1.7438	10	-0.27	0.7896	Tukey- Kramer	0.9923
EvalGRP	3	4	-2.6771	1.8984	10	-1.41	0.1888	Tukey- Kramer	0.5212

Likewise, the estimates for the contrasts of education and AOA usage in table 23 show that there are estimated differences but none that show statistical significance for the power-off condition for University B.

Table 23. University B—Estimates and contrast for power off

Estimates										
Label	Estimate	Standard Error	DF	t Value	Pr > t					
Education-No Education	0.5720	2.9448	10	0.19	0.8499					
AOA–No AOA	-3.8262	2.9448	10	-1.30	0.2230					
Education*AOA	1.5279	2.9448	10	0.52	0.6152					

Contrasts									
Label	Num DF	Den DF	F Value	Pr > F					
Education-No Education	1	10	0.04	0.8499					
AOA–No AOA	1	10	1.69	0.2230					
Education*AOA	1	10	0.27	0.6152					

University C had an interaction effect worthy of analyzing for both the EvalGRP*Pwr and the EvalGRP*VASI conditions. Like University A, the data are analyzed with a separation of data on various conditions to determine if the EvalGRPs perform differently under varying circumstances as shown in table 24.

Table 24. University C—EvalGRP comparisons for power on

			Difference	s of Least So	quares M	I eans			
				Standard					
Effect	EvalGRP	_EvalGRP	Estimate	Error	DF	t Value	Pr > t	Adjustment	Adj P
EvalGRP	1	2	0.1371	0.3763	34.2	0.36	0.7178	Tukey- Kramer	0.9832
EvalGRP	1	3	-0.01537	0.3815	34.4	-0.04	0.9681	Tukey- Kramer	1.0000
EvalGRP	1	4	-0.01493	0.4035	35.2	-0.04	0.9707	Tukey- Kramer	1.0000
EvalGRP	2	3	-0.1525	0.3800	34	-0.40	0.6908	Tukey- Kramer	0.9778
EvalGRP	2	4	-0.1520	0.4021	34.8	-0.38	0.7077	Tukey- Kramer	0.9813
EvalGRP	3	4	0.000434	0.4070	35	0.00	0.9992	Tukey- Kramer	1.0000

Like University A, the *p*-values of the comparisons in this condition show that none of the relationships between any of the groups for University C in the power-on condition are statistically significant.

In table 25, the *p*-values of the comparisons in this condition show that none of the relationships between any of the groups for power-off condition are statistically significant, but the *p*-values do

approach statistical significance for the relationship of EvalGRPs 2 and 3 with respect to EvalGRP 4, and the relationship of EvalGRP 1 strengthens with respect to EvalGRPs 2 and 3. The estimate and contrast assessments in table 26 help to explain this relationship.

Table 25. University C—EvalGRP comparisons for power off

			Differences of	of Least Squa	ares Me	eans			
				Standard					
Effect	EvalGRP	_EvalGRP	Estimate	Error	DF	t Value	Pr > t	Adjustment	Adj P
EvalGRP	1	2	0.6679	0.7272	32	0.92	0.3652	Tukey- Kramer	0.7952
EvalGRP	1	3	0.6717	0.7713	32	0.87	0.3903	Tukey- Kramer	0.8197
EvalGRP	1	4	-0.4799	0.7713	32	-0.62	0.5382	Tukey- Kramer	0.9242
EvalGRP	2	3	0.003833	0.7713	32	0.00	0.9961	Tukey- Kramer	1.0000
EvalGRP	2	4	-1.1478	0.7713	32	-1.49	0.1465	Tukey- Kramer	0.4562
EvalGRP	3	4	-1.1516	0.8130	32	-1.42	0.1663	Tukey- Kramer	0.4986

Table 26. University C—Estimates and contrast for power off

Estimates										
Label	Estimate	Standard Error	DF	t Value	Pr > t					
Education-No Education	-0.4760	1.0907	32	-0.44	0.6654					
AOA–No AOA	-0.4837	1.0907	32	-0.44	0.6604					
Education*AOA	1.8195	1.0907	32	1.67	0.1050					

Contrasts					
Label	Num DF	Den DF	F Value	Pr > F	
Education-No Education	1	32	0.19	0.6654	
AOA–No AOA	1	32	0.20	0.6604	
Education*AOA	1	32	2.78	0.1050	

The differences in education versus no education indicate that participants who receive education have a lower mean SumFPA than those who do not. Likewise, participants who are allowed access to the AOA display have a lower mean SumFPA than those not allowed access to the AOA. However, neither of these relationships are statistically significant. The combination of education and AOA usage results in a positive estimate, but at the 0.1000 *p*-value level, it is not statistically significant. Comparisons of the groups show that EvalGRPs 2 and 3 were more stable than EvalGRP 4, but at *p*-values of 0.1465 and 0.1663, respectively, they are still too far away from

statistical significance to draw conclusions. There are differences among the various groups during a power-off approach, whereas little difference is present during a power-on approach.

University C also had an interaction between EvalGRP and VASI. Universities A and B did not conduct approaches at airports where at least one of the runways used did not have visual guidance available for the participants to use. The following analysis could only be conducted for University C.

The approaches analyzed for the VASI condition are shown in table 27.

Table 27. University C—Approaches analyzed for VASI condition

University C Power On VASI Available		University C Power On No VASI Available	
Group 1	35	Group 1	14
Group 2	38	Group 2	12
Group 3	33	Group 3	14
Group 4	29	Group 4	9
Total	135	Total	49

Table 28 shows that when a visual guidance system is available, there is little difference in the SumFPA among the EvalGRPs.

Table 28. University C—EvalGRP comparisons for VASI

	Differences of Least Squares Means								
Effect	EvalGRP	_EvalGRP	Estimate	Standard Error	DF	t Value	Pr > t	Adjustment	Adj P
EvalGRP	1	2	0.5120	0.4241	32.1	1.21	0.2362	Tukey- Kramer	0.6267
EvalGRP	1	3	0.3785	0.4352	34.2	0.87	0.3906	Tukey- Kramer	0.8204
EvalGRP	1	4	0.1420	0.4532	32.9	0.31	0.7560	Tukey- Kramer	0.9891
EvalGRP	2	3	-0.1335	0.4292	32.7	-0.31	0.7577	Tukey- Kramer	0.9894
EvalGRP	2	4	-0.3700	0.4475	31.5	-0.83	0.4145	Tukey- Kramer	0.8413
EvalGRP	3	4	-0.2365	0.4580	33.4	-0.52	0.6091	Tukey- Kramer	0.9546

Table 29 shows that when a visual guidance system is not available, there is a strengthened relationship among the groups. None of the specific relationships become statistically significant,

but it does warrant further inquiry to determine if AOA education or AOA usages have an effect on SumFPA when a visual guidance system is not available for use.

Table 29. University C—EvalGRP comparisons for no VASI

	Differences of Least Squares Means								
				Standard					
Effect	EvalGRP	_EvalGRP	Estimate	Error	DF	t Value	Pr > t	Adjustment	Adj P
EvalGRP	1	2	-0.9487	0.6163	28.8	-1.54	0.1346	Tukey- Kramer	0.4283
EvalGRP	1	3	-0.8450	0.6163	25.4	-1.37	0.1824	Tukey- Kramer	0.5272
EvalGRP	1	4	-0.2870	0.6741	28.3	-0.43	0.6735	Tukey- Kramer	0.9736
EvalGRP	2	3	0.1038	0.6163	28.8	0.17	0.8675	Tukey- Kramer	0.9983
EvalGRP	2	4	0.6617	0.6740	31.4	0.98	0.3338	Tukey- Kramer	0.7609
EvalGRP	3	4	0.5579	0.6741	28.3	0.83	0.4148	Tukey- Kramer	0.8409

In table 30, the differences in education versus no education indicate that participants receiving education have a lower mean SumFPA than those who do not. Likewise, participants who are allowed access to the AOA display have a lower mean SumFPA than those who are not allowed access to the AOA. However, neither of these relationships are statistically significant. It can be seen that the combination of education and AOA usage results in a negative estimate, but at the 0.1000 *p*-value level, it is not statistically significant.

Table 30. University C—Estimates and contrast for no VASI

Estimates					
Label	Estimate	Standard Error	DF	t Value	Pr > t
Education-No Education	-0.1833	0.9133	28.6	-0.20	0.8424
AOA–No AOA	-0.3908	0.9133	28.6	-0.43	0.6719
Education*AOA	-1.5066	0.9133	28.6	-1.65	0.1100

Contrasts				
Label	Num DF	Den DF	F Value	Pr > F
Education-No Education	1	28.6	0.04	0.8424
AOA–No AOA	1	28.6	0.18	0.6719
Education*AOA	1	28.6	2.72	0.1100

In summary, based on these results, it is appropriate to determine that when a landing situation presents itself with normal characteristics, there is no significant difference in the stability of an approach whether or not an AOA device is used. However, when complexity is introduced into the equation, such as the lack of visual guidance information, (e.g., VASI, PAPI, or a power-off situation), there is an attributable difference in the stability of the FPA variation when an AOA device is or is not used and whether the participant received education on the display.

4.7.1 Tailwind Considerations

There were 94 approaches conducted at airports where a tailwind situation was present on base to final. When those approaches were evaluated for the airport location, the runway used, and the direction of turn, there were 13 approaches at KMLB to runway 5 that were conducted under similar circumstances and 13 approaches at KCFJ to runway 4 that were conducted under similar circumstances. Of the approaches at KMLB, two were conducted by EvalGRP 1, two were conducted by EvalGRP 2, seven were conducted by EvalGRP 3, and two were conducted by EvalGRP 4. Of the approaches at KCFJ, four were conducted by EvalGRP 1, four were conducted by EvalGRP 2, three were conducted by EvalGRP 3, and two were conducted by EvalGRP 4.

Because of the low number of approaches conducted under circumstances similar enough for evaluation, this portion of the analysis cannot be conducted with enough strength to draw conclusions regarding the effect of the AOA devices on the base to final turn and whether they facilitated the participants in establishing a square pattern during approach. The information contained in figures 12–14 is a representation of the approaches that were captured and the corresponding maximum overshoot beyond the extended centerline of the runway.

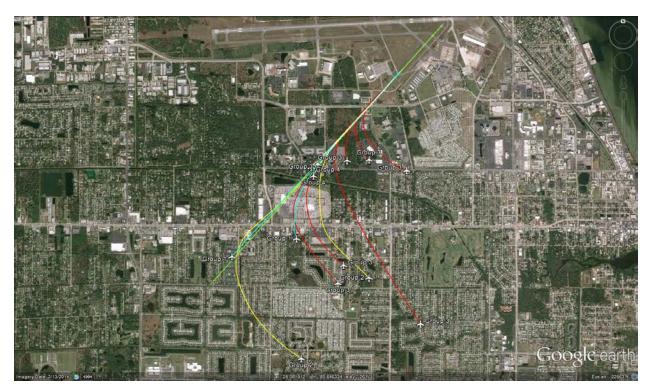


Figure 12. Overhead image of approaches at KMLB



Figure 13. Measurements of overshoot beyond extended runway centerline

Measurements of maximum exceedances for all groups at KMLB:

Group 1—Largest overshoot was 126 feet beyond centerline at 1.51 nautical miles (NM) away from the threshold.

Group 2—Largest overshoot was 270 feet beyond centerline at 1.45 NM away from the threshold.

Group 3—Largest overshoot was 99 feet beyond centerline at .45 NM away from the threshold.

Group 4—Largest overshoot was 132 feet beyond centerline at .85 NM away from the threshold.



Figure 14. Overhead image of approaches at KCFJ

Measurements of maximum exceedances for all groups at KCFJ

Group 1—Had two overshoots that were worth mentioning. One overshoot was 118 feet beyond centerline at 332 feet away from the threshold. The other overshoot was 419 feet beyond the centerline at .85 NM away from the threshold.

Group 2—Largest overshoot was 103 feet beyond centerline at .86 NM away from the threshold.

Group 3—Largest overshoot was 341 feet beyond centerline at 1.01 NM away from the threshold.

Group 4—Largest overshoot was 20 feet beyond centerline at .8 NM away from the threshold.

4.7.2 Conclusions for Experimental Hypothesis

This section will discuss the experiment's hypotheses. The statistical analysis used for these hypotheses was the Analysis of Variance (ANOVA) technique. It was theorized by the researchers and the sponsors for this research project that the use of an angle of attack (AOA) system would result in more stable approaches for general aviation (GA) pilots.

The statistical results of this project did not show the expected results when looking at all of the participants in their entirety. This result could be for several reasons, one of which may be that the majority of pilots used as participants in this study are those participating in an advanced flight school environment, are flying regularly, and are therefore quite proficient.

Hypothesis 1

Training about AOA, the use and operation of an AOA system, and the use of the AOA system in flight will allow GA pilots to conduct a more stable approach to landing.

The statistical analysis of the evaluation groups did not support the hypothesis that training pilots in the use of an AOA system and the use and operation of an AOA system would allow GA pilots to conduct a more stable approach to landing while using an AOA system for approaches to landing in all conditions.

Hypothesis 2

Training about AOA and the use and operation of an AOA system will allow GA pilots to conduct a more stable approach to landing, even without the use of an AOA system in flight.

The statistical analysis of the evaluation groups did not support the hypothesis that training pilots in the use and operation of an AOA system would allow GA pilots to conduct a more stable approach to landing, even without the use of an AOA system.

Hypothesis 3

The use of an AOA system in flight will allow GA pilots to conduct a more stable approach to landing, even without training on the use of an AOA system.

The statistical analysis of the evaluation groups did not support the hypothesis that the use of an AOA system in flight would allow GA pilots to conduct a more stable approach to landing, even without training in the use of an AOA system.

4.7.3 Conclusions for Research Questions

Research Question 1

Of the groups evaluated, which pilots had a more stable approach?

The overall experimental results and analysis concluded that all groups had an equal chance of having a stable approach. Any differences found in approach stability did not meet the criteria for statistical significance and could be the result of random effects. More detail is available in the results interpretation provided in this section. Although experimental treatments, such as AOA display access, training on AOA usage, or a combination of both sometimes decreased the mean SumFPA, they did not reveal a statistical significance that could be determined beyond the *p*-value of less than a 0.1000 level.

The exception to this conclusion was when the approaches conducted by University B were evaluated in the power-on condition only. Groups 1 and 3 at University B (which had access to the AOA display) had more stable approaches than Groups 2 and 4, which did not have AOA access during the power-on approaches.

Research Question 2

What difference does it make on approach stability whether AOA training occurs?

Groups 1 and 2 were given training on the use of AOA technology; however, only Group 1 was allowed to use the AOA display during the evaluation flight. After the statistical analysis of power-on and power-off approaches at all three universities, there was no notable correlation between AOA training and the stability of approaches. Participants who received AOA training did have a lower SumFPA than those who did not in some cases; however, it was not possible to find a statistical significance that appeared to be more than random effects in any of the models.

Research Question 3

What difference does it make on approach stability whether AOA is visible?

In our sample, universities A and C did not show any statistical differences in approach stability, whether power on or off, when comparing approaches with access to an AOA display versus those that did not have access to an AOA device. However, participants at University B revealed a statistically significant result when power-on approaches with AOA access were compared to those without access to the AOA display.

Because this result was not consistent across all three universities, further exploration of the reasoning for this outcome is necessary. Universities A and C both used low-wing training aircraft on which most participants flew on a regular basis as students in the respective collegiate flight programs. University B used a complex aircraft for this experiment. (A complex airplane has retractable landing gear, adjustable pitch propeller, and wing flaps.) Many participants, either enrolled as students or from the local pilot community, had never flown this make and model of aircraft or had very little experience with complex aircraft in general. Despite operational training occurring during training and evaluation flights, this could have resulted in opportunities for distraction while participants adjusted to the unique flying characteristics of the complex aircraft.

Of the data analyzed at University B, 29% of participants were not flight students enrolled in the collegiate aviation program. Although the other 71% were recruited from within the university's aviation flight program, an evaluation of the intake information provided to researchers by recruited participants reveals that the frequency at which these pilots flew varied, and not all of those students had progressed to flying the complex aircraft. Formal demographic data pertaining to proficiency, currency, or experience in complex aircraft were not recorded by researchers.

Therefore, it is possible that pilots who were less or not at all familiar with an aircraft have more stabilized approaches when given visual access to an AOA display than those who are current and proficient in flying a particular make and model of aircraft.

Research Question 4

What difference does it make on approach stability between the different aircraft?

Each university used different aircraft while conducting this experiment. The aircraft used in the study were a Piper Warrior aircraft with an Avidyne Entegra flight deck system, a Piper Arrow

with an Avidyne Entegra flight deck system, and a Cirrus SR-20 with Garmin G-1000 flight deck equipment. The Piper Arrow is a complex aircraft with retractable landing gear, whereas the Cirrus SR-20 and the Piper Warrior are both fixed-gear aircraft.

To determine if the use of an AOA device would assist in the stability of an approach on the different aircraft, further information needs to be collected in future studies. The factor "university" incorporates not only the type of aircraft used but also many other components that it is not possible to separate at this time.

Research Question 5

What difference does it make on approach stability during "normal" versus "engine-off" approaches?

During the evaluation flights, the safety pilot/flight instructor pulled the throttle to idle on the second approach to landing at the second airport. The participant was to attempt the power-off landing. The research question asks if the AOA system helped the participants who had access to the AOA display to make a better approach during the power-off landing.

The data analysis shows that the use of power during the approach was statistically significant for the measurement of SumFPA for all participants. This indicates that the stability of an approach is affected by the availability of engine power. When looking at whether the presence of an AOA device was a contributing factor in the stability of the approach, there were only two situations in which this component of complexity approached statistical significance. The interaction of the Power and EvalGRP (Pwr*EvalGRP) was slightly higher than a *p*-value of 0.1000 for universities A and C during the power-off condition. The stability of the approaches for University B as measured by the SumFPA was not statistically different among the EvalGRPs.

University A EvalGRP 3 had the most variation in the SumFPA during power-off approaches. EvalGRP 3 did not receive any training on the AOA display indications and had the potential for the display to be a distracter in the completion of the power-off landing, which could explain why its performance was the most unstable.

University C EvalGRPs 2 and 3 had less variation in the SumFPA during power-off approaches than EvalGRP 4. EvalGRP 1 was not statistically different from EvalGRPs 2, 3, or 4.

When combining the results of the universities, the exact relationship of AOA usage and approach stability during a power-off approach situation is unclear. The contrast statement assessments for universities A and C and the performance results of the various groups seem to indicate that additional factors need to be considered. Factors such as the length of time between AOA education and performance, the determination of participant proficiency in the use of AOA, and the familiarity of the participants with satellite airport operations could all be contributors to approach-stability variability. Each of these factors, and likely others, would need to be considered to fully understand this relationship. At this point, a definitive conclusion cannot be made.

Research Question 6

What difference does it make if visual guidance is available for each of the groups?

The two most common types of visual-guidance information available for approaches are Visual Approach Slope Indicator (VASI) and Precision Approach Path Indicator (PAPI). The descriptions of the visual systems from the Aeronautical Information Manual (AIM) are below:

AIM 2-1-2 (a) (3-4): The basic principle of the VASI is that of color differentiation between red and white. Each light unit projects a beam of light having a white segment in the upper part of the beam and red segment in the lower part of the beam. The light units are arranged so that the pilot using the VASIs during an approach will see the combination of lights shown in figure 15.

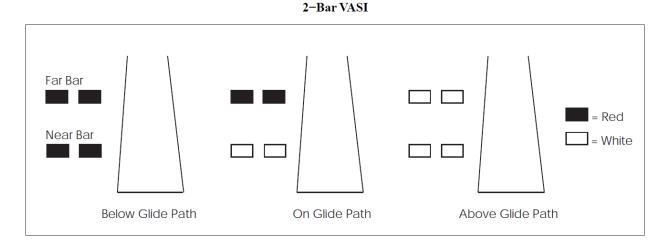


Figure 15. Two-bar VASI system (AIM, 2014)

The VASI is a system of lights arranged to provide visual descent guidance information during the approach to a runway. These lights are visible from 3–5 miles away during the day and up to 20 miles or more at night. The visual glide path of the VASI provides safe obstruction clearance within plus or minus 10 degrees of the extended runway centerline and to 4 NM from the runway threshold.

AIM 2-1-2 (b): The PAPI uses light units similar to the VASI but is installed in a single row of either two or four light units, as shown in figure 16. These lights are visible from approximately 5 miles during the day and up to 20 miles at night. The visual glide path of the PAPI typically provides safe obstruction clearance within plus or minus 10 degrees of the extended runway centerline and to 4 statute mile (SM) from the runway threshold.

Precision Approach Path Indicator (PAPI)

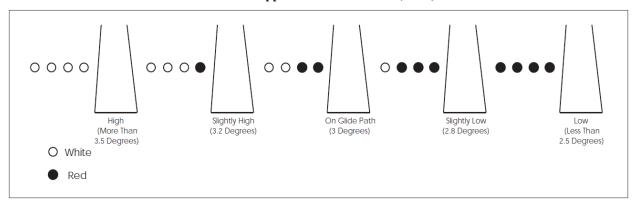


Figure 16. PAPI (AIM, 2014)

There was only one airport in the study that did not have visual guidance available to assist in the visual approach to landing. For the purposes of answering this research question, only the approaches conducted by the university having potential for an approach without visual guidance were evaluated, and of those approaches only the ones that were conducted in a power-on condition were considered because the airport where power-off approaches were conducted all had visual guidance information available for use.

It can be determined from the statistical analysis that visual guidance alone is not a significant factor in the determination of the stability of an approach under normal circumstances. There was an interaction effect between the evaluation groups and visual guidance, which warranted further inquiry. On further inquiry, it was determined that at an alpha level of 0.1000, there was no statistically significant difference in the group performance when visual guidance was or was not available. However, the combination of AOA education and AOA usage was a *p*-value of 0.1100, and it should be considered for practical significance. When looking at the differences in the group performance, Group 1 performed better than the rest of the groups. Group 4 performed better than Groups 2 and 3. A conclusion can be drawn that with both AOA education and access to AOA displays, approaches are more stable. For instances in which either just AOA access or just AOA education are provided, and a pilot is attempting an approach without visual guidance, the approaches are then more stable when the pilot has not been influenced by an AOA device. This indicates that proper education and proper usage are important to the stability of an approach when conducted to runways without visual guidance information.

4.8 COST/BENEFIT/RISKS ASSESSMENT

4.8.1 Cost Summary

Details and Explanations for:

- 1. Training
- 2. Equipment installed; equipment acquisition and installation (including all paperwork and approvals)
- 3. Equipment maintenance
- 4. Recurring training

Table 31 shows a typical cost for purchasing, installing, and training with an AOA system in a GA aircraft. Alpha Systems' equipment prices are from their website. Other costs are from analysis of traditional hourly rates for aircraft and instructor costs.

Table 31. Estimated cost for a typical AOA in GA aircraft

Item	Cost	Qty	Total Cost
Instructor cost for initial training	\$35/Hr	1.5	\$52.50
Aircraft cost for initial training	\$150/Hr	1.5	\$225
Labor cost for A&P installation	\$85/Hr	3–5	\$255–425
Labor cost for continued maintenance	\$85/Hr	0.5	\$42.50
Time on AOA during flight review for aircraft & instructor	\$185/Hr	0.5	\$92.50
Alpha Systems Legacy AOA Display	\$1600	1	\$1600
Alpha Systems Vertical Swivel Mount	\$90	1	\$90
		Total	\$2357.50-\$2527.50

4.8.2 Benefit Summary

Training

From the data collected during the planned experiments and a critical alpha of 0.10, a statistically significant difference cannot be shown in approach stability measures when AOA training has occurred versus when it has not. The difference in the averages of the approach stability measure is not statistically significant and is regarded as negligible based on this study. In this study, the cost of AOA training is 1 hour of classroom training using recorded video instruction and a 1.5-hour educational flight conducted with a certified flight instructor proficient in the specific AOA equipment.

AOA equipment

From the data collected during the planned experiments and a critical alpha of 0.10, it can be shown that there is a statistically significant difference in approach stability at University B measures when AOA equipment is installed and used versus when it was not used. The difference in the averages of the approach stability measure is 2.9362. As of October 2013, the total cost of the

Alpha Systems AOA device was \$1856.00. The installation for the Cirrus SR-20 also required a specialized mounting plate that cost an additional \$400. In a practical analysis, the cost of AOA equipment is to include acquisition cost, installation, all required paperwork and approvals, and manufacturer-recommended recurring maintenance.

AOA Equipment Training

From the data collected during the planned experiments and a critical alpha of 0.10, a statistically significant difference cannot be seen.

The assessment as to whether the gain in approach stability is worth the cost of the equipment is largely an individual question. Even with the approach stability varying among the groups in the various conditions at each university, the approaches were within acceptable conditions and resulted in acceptable landings. The qualitative feedback received from the participants does indicate that there is value for interpretation of approach stability during the approach to landing, and it is a useful tool to facilitate consistency.

5. RECOMMENDATIONS FOR FUTURE EXPERIMENTS

The main potential benefit of an AOA device is in reducing accidents due to loss of control in flight, predominately during departure and arrival operations. To determine the true impact of this device, it would be necessary to create situations in which individual pilots make decisions that put them in a position where a stall or stall/spin is likely to occur. Then, the degree to which an AOA device provides guidance information could be measured and compared against other scenarios. To conduct safe research using AOA systems for the loss of control issue, the research should be conducted using simulators (or high-fidelity advanced aviation training devices) that are equipped with an AOA system display. This would facilitate creating a more realistic scenario that has caused the most fatal accidents during approach to landing for GA (the base turn to final). Using a simulator, researchers can better control the environment and cause situations that would exacerbate a possible loss of control situation during each phase of a departure or an approach to landing without it being obvious to the participant. Additional parameters that could be considered for the impact of an AOA display could also be measured and incorporated into the analysis. Factors such as the pilot's degree of overall proficiency and experience, the pilot's degree of aircraft-specific proficiency and experience, the pilot's familiarity with the intended landing airport and runway, the presence or lack thereof of visual guidance information, and the pilot's response to emergency situations should also be considered. Additionally, eye-tracking equipment and software could be incorporated to determine the degree of the AOA display use by various participants and how that correlates to the overall approach stability.

6. REFERENCES

- 1. Federal Aviation Administration. (2014). *Aeronautical Information Manual*. Section 2-1-2 (a) (3-4). Retrieved from http://www.faa.gov/air_traffic/publications/atpubs/AIM/Index.htm.
- 2. Federal Aviation Administration. (2014). *Aeronautical Information Manual*. Section 2-1-2 (b). Retrieved from http://www.faa.gov/air_traffic/publications/atpubs/AIM/Index.htm.
- 3. Alpha Systems AOA/DepotStar, Inc. (2010). *Installation and Operations Manual for the "Legacy" Angle of Attack (AOA) Indicator*. Retrieved September 14, 2014.

APPENDIX A—SMALL AIRCRAFT DIRECTORATE LETTER

Small Airplane Directorate 901 Locust, Room 301 Kansas City, MO 64106



U.S. Department of Transportation

Federal Aviation Administration

DEC 15 2011

DepotStar Inc. Attn: Mark Korin 6180 140th Avenue NW Ramsey, Minnesota 55303

Dear Mr. Korin:

This letter is in regards to the installation of your Alpha Systems - AOA system on Normal, Utility, Acrobatic, and Commuter Category airplanes.

The installation of any component on an aircraft must be evaluated for its affect on weight, balance, structural strength, performance, powerplant operation, flight characteristics, or other qualities affecting airworthiness.

The Small Airplane Directorate views your system as non-required equipment that provides a safety benefit. We also recognize that there appears to be a conflict between 14 CFR parts 1, 21 and 43 regarding the classification of a major change. 14 CFR part 43, Appendix A does not use the word "appreciable" when classifying a change as do parts 1 and 21. As such, the Small Airplane Directorate and the Flight Standards Service, Aircraft Maintenance Division has evaluated the installation of the Alpha Systems - AOA system on Normal, Utility, Acrobatic CAR 3 or Part 23 airplanes. We conclude the installation can be considered a minor alteration, provided the following provisions are met:

- The system is non-required and used in an advisory or supplementary manner. The
 system will not be used in lieu of the airspeed indicator or aircraft stall warning system.
 No operational credit may be taken for the installation, such as reduced stall speeds,
 reduced approach speeds, reduced takeoff or landing distances, etc.
- Accuracy of indication of stall must coincide with the stall horn, or be conservative (indicate stall at a higher airspeed) as compared to existing stall warning devices.
- The installation of the system is on an unpressurized aircraft.
 NOTE: The installation on a pressurized aircraft may be a minor alteration; however, the installations will have to be evaluated on a case by case basis.
- The installation of the AOA system does not require interface with the pitot-static system; the installation does not rely on direct pressure input from the pitot-static system.
- The AOA system cannot be used as an input source to any automation or system that controls the aircraft, such as an autopilot or stick pusher unless done by STC.
- 6. If the system provides an aural warning, it should not be a source of nuisance warnings.
- 7. The installation of the AOA probe is:
 - a. On the wing:
 - On an inspection panel, or is substituting for an inspection panel, provided that the probe is located where it does not interfere with the functioning of a flight

control surface (aileron or spoiler) and does not interfere with the pitot-static system or aircraft stall warning system.

- b. On the fuselage of an unpressurized aircraft:
 - On an inspection panel, or is substituting for an inspection panel, provided that the probe is located in an area that does not interfere with pitot-static system or aircraft stall warning system.
 - On an area of the fuselage that would accommodate a like installation of an antenna, and is installed in accordance with acceptable practices such as the aircraft maintenance manual or Advisory Circulars AC 43.13-1B and AC 43.13-2B
- 8. The installation of the AOA probe pressure tubes and wiring does not require adding additional openings within the aircraft wing or fuselage primary structure.
- The installation of the AOA display does not interfere with the pilot's view of the primary flight instruments.
- 10. The electrical load requirements of the AOA system do not exceed the total generating capacity of the aircraft when operating in conjunction with the required equipment.
- 11. All electrical wiring is installed in accordance with acceptable practices such as the aircraft maintenance manual or Advisory Circulars AC 43.13-1B and AC 43.13-2B.
- 12. The calibration procedure must be simple, and repeatable.
- 13. Calibration procedures, if done in flight, can be accomplished by a pilot of average skill.

If you have any questions or need additional information, please contact Peter Rouse at 816-329-4135, or by e-mail at peter.rouse@faa.gov.

Sincerely,

Earl Lawrence

Manager, Small Airplane Directorate

APPENDIX B—CHECKLISTS

Flight Instructor Checklist Education

Date:/_ Airplane (Circle One): N586PU or N Flight Instructor: Participant Numer:	591PU
	Comments
Pre-Flight: Verify Student's Medical & Pilot Certificate Student's Total Cirrus Time (Approximate) Push in AOA Circuit Breaker Remove AOA Device Sticker Verify Volume Toggle Switch is Down Record "Start" Time (hh:mm) In-Flight: Power Off Stall Power On Stall Accelerated Stall (CFI Demonstration) Crawfordsville Municipal Airport (KCFJ): Touch & Go #1 Touch & Go #2 Was Visual Guidance Available? Frankfort Municipal Airport (KFKR): Full Stop #1 Full Stop #2 Was Visual Guidance Available? Purdue University Airport (KLAF): Touch & Go #1 Full Stop Landing Was Visual Guidance Available? Post Flight: Record "Stop" Time (hh:mm) Record Total Hobbs Time Return Sticker to AOA Device Pull Out AOA Circuit Breaker Check In Aircraft/iPad (No Logbook Entry) Return to AOA Office With Participant Additional Notes or Comments	Yes / No Yes / No Yes / No Yes / No

Date:// Airplane (Circle One): N586PU or N591 Flight Instructor: Participant Number:	PU
	Comments
Pre-Flight:	
Verify Student's Medical & Pilot Certificate	
Student's Total Cirrus Time (Approximate)	
Push in AOA Circuit Breaker	
Remove AOA Device Sticker	
Verify Toggle Switch is Down	
Record "Start" Time (hh:mm)	
Crawfordsville Municipal Airport (KCFJ):	¬
Touch & Go #1	
Touch & Go #2	
Was Visual Guidance Available?	Yes / No
Frankfort Municipal Airport (KFKR):	
Full Stop #1	
Full Stop #2 (Simulated Engine Failure)	
Was Visual Guidance Available?	Yes / No
Purdue University Airport (KLAF):	٦
Touch & Go #1	-
Full Stop Landing Was Visual Guidance Available?	Yes / No
Post Flight:	
Record "Stop" Time (hh:mm)	7
Record Total Hobbs Time	
Return Sticker to AOA Device	
Pull Out AOA Circuit Breaker	
Checkin Aircraft/iPad	
Return to AOA Office With Participant	
Additional Notes or Comments	

Date:/Airplane (Circle One): N586PU or Note	591PU
	Comments
Pre-Flight:	
Verify Student's Medical & Pilot Certificate	
Student's Total Cirrus Time (Approximate)	
Pull Out AOA Circuit Breaker	
Leave AOA Device Sticker in Place	
Verify Toggle Switch is Down	
Record "Start" Time (hh:mm)	
Crawfordsville Municipal Airport (KCFJ):	
Touch & Go #1	
Touch & Go #2 Was Visual Guidance Available?	Vec / No
	Yes / No
Frankfort Municipal Airport (KFKR): Full Stop #1	
Full Stop #2 (Simulated Engine Failure)	
Was Visual Guidance Available?	Yes / No
Purdue University Airport (KLAF):	103 / 140
Touch & Go #1	
Full Stop Landing	
Was Visual Guidance Available?	Yes / No
Post Flight:	
Record "Stop" Time (hh:mm)	
Record Total Hobbs Time	
Checkin Aircraft/iPad	
Return to AOA Office With Participant	
Additional Notes or Comments	

Date://///Airplane (Circle One): N586PU or N591 Flight Instructor:Participant Number:	
	Comments
Pre-Flight:	_
Verify Student's Medical & Pilot Certificate	
Student's Total Cirrus Time (Approximate)	
Push in AOA Circuit Breaker	
Remove AOA Device Sticker	
Verify Toggle Switch is Down	
Record "Start" Time (hh:mm)	
Crawfordsville Municipal Airport (KCFJ):	٦
Touch & Go #1 Touch & Go #2	
<u> </u>	Voc. / No.
Was Visual Guidance Available?	Yes / No
Frankfort Municipal Airport (KFKR):	٦
Full Stop #1 Full Stop #2 (Simulated Engine Failure)	-
Was Visual Guidance Available?	Yes / No
Purdue University Airport (KLAF):	
Touch & Go #1	٦
Full Stop Landing	
Was Visual Guidance Available?	Yes / No
Post Flight:	
Record "Stop" Time (hh:mm)	7
Record Total Hobbs Time	
Return Sticker to AOA Device	
Pull Out AOA Circuit Breaker	
Checkin Aircraft/iPad	
Return to AOA Office With Participant	
Additional Notes or Comments	

Date://Airplane (Circle One): N586PU or N5 Flight Instructor: Participant Number:	91PU
	Comments
Pre-Flight:	
Verify Student's Medical & Pilot Certificate	
Student's Total Cirrus Time (Approximate)	
Pull Out AOA Circuit Breaker	
Leave AOA Device Sticker in Place	
Verify Toggle Switch is Down	
Record "Start" Time (hh:mm) Crawfordsville Municipal Airport (KCFJ):	
Touch & Go #1	
Touch & Go #2	
Was Visual Guidance Available?	Yes / No
Frankfort Municipal Airport (KFKR):	
Full Stop #1	
Full Stop #2 (Simulated Engine Failure)	
Was Visual Guidance Available?	Yes / No
Purdue University Airport (KLAF):	
Touch & Go #1	
Full Stop Landing	
Was Visual Guidance Available?	Yes / No
Post Flight:	
Record "Stop" Time (hh:mm)	
Record Total Hobbs Time	
Checkin Aircraft/iPad Patrim to AOA Office With Porticipant	
Return to AOA Office With Participant	
Additional Notes or Comments	
<u> </u>	

APPENDIX C—AOA CALIBRATION PROCEDURE



Legacy AOA Kit AOA Set Points Calibration Procedure

From the factory, all Alpha Systems AOA Displays are not calibrated

AOA Set Point Calibration - 3 steps:

- 1. Ground
- Optimum Alpha Angle
- Cruise

All LEDs flash then display goes dark - indicates a non-calibrated unit

#1 - Put Display into Ground Set Point Calibration Mode:

To calibrate the Ground Set Point:

- Make sure aircraft is in a zero pressure condition, preferably a no wind environment, such as in a hanger.

- d Continue to hold the calibration button for about 6-8 seconds after power is applied

If NO LEDs are illuminated, the ground calibration procedure was a success and the ground set point has been entered into the system.

Upon releasing the calibration button, or system power up, the blue and last green LEDs will flash five times then display turns dark.

This lets you know that the unit has successfully completed ground calibration but is not functional at this time as the last two calibration set points must be calibrated.

After this step, ground calibration will never have to be recalibrated again unless the system is reset to factory defaults.

Page 1 of 3

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Legacy AOA Kit AOA Set Points Calibration Procedure

#2a - Put Display into Optimum Alpha Angle (OAA) Set Point Calibration Mode:

To put the display into OAA calibration mode:

- a powering the unit on
- after the unit is powered on, press and hold brightness button for eight (8) seconds If the above two steps were done correctly the Display will flash the Green Donut three times, and then continue to repeat a flashing pattern of: two flashes every six seconds until unit is out of OAA calibration mode.

#2b –Flying the correct configuration for OAA calibration:

To get into the correct flying configuration for OAA calibration, we ask you fly:

- at a low, constant power setting

Then, once in this flight configuration, slowly pitch back until your aircraft no longer increases in altitude but also does not decrease in altitude. We call this point: minimum maneuverability.

ANOTHER way to reach configuration for OAA calibration is to determine Vstall for your aircraft weight on that day, for that particular flight. Once you have determined Vstall, fly:

- d at 1.3 x Vstall
- ₫ clean

and calibration the OAA set point in this configuration.

#2c -Calibrating the OAA Set Point:

To calibrate the OAA set point on the Display:

- - - o display will go back to flashing donut, but donut will stay illuminated between flashes

 - d Flash the Green Donut and Yellow Chevron three times Probe Angle must be decreased

Page 2 of 3

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Legacy AOA Kit AOA Set Points Calibration Procedure

#3a - Put Display into Cruise Set Point Calibration Mode:

To put the display into cruise calibration mode:

After OAA has been calibrated, press and hold brightness button for eight (8) seconds If the above step is done correctly, then the Display will flash the Blue Bar three times, and then continue to repeat a flashing pattern of: two flashes every six seconds until unit is out of Cruise calibration mode.

#3b -Flying Configuration for Cruise Calibration:

To get into the correct flying configuration for Cruise calibration we ask you fly:

of at 70% Power

ANOTHER way to reach configuration for Cruise calibration is to fly:

xt at 70% Power

and calibration the Cruise set point in this configuration.

#3c -Calibrating the Cruise Set Point:

To calibrate the Cruise set point on the Display:

#4 - Storing your Calibrated OAA and Cruise Set Points:

To save both the OAA and Cruise set points, on the Display:

press and hold brightness button for eight (8) seconds.

If the above was done correctly, then the Display will:

Illuminate it's light segments upwards and then downwards, one by one – Calibration complete, OAA and Cruise set points are saved.

If the above was not done correctly, the Display will:

Page 3 of 3

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APPENDIX D—IRB CONSENT FORMS

RESEARCH PARTICIPANT CONSENT FORM - PARTICIPANTS

Angle of Attack Equipment General Aviation Operations

Brian Dillman, Associate Professor

Aviation Technology

Purdue University

What is the purpose of this study?

Purdue University, in conjunction with The Ohio State University and Florida Institute of Technology, has received funding from the FAA Center of Excellence Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS) to conduct the following research.

The central analysis of this research is the ability of an angle of attack (AOA) display to enhance the situational awareness of a pilot concerning AOA and assist in the representation of the flight approach path in conjunction with the traditional means of approach path analysis. The experimental design will be such that pilots will be trained in an actual aircraft to understand the dynamics of AOA displays and their functionality and use in regards to angle of attack awareness and the proximity to a stalled condition. You, along with approximately 50 other individuals, have been selected to participate in this study because you meet the flight experience qualifications. These qualifications include total flight hours between 50 and 200, as well as a Private Pilot Certificate.

What will I do if I choose to be in this study?

You, as a participant, will be divided into one of four possible groups shown in the table below.

		Education	
		None	AOA Ground Instruction
splays	No Access	10 Participants	10 Participants
AOA Displays	AOA Display Access	10 Participants	10 Participants

Prior to any training or flight evaluation, you will be asked to complete a survey regarding your flight experience and your knowledge of angle of attack in regards to its use for approach stabilization. You must complete this survey to progress with the experiment.

If assigned to a group scheduled to receive training on the use of angle of attack devices. You will receive approximately .5 hours of ground training and 1.5 hours flight training with a certified flight instructor.

Regardless of the group you are assigned, you will then all fly visual approaches to landing during a 2 hour evaluation period. An evaluator will be present in the cockpit that is a certified flight instructor. The certified flight instructor is present primarily for safety purposes. However, because of their presence in the cockpit, they will also be taking notes on your performance. Your performance will be measured via accuracy of approach path stabilization and the length of time between the recognition of a deviation situation and a corresponding input for correction.

Finally, you will complete a qualitative, open-ended interview on the your impression of angle of attack displays for stabilized approaches and whether or not the training module was sufficient to facilitate proficiency in analysis and control. Either the principal investigator or a co-investigator will be conducting this interview.

How long will I be in the study?

If assigned to a group in which you will receive training prior to the evaluation, you will receive one session of ground training lasting .5 hours, one session of flight training lasting 1.5 hours, and then a 2 hour evaluation session. These sessions may be broken up over numerous days. If assigned to a group without training prior to evaluation, you will only complete the 2 hour evaluation session. The total time commitment will vary from 3 to 6 total hours over 5 days.

What are the possible risks or discomforts?

The risk associated with this study is not greater than that of every day activates associated with the Professional Flight Program. The presence of the flight instructor in the cockpit is for observational purposes only, but will assist in the event of an emergency.

It is possible that a breach of confidentiality may occur. They provisions taken to ensure this does not occur are outlined in the confidentiality section of this document. The device installed does not pose any additional safety risk than that of normal flight.

Are there any potential benefits?

Benefits to you are the provision of information that could potentially help the pilots to better interpret the flight path & aircraft attitude relationship. Additionally, you will receive between 2 and 3.5 flight hours at no cost. Benefits gained by the general aviation community are potentially the reduction of loss of control incidents/accidents and an improvement of safety in general aviation.

What alternatives are available?

You will be randomly assigned to one of four different experimental groups. You, as a participant, do not have control over which group you are assigned to. Participation in this study is completely voluntary and you may choose not to participate in this study.

Will I receive payment or other incentive?

As a participant, you will be monetarily compensated for this study. Compensation is allocated per flight hour in the amount of \$10 per hour. All payments will be made in cash and checks.

Information will be recorded on each individual paid for their participation and will be reported to the business office. Provisions for international students will be made. In the event that you choose to withdraw from the study, you will be compensated based on the total flight hours flown at the time of withdrawal.

Are there costs to me for participation?

You are responsible for transportation to and from the Purdue University Airport where the study will be conducted.

Will information about me and my participation be kept confidential?

The project's research records may be reviewed by the principal investigator, co-investigators, and by departments at Purdue University responsible for regulatory and research oversight.

You will be assigned a random number code determined using a random number generator. Your results will only be identifiable by the randomly assigned code. Recorded data, both physical and numerical will be stored in the office of the principal investigator, Brian Dillman. This office will remain locked when he is not present. Any physical identifiers found in the video recordings will be erased, along with the video, after use. Any and all personal information will remain confidential and only be viewable by the principal and co-investigators. All personal data will be destroyed upon the completion of the experiment (Expected: September 31, 2014).

Flight instructors present in the cockpit during your training and evaluation will have signed a confidentiality agreement to ensure that your privacy is maintained.

What are my rights if I take part in this study?

Your participation in this study is voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Any re-existing relationships you may have with a participant, evaluator, or investigator will not be affected if you choose to withdraw form this study.

If you choose to withdraw from this study, please alert the principal investigator, a co-investigator, or the flight instructor observing the flight at any time. If you wish to withdraw from the study after data has already been collected, please contact the principal investigator or a co-investigator.

However, upon completion of the experiment, when the code identifier key is destroyed, it will not be possible to withdraw your data.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, please contact any of the researchers listed below:

Brian Dillman	Principal Investigator	765-494-9978	dillman@purdue.edu
Gil Jones	Co-Investigator	203-927-1421	jones273@purdue.edu
Lucas Rudari	Co-Investigator	765-637-1361	lrudari@purdue.edu

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Human Research Protection Program at (765) 494-5942, email (irb@purdue.edu) or write to:

Human Research Protection Program - Purdue University

Ernest C. Young Hall, Room 1032

155 S. Grant St.

West Lafayette, IN 47907-2114

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

Participant's Signature	Date	
Participant's Name	_	
Researcher's Signature	 Date	

RESEARCH PARTICIPANT CONSENT FORM - PARTICIPANTS

Angle of Attack Equipment General Aviation Operations

Steve Cusick, Associate Professor

College of Aeronautics

Florida Institute of Technology

What is the purpose of this study?

Florida Institute of Technology, in conjunction with The Ohio State University and Purdue University, has received funding from the FAA Center of Excellence Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS) to conduct the following research.

The purpose of this study is to compare how use of an angle of attack (AOA) gauge influences participant's knowledge and awareness of aircraft stalls in an experimental setting. The experimental design will be such that pilots will be trained in an actual aircraft to understand the dynamics of AOA displays and their functionality and use in regards to angle of attack awareness and the proximity to a stalled condition.

The research question will be: does the usage of an Angle of Attack indicator increase student performance and situational awareness of stall angle when completing a straight in approach to landing?

What will I do if I choose to be in this study?

Prior to any training or flight evaluation, you will be asked to complete a survey regarding your flight experience and your knowledge of angle of attack in regards to its use for approach stabilization. You must complete this survey to progress with the experiment.

Participants will receive a ground briefing and you will then all fly visual approaches to landing during a 2 hour evaluation period. An evaluator will be present in the cockpit that is a certified flight instructor. The certified flight instructor is present primarily for safety purposes. However, because of their presence in the cockpit, they will also be taking notes on your performance. Your performance will be measured via accuracy of approach path stabilization and the length of time between the recognition of a deviation situation and a corresponding input for correction.

Finally, you will complete a qualitative, open-ended interview on your impression of angle of attack displays for stabilized approaches.

How long will I be in the study?

The total time commitment will vary from 3 to 6 total hours over 5 days.

What are the possible risks or discomforts?

The risk associated with this study is not greater than that of everyday activities associated with the Flight Program. The presence of the flight instructor in the cockpit is for observational purposes only, but will assist in the event of an emergency.

The provisions taken to ensure this does not occur are outlined in the confidentiality section of this document. The device installed does not pose any additional safety risk than that of normal flight.

Are there any potential benefits?

The potential benefits are educational in nature. Learning about Angle of Attack indicator systems and their potential for reducing loss of control is of benefit to all pilots that are unaware of these systems. Benefits to the General Aviation community are unknown, but could assist in the reduction of loss of control accidents.

Will I receive payment or other incentive?

You will be compensated for this study in flight time. Flight time for each participant is expected to be 2.5 to 3 hours of flight time. Those participants that complete the study will be provided a stipend of \$100 as compensation in addition to the flight time.

Are there costs to me for participation?

You are responsible for transportation to and from the Melbourne International Airport and the FIT Aviation Campus where the study will be conducted.

Will information about me and my participation be kept confidential?

The project's research records may be reviewed by the principal investigator, co-investigators, and by departments at Florida Institute of Technology responsible for regulatory and research oversight.

You will be assigned a random number code determined using a random number generator. Your results will only be identifiable by the randomly assigned code. Recorded data, both physical and numerical will be stored in the office of the principal investigator, Steve Cusick. This office will remain locked when he is not present. Any and all personal information will remain confidential and only be viewable by the principal and co-investigators. All personal data will be destroyed upon the completion of the experiment (Expected: December 31, 2014).

Flight instructors present in the cockpit during your training and evaluation will have signed a confidentiality agreement to ensure that your privacy is maintained.

What are my rights if I take part in this study?

You will be randomly assigned to one of four different experimental groups. As a participant, you do not have control over which group you are assigned.

Your participation in this study is voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled. If you withdraw, the \$100 stipend for completing the study will not be provided. You will receive the flight time that you have completed up until the time you choose to withdraw. Any of your data that has been collected will be removed from the study and destroyed if you so choose. Any re-existing relationships you may have with a participant, evaluator, or investigator will not be affected if you choose to withdraw form this study.

If you choose to withdraw from this study, please alert the principal investigator, a co-investigator, or the flight instructor observing the flight at any time. If you wish to withdraw from the study after data has already been collected, please contact the principal investigator or a co-investigator.

However, upon completion of the experiment, when the code identifier key is destroyed, it will not be possible to withdraw your data.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, please contact any of the researchers listed below:

Steve Cusick Principal Investigator	(321) 674-7628	scusick@fit.edu
Scott Winter Co-Investigator	(321) 674-7639	swinter@fit.edu
Dennis Wilt Co-Investigator	(757) 784-8113	dwilt2012@fit.edu

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Chairman of the Institutional Review Board of the Florida Institute of Technology, Dr. Lisa Steelman at (321) 674-7316 or e-mail (lsteelma@fit.edu).

Documentation of Informed Consent

Researcher's Signature

I have had the opportunity to read this consent form and have the research study explained had the opportunity to ask questions about the research study, and my questions had answered. I am prepared to participate in the research study described above. I will be copy of this consent form after I sign it.		
Participant's Signature	Date	
Participant's Printed Name		

D-7

Date

RESEARCH PARTICIPANT CONSENT FORM - PARTICIPANTS

Angle of Attack Equipment General Aviation Operations

Shawn Pruchnicki, Research Coordinator

Center for Aviation Studies

The Ohio State University

What is the purpose of this study?

The Ohio State University, in conjunction with Purdue University and Florida Institute of Technology, has received funding from the FAA Center of Excellence Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS) to conduct the following research.

The central analysis of this research is the ability of an angle of attack (AOA) display to enhance the situational awareness of a pilot concerning AOA and assist in the representation of the flight approach path in conjunction with the traditional means of approach path analysis. The experimental design will be such that pilots will be trained in an actual aircraft to understand the dynamics of AOA displays and their functionality and use in regards to angle of attack awareness and the proximity to a stalled condition. You, along with approximately 40 other individuals, have been selected to participate in this study because you meet the flight experience qualifications. These qualifications include total flight hours between 50 and 200, as well as a Private Pilot Certificate

What will I do if I choose to be in this study?

You, as a participant, will be randomly assigned into one of four possible groups shown in the table below.

		Education	
		None	AOA Ground Instruction
splays	No Access	10 Participants	10 Participants
AOA Displays	AOA Display Access	10 Participants	10 Participants

Prior to any training or flight evaluation, you will be asked to complete a survey regarding your flight experience and your knowledge of angle of attack in regards to its use for approach stabilization. You must complete this survey to progress with the experiment.

If assigned to a group scheduled to receive training on the use of angle of attack devices. You will receive approximately .5 hours of ground training and 1.5 hours flight training with a certified flight instructor.

Regardless of the group you are assigned to, you will then fly several touch-n-goes in visual conditions during a 2 hour period. A certified flight instructor will be with you at all times and is there to act primarily for safety purposes. However, because of their presence in the cockpit, they will also be collecting data as you perform several maneuvers. Your performance will be measured via accuracy of approach path stabilization and the length of time between the recognition of a deviation situation and a corresponding input for correction.

Finally, you will complete a qualitative, open-ended interview on the your impression of angle of attack displays for stabilized approaches and whether or not the training module was sufficient to facilitate proficiency in analysis and control. Either the principal investigator or a co-investigator will be conducting this interview.

How long will I be in the study?

If assigned to a group in which you will receive training prior to the evaluation, you will receive one session of ground training lasting .5 hours, one session of flight training lasting 1.5 hours, and then a 2 hour evaluation session. These sessions may be broken up over numerous days. If assigned to a group without training prior to evaluation, you will only complete the 2 hour evaluation session. The total time commitment will vary from 3 to 6 total hours depending on your group assignment.

What are the possible risks or discomforts?

The risk associated with this study is not greater than that of every day activates associated with the Professional Pilot Program. The presence of the flight instructor in the cockpit is for observational purposes only, but will assist in the event of an emergency.

It is possible that a breach of confidentiality may occur. They provisions taken to ensure this does not occur are outlined in the confidentiality section of this document. The device installed does not pose any additional safety risk than that of normal flight.

Are there any potential benefits?

There are no direct benefits to the participant. Indirect benefits include the provision of information that could potentially help the pilots to better interpret the flight path & aircraft attitude relationship. Additionally, you will receive between 2 and 3.5 flight hours at no cost. Benefits gained by the general aviation community are potentially the reduction of loss of control incidents/accidents and an improvement of safety in general aviation.

What alternatives are available?

You will be randomly assigned to one of four different experimental groups. You, as a participant, do not have control over which group you are assigned to. Participation in this study is completely voluntary and you may choose not to participate in this study.

Will I receive payment or other incentive?

As a participant, you will be monetarily compensated for this study. Compensation is allocated per flight hour in the amount of \$10 per hour. Depending on your group assignment, you will have to fly 2 or 3.5 hours. Your maximum compensation is \$35, your minimum compensation is \$20. All payments will be made by check.

Information will be recorded on each individual paid for their participation and will be reported to the business office. Provisions for international students will be made. In the event that you choose to withdraw from the study, you will be compensated based on the total flight hours flown at the time of withdrawal.

Are there costs to me for participation?

You are responsible for transportation to and from The Ohio State University Airport where the study will be conducted.

Will information about me and my participation be kept confidential?

The project's research records may be reviewed by the principal investigator, co-investigators, and by departments/centers at the Ohio State University responsible for regulatory and research oversight.

You will be assigned a random number code determined using a random number generator. Your results will only be identifiable by the randomly assigned code. Recorded data, both physical and numerical will be stored in the office of the co-investigator, Shawn Pruchnicki. This office will remain locked when he is not present. Any physical identifiers found in the video recordings will be erased, along with the video, after use. Any and all personal information will remain confidential and only be viewable by the principal and co-investigators. All personal data will be destroyed upon the completion of the experiment (Expected: December 31, 2014).

Flight instructors present in the cockpit during your training and evaluation will have signed a confidentiality agreement to ensure that your privacy is maintained.

What are my rights if I take part in this study?

Your participation in this study is voluntary. You may choose not to participate or, if you agree to participate, you can withdraw your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Any re-existing relationships you may have with a participant, evaluator, or investigator will not be affected if you choose to withdraw form this study. Furthermore, if you choose to withdraw from the study, there will be no effect on the grade you receive in any course if you are a student at this university.

If you choose to withdraw from this study, please alert the principal investigator, a co-investigator, or the flight instructor observing the flight at any time. If you wish to withdraw from the study after data has already been collected, please contact the principal investigator or a co-investigator. However, upon completion of the experiment, when the code identifier key is destroyed, it will not be possible to withdraw your data.

Who can I contact if I have questions about the study?

If you have questions, comments or concerns about this research project, please contact any of the researchers listed below:

Seth Young Principal Investigator	(614) 292-4556	young.1460@osu.edu
Shawn Pruchnicki Co-Investigator	(614) 565-8795	pruchnicki.4@osu.edu
Marshall Pomeroy Research Assistant	(814) 574-8764	pomeroy.34@osu.edu
Justin Abrams Research Assistant	(860) 502-9401	abrams.130@osu.edu

If you have questions about your rights while taking part in the study or have concerns about the treatment of research participants, please call the Office of Responsible Research Practices: Human Research Protection Program at (614) 688-8457, anonymously at (800) 294-9350, email hsconcerns@osu.edu or write to:

Institutional Review Board c/o Office of Responsible Research Practices 300 Research Administration Building 1960 Kenny Road Columbus, OH 43210

Documentation of Informed Consent

I have had the opportunity to read this consent form and have the research study explained. I have had the opportunity to ask questions about the research study, and my questions have been answered. I am prepared to participate in the research study described above. I will be offered a copy of this consent form after I sign it.

		·
Participant's Signature	Date	
Participant's Name		
Researcher's Signature	Date	

APPENDIX E—PILOT QUESTIONNAIRES

Pre-Flight Survey - Angle of Attack Equipment in General Aviation Operations

1. Participant Identification Number (Entered by Examiner)
2. Gender
[] Male
[] Female
3. Age
4. What Certifications and Ratings do you hold? (Select all that apply)
[] Private
[] Instrument [] Commercial [] Multi-Engine [] CFI [] CFII [] MEI [] MEI
5. What is your total flight hour experience level?
Number of flight hours(total time)
6. During a visual approach to landing, what mechanisms do you use to assist with your approach?
7. To the best of your ability, please describe what causes a wing to stall.
8. To the best of your ability please describe an accelerated stall.
9. To the best of your ability, please describe angle of attack.
10. Which of the following best describes your use of angle of attack devices?

[] I have never used an angle of attack device
[] I have some experience with angle of attack devices
[] I often use angle of attack devices
11. To the best of your ability, please describe how an angle of attack device works.
Post Flight Survey - Angle of Attack Equipment in General Aviation Operations (Participants without access to an AOA display)
1. Participant Identification Number
2. Have you heard of an Angle of Attack system?
[] Yes
[] No
3. If the answer to question number 2 is yes, describe how you think an Angle of Attack system works.
4. What instruments and visual cues do you use to assist you in your approach?
5. During what phase of the approach would you most often use an AoA indicator and visual cues
6. Did you encounter a situation while flying as part of this study in which these instruments and visual cues prevented a stall situation (not intentional)?
[] Yes
[] No
7. Do you have any other additional comments about the study?

Post Flight Survey - Angle of Attack Equipment in General Aviation Operations (Participants with access to an AoA display)

1. Participant Identification Number
2. To the best of your ability, please describe how an angle of attack device works.
3. Did you find that the angle of attack device helped with your approach to landing?
[] Yes
[] No
4. How did you use the device to assist with your approach?
5. If yes, during what phase of the approach did you most often use the device?
6. Did you encounter a situation in which the angle of attack device prevented a stall situation?
7. Do you believe that angle of attack devices would be useful in the cockpit of any aircraft you are flying? Why?
8. What could be better about the device?
9. Did you find the angle of attack device to be distracting? If so, how?
10. Could the device be better positioned in the cockpit? If so, how?
11. Were there any drawbacks to the device that you could share?
12. Did this study change your understanding of angle of attack? If so, how?

13. Are there other phases of flight that this device may be useful?
14. If you received training on AoA as part of this study, are there any aspects of the training that need improvement?
15. Do you have any other additional comments?

APPENDIX F—OSU SAFETY PILOT REFERENCE GUIDE

Instructor Quick Reference Guide: AOA Research Flights Angle of Attack Equipment in General Aviation Operations

Group 1: Receives AoA Training / Allowed AoA Access

In this condition participants receive training on the use of the AoA and have access to the AoA indicator during the data collection.

This group has both experimental conditions applied allowing researchers to compare findings with the other experimental and control groups. This condition has **two flights**: one to provide AoA training and a second flight to collect data during approach and landings with the AoA ON.





Group 2: Receives AoA Training / No AoA Access

In this condition participants are trained on the use of the AoA but do not have access to the AoA indicator during the data collection.

The purpose of this group is to investigate participants that must revert back to not having an AoA during flight and seeks to determine if the AoA training provides an educational transfer of AoA information. This condition has **two flights**: one to provide AoA training and a second flight to collect data during approach and landings with the AoA OFF.

Group 3: No AoA Training / Allowed AoA Access

In this condition participants do not receive training on the use of the AoA but have access to the AoA indicator during the data collection.

Having a group that does not receive AoA training but access in flight to an AoA indicator will help to determine if the AoA education and training is beneficial. It also simulates a scenario where pilots fly an aircraft with an AoA installed but have not received training on the use of the AoA. This condition has only one flight to collect data during approach and landings with the AoA ON.





Group 4: No AoA Training / No AoA Access

In this condition participants do not receive AoA training and do not have access to the AoA indicator during the data collection.

This is the control group. It allows investigators to compare pilots in this group to pilots in groups 1, 2, or 3 who have experimental conditions applied. This condition has only one flight to collect data during approach and landings with the AoA OFF.

What is "AoA Training"?

Training involves two parts:

- 1. Watching the AoA training video
- 2. In-flight instruction on the use of AoA during the following maneuvers: power off stall, power on stall, accelerated stall (instructor demo only) and 6 takeoffs/landings (2 at each airport)

What is "AoA Access"?

AoA access refers to the use of the AoA indicator by the participant during the data collection flight.

All participants complete a flight where flight data is recorded. However, only two of the groups will have access to the AoA indicator during this flight.

Center for Aviation Studies





THE OHIO STATE UNIVERSITY

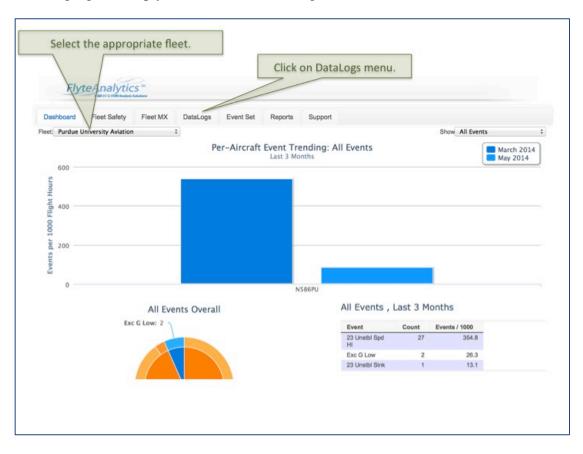
Please feel free to contact the research team with any questions!

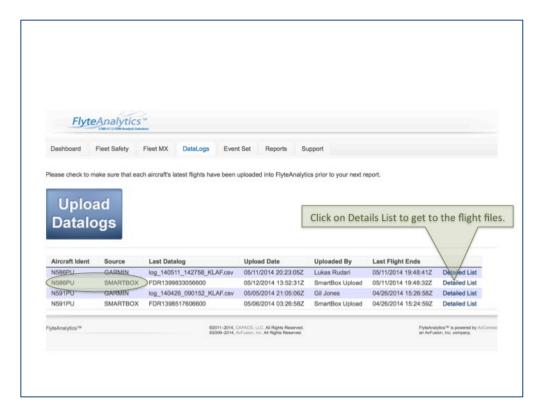
Shawn Pruchnicki (614) 595-8765 Marshall Pomeroy (814) 574-8764 Justin Abrams (860)502-9401

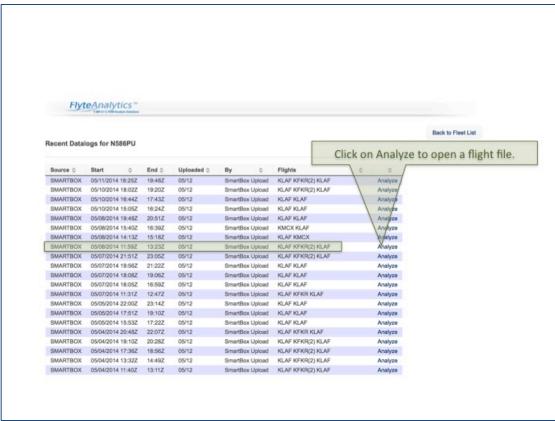
APPENDIX G—PROCEDURE FOR FPA ANALYSIS

Procedure: How to analyze FPA using FlyteAnalytics

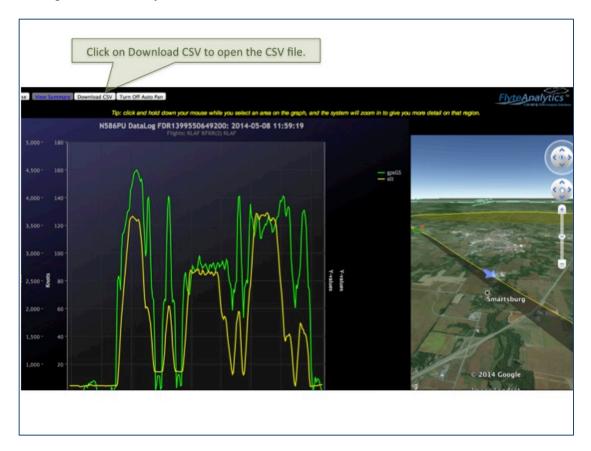
The first thing to do is to get used to FlyteAnalytics (FA) Portal and how to locate a specific flight listed as participant in the study. The flights are organized by aircraft and time. So, first determine which aircraft will be used to extract the data and then locate its file using the date and time of flight. Remember that FA portal uses GMT, so it is necessary to add hours to the time indicated by the university to find the actual flight on FA portal. There might also be some slight differences (5 minutes maximum) between what the university provides and what is recorded on FA Portal. The following figures help you with FA Portal design.







After identifying the correct flight file, download the CSV file and save it in a hard drive or in the cloud. The idea is to have all flights saved in a location in which they can be reanalyzed as many times as necessary. It is also important to remember that some changes can be made to the study parameters or methods and having the file ready to change is essential to avoid working on the same file again if necessary.



On each flight file, copy the spreadsheet named "Approach X" to the file and start looking for the approaches that are the scope of the study. The best way of doing it is going to the end of the file and move backwards, looking at the altitude as a parameter to limit each approach. After establishing each approach boundaries (use a background color to make it easier to identify them), copy and paste the parameters listed in the "Approach" spreadsheet and the calculations will be completed automatically. Copy the calculated cells to the "Data Collection" MS Excel file.

After finishing each approach, rename the spreadsheet as "Approach Y", using Y to identify the approach, numbering from 1 to 6, from the last to the first. This way, there is standardization among all files. In the end of each flight, each flight file should have 7 spreadsheets, one with the flight data and 6 with approaches calculations. Save the file and move to the next flight.

APPENDIX H—DATA ORGANIZATION

Procedure: Organizing Flight Data

Adding evaluation sheet info to the flight list

To add the flight information, the first thing that should be done is creating a spreadsheet to hold all of the information. It should have 8 columns, plus one column for each airport. The columns should be the date of the flight, time of the flight, aircraft ID, evaluation group number, "how device was used," "student performance," "frequency of use," "total Cirrus time," and then one column for whether visual guidance was used at each airport. The spreadsheet may look something like this:

4	Α	В	С	D	E	F	G	Н	T.	J	K
	Date	Start Time	Aircraft	Eval Group	How device was used	Student Performance	Frequency of use	Total Cirrus time	Visual Frank.	Visual Craw.	Visual Laf.
	4/9/2014	0935	N586PU	2	3	1	3	140	NO	YES	YES
	4/9/2014	1146	N586PU	4	3	1	1	187	NO	YES	YES
	4/9/2014	1152	N591PU	3	2	1	2	120	NO	YES	YES
- 1	4/9/2014	1718	N586PU	3	2	4	2	80	NO	YES	YES
	4/11/2014	0949	N591PU	4	3	1	1	60	NO	YES	YES
	4/11/2014	1134	N591PU	3	2	2	2	84	NO	YES	YES
1	4/12/2014	0939	N586PU	3	2	3	3	65	NO	YES	YES
1	4/12/2014	0935	N591PU	4	3	1	1	0	NO	YES	YES
0	4/15/2014	1748	N586PU	3	3	2	2	60	NO	YES	YES
1	4/18/2014	1746	N591PU	3	3	2	2	120	NO	YES	YES
2	4/22/2014	1759	N591PU	1	1	2	4	86	NO	YES	YES
3	4/26/2014	1156	N586PU	2	2	2	2	102	NO	YES	YES
4	4/30/2014	0736	N586PU	1	X	1	X	185	NO	YES	YES
5	5/4/2014	0745	N586PU	1	2	1	4	140	NO	YES	YES
6	5/4/2014	0933	N586PU	2	3	4	1	80	NO	YES	YES
7	5/4/2014	1338	N586PU	1	2	2	2	80	NO	YES	YES
8	5/4/2014	1650	N586PU	4	3	4	1	50	NO	YES	YES
9	5/7/2014	0733	N586PU	1	2	4	2	90	NO	YES	YES
0	5/7/2014	1754	N586PU	1	2	1	2	39	NO	YES	YES
1	5/8/2014	0758	N586PU	1	2	1	2	190	NO	YES	YES
2	5/10/2014	1404	N586PU	1	2	2	3	180	NO	YES	YES
3	5/11/2014	1426	N586PU	2	3	2	1	150	NO	YES	YES
4	6/17/2014	0950	N586PU	4	3	4	2	4	NO	YES	YES
5	7/2/2014	1310	N586PU	4	3	2	1	150	NO	YES	YES
6	7/2/2014	1621	N586PU	2	3	2	1	100	NO	YES	YES
7	7/9/2014	1343	N586PU	2	3	3	1	91	NO	YES	YES
8	7/9/2014	1520	N586PU	2	3	2	1	80	NO	YES	YES

Each evaluation sheet contains a good amount of information, but not all of it will be entered into the spreadsheet. For total cirrus time, simply enter in the recorded amount of time. The same goes for the time, date, aircraft, and EvalGRP. The 3 other columns correspond to multiple choice questions filled out by the instructor. For these, assign a number to each answer starting with 1 for the top answer.

To the best of your ability, please describe how the device was used by the student.

O Primary Airspeed Instrument

O Secondary Airspeed Instrument

Device Usage Not Permitted

Using this method, fill in the rest of the spreadsheet. To the side, create a key that shows what number corresponds to what value.

- 1	
1	Primary Instrument
2	Seconday Instrument
3	Not Used
e:	
1	0-200 ft. past the point
2	>200 ft. past the point
3	short of the point
4	add power/ go around
1	Never
2	Rarely
3	Sometimes
4	Often
_	All of the time
	2 3 e: 1 2 3 4 1 2 3 4

Finding wind information

To gather wind information for each flight, one must know the start time of the flight, end time of the flight, and the overall location of the flight. The first thing that should be done is converting the times to Zulu time. This usually entails adding a certain amount of hours to each time (In Lafayette, adding 4 hours gets to Zulu time). Once the times are in Zulu time, open http://www.ogimet.com/metars.phtml.en in an internet browser. This will supply the wind information for each flight.

On the site, fill in the airport code under "ICAO Indexes" and fill in the date. Under "hour," make the top drop-down menu 00 and the bottom drop-down menu 23. This will have the site display all wind records for that day. Once the date, hour, and airport code has been entered, click "send."

OCIMET

Metar/Speci/Taf reports selection query ICAO INDEXES TYPE SORT ORDER NIL REPORTS FORMAT ALL ▼ HTML ▼ Newest the first ▼ NIL reports included ▼ TIME INTERVAL Year Month Day Hour 2014 ▼ July BEGIN: 14 ▼ END: 2014 ▼ 15 ▼ 20 ▼ send Clean

You have to set:

- 1. The ICAO indexes from desired stations, with a comma or space separing indexes. If you don't know the index, you can visit this page
- 2. The type of report you want to get
 - ALL It will show METAR, SPECI and TAF reports
 - · SA METAR y SPECI.
 - · SP only SPECI.
 - . FC Only short TAF reports (validity 9 Hours).
 - o FT Only large TAF reports (18 or 24 Hours).
- 3. Order of displayed results. You can select cronological or reverse order
- 4. You also can decide about to get "NIL" void reports
- 5. Output format
 - . HTML Rich HTML output format
 - o TXT Single plain TXT mode
- 6. Begin and end of time interval query. Time is UTC

Query made at 07/15/2014 20:26:33 UTC

Time interval: from 07/14/2014 00:00 to 07/14/2014 23:59 UTC

KLAF, Lafayette, Purdue University Airport (United States). WMO index: ----. Latitude 40-24-45N. Longitude 086-56-51W. Altitude 184 m.

METAR/SPECI from KLAF, Lafayette, Purdue University Airport (United States).

SA 14/07/2014 23:54-> METAR KLAF 142354Z 22005KT 10SM FEW015 BKN090 21/19 A2983 RNK AD2 RAE12 SLP099 P0000 60043 T02060189 10267 20183 53000= SA 14/07/2014 22:54-> METAR KLAF 142254Z 17006KT 10SM -RA FEW008 BKN070 CVC120 20/18 A2983 RNK AD2 RAB53 SLP097 P0000 T02000183= SP 14/07/2014 22:26-> SPECI KLAF 142226Z 16005KT 10SM SCT009 BKN120 20/18 A2983 RMK AO2 T02000183= SA 14/07/2014 21:54-> METAR KLAF 142154Z 20006KT 10SM FEW120 21/18 A2983 RNK AO2 SLP099 T02060183= SA 14/07/2014 20:54-> METAR KLAF 142054Z 00000KT 10SM CLR 19/18 A2983 RNK AD2 LTG DSNT E RAE20 TSE20 SLP098 P0007 60043 T01890178 50007= SP 14/07/2014 20:26-> SPECI KLAF 14206Z VRB03KT 10SM FEW055 FEW100 18/18 A2983 RMK AO2 LTG DSNT NE-S RAE20 TSE20 P0007 T01830178=
SP 14/07/2014 22:26-> SPECI KLAF 14226Z 16005KT 10SM SCT009 BKN120 20/18 A2983 RMK A02 T02000183= SA 14/07/2014 21:54-> METAR KLAF 142154Z 20006KT 10SM FEW120 21/18 A2983 RMK A02 SLP099 T02060183= SA 14/07/2014 20:54-> METAR KLAF 142054Z 00000KT 10SM CLR 19/18 A2983 RMK A02 LTG DSNT E RAE20 TSE20 SLP098 P0007 60043 T01890178 50007= SP 14/07/2014 20:26-> SPECI KLAF 142026Z VRB03KT 10SM FEW055 FEW100 18/18 A2983 RMK A02 LTG DSNT NE-S RAE20 TSE20 P0007 T01830178=
SA 14/07/2014 21:54-> METAR KLAF 142154Z 20006KT 10SM FEW120 21/18 A2983 RMK A02 SLP099 T02060183= SA 14/07/2014 20:54-> METAR KLAF 142054Z 00000KT 10SM CLR 19/18 A2983 RMK A02 LTG DSNT E RAE20 TSE20 SLP098 P0007 60043 T01890178 50007= SP 14/07/2014 20:26-> SPECI KLAF 142026Z VRB03KT 10SM FEW055 FEW100 18/18 A2983 RMK A02 LTG DSNT NE-S RAE20 TSE20 P0007 T01830178=
SLP099 T02060183= METAR KLAF 142054Z 00000KT 10SM CLR 19/18 A2983 RMK AD2 LTG DSNT E RAE20 TSE20 SLP098 P0007 60043 T01890178 50007= SP 14/07/2014 20:26-> SPECI KLAF 142026Z VRB03KT 10SM FEW055 FEW100 18/18 A2983 RMK AD2 LTG DSNT NE-S RAE20 TSE20 P0007 T01830178=
SA 14/07/2014 20:54-> DSNT E RAE20 TSE20 SLP098 P0007 60043 T01890178 50007= SP 14/07/2014 20:26-> SPECI KLAF 142026Z VRB03KT 10SM FEW055 FEW100 18/18 A2983 FMK A02 LTG DSNT NE-S RAE20 TSE20 F0007 T01830178=
RMK AO2 LTG DSNT NE-S RAE20 TSE20 P0007 T01830178=
SP 14/07/2014 20:14-> SPECI KLAF 142014Z 18005KT 7SM -TSRA FEW049 SCT075 BKN100 18/17 A2983 RMK A02 LTG DSNT NE-S P0007 T01830172=
SP 14/07/2014 20:05-> SPECI KLAF 142005Z 22003KT 25M TSRA BR BKN044 BKN075 OVC100 18/17 A2985 RMK A02 LTG DSNT ALQDS P0006 T01830172=
SP 14/07/2014 19:59-> SFECI KLAF 141959Z 18004KT 3/4SM +TSRA BR FEW021 BKN044 OVC080 18/17 A2986 RMK A02 LTG DSNT ALQDS P0005 T01830167=
METAR KLAF 141954Z VRB06G15KT 2 1/2SM TSRA BR FEW021 BKN044 SA 14/07/2014 19:54-> OVC075 19/17 A2986 RMK AO2 PK WND 26035/1932 LTG DSNT ALQDS RAB28 TSB24 SLP108 P0036 T01890167=
SPECI KLAF 141952Z 20006G15KT 1SM TSRA FEW021 BKN044 OVC080 SP 14/07/2014 19:52-> 19/16 A2986 RMK A02 PK WND 26035/1932 LTG DSNT ALQDS RAB28 TSB24 P0034=

A page similar to this one will then pop up.

The left column shows the date and time of each record. This column will be used to find the specific wind data for the flight. Now find the first record with a time before the start time. Example: if the Zulu start time was 21:20, then the data to be looked at would be 20:54 because it is the closest data point before the start time. Do the same for the stop time (the reason for also using the stop time is so that if the wind was variable, then the angle of the stop time could be used).

Now that the data sets have been identified, the information that should be copied is the second set of numbers/letters. In the above example, the wind data would be 00000KT.

These two strings of numbers/letters can then be placed in the flight list.

							/	/	
^	U	U	U	L		J	.¥	.,/.	
Date	Start Time	Zulu Start	Stop Time	Zulu Stop	Aircraft	Eval Group	Wind (Start)	Wind (Stop)	
4/9/2014	0935	1335	1047	1447	N586PU	2	00000KT	00000KT	
4/9/2014	1146	1546	1309	1709	N586PU	4	25003KT	25009KT	
4/9/2014	1152	1552	1315	1715	N591PU	3	25003KT	25009KT	
4/9/2014	1718	2118	1836	2236	N586PU	3	26011KT	27011KT	
4/11/2014	0949	1349	1104	1504	N591PU	4	27003KT	00000KT	
4/11/2014	1134	1534	1252	1652	N591PU	3	00000KT	00000KT	
4/12/2014	0939	1339	1105	1505	N586PU	3	14008KT	16011KT	
4/12/2014	0935	1335	1055	1455	N591PU	4	14008KT	16011KT	
4/15/2014	1748	2148	1907	2307	N586PU	3	33010KT	VRB06KT	
4/18/2014	1746	2146	1854	2254	N591PU	3	01004KT	36010G18KT	
4/22/2014	1759	2159	1926	2326	N591PU	1	31009G15KT	33011G18KT	
4/26/2014	1156	1556	1325	1725	N586PU	2	02008KT	02009KT	
4/30/2014	0736	1136	0853	1253	N586PU	1	00000KT	23004KT	
5/4/2014	0745	1145	0905	1305	N586PU	1	25004KT	27004KT	
5/4/2014	0933	1333	1049	1449	N586PU	2	27004KT	35009KT	
5/4/2014	1338	1738	1457	1857	N586PU	1	36009G16KT	03012KT	
5/4/2014	1650	2050	1807	2207	N586PU	4	02009KT	03008KT	
5/7/2014	0733	1133	0848	1248	N586PU	1	08003KT	07006KT	
5/7/2014	1754	2154	1906	2306	N586PU	1	18013G21KT	19008G16	
5/8/2014	0758	1158	0923	1323	N586PU	1	19006KT	23009KT	
5/10/2014	1404	1804	1520	1920	N586PU	1	VRB03KT	27010G17KT	
5/11/2014	1426	1826	1548	1948	N586PU	2	20008G15KT	21010KT	
6/17/2014	950	1350	1111	1511	N586PU	4	22011G18KT	23013G23KT	
7/2/2014	1310	1710	1438	1838	N586PU	4	25008KT	22007KT	
7/2/2014	1621	2021	1737	2137	N586PU	2	29011KT	29010KT	
7/9/2014	1343	1743	1449	1849	N586PU	2	31012G18KT	29015G20KT	
7/9/2014	1520	1920	1635	2035	N586PU	2	30010G18KT	27008KT	

Organizing the Data

The first thing that should be done is pulling up all necessary data. This includes the list that contains flight dates and times, the template used for organizing the data, and the online flight data itself. The template should contain 7 different tabs, 1 for raw data and then 6 more for each approach. If the template does not include these, they should be created.



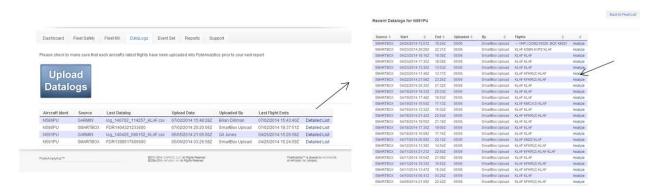
The online data will be found on a server similar to this one:

4	Α	В	C	ט	E	F	G	Н	1	J	K	L	M	N	U	Р	Q	R
	Date	Start Time	Zulu Start	Stop Time	Zulu Stop	Aircraft	Eval Group	Wind (Start)	Wind (Stop)	KLAF	KFKR	KCFJ	KLAF(DEG)	KFKR(DEG)	KCFJ(DEG)	KLAF Check	KFKR Check	KCFJ Check
	4/9/2014	0935	1335	1047	1447	N586PU	2	00000KT	00000KT	L23	L4.	L4.	230	40	40	CHECK	X	X
	4/9/2014	1146	1546	1309	1709	N586PU	4	25003KT	25009KT	L23	L22	L4.	20	30	210	X	X	X
	4/9/2014	1152	1552	1315	1715	N591PU	3	25003KT	25009KT	L23	L22	L22	20	30	30	X	X	X
	4/9/2014	1718	2118	1836	2236	N586PU	3	26011KT	27011KT	L23	R/L22	L22	30	40	40	X	X	X
	4/11/2014	0949	1349	1104	1504	N591PU	4	27003KT	00000KT	L23	L4.	L22	40	230	50	X	CHECK	X
	4/11/2014	1134	1534	1252	1652	N591PU	3	00000KT	00000KT	L23	L4.	L22	230	40	220	CHECK	X	X
	4/12/2014	0939	1339	1105	1505	N586PU	3	14008KT	16011KT	L23	L22	L22	90	80	80	X	X	X
	4/12/2014	0935	1335	1055	1455	N591PU	4	14008KT	16011KT	L23	L22	L22	90	80	80	X	X	X
0	4/15/2014	1748	2148	1907	2307	N586PU	3	33010KT	VRB06KT	L5/L28	R/L4.	L4.	50	290	290	X	X	CHECK
1	4/18/2014	1746	2146	1854	2254	N591PU	3	01004KT	36010G18KT	R5.	L4.	L4.	40	30	30	X	X	X
2	4/22/2014	1759	2159	1926	2326	N591PU	1	31009G15KT	33011G18KT	R5.	L4.	L4.	260	270	270	X	CHECK	CHECK
3	4/26/2014	1156	1556	1325	1725	N586PU	2	02008KT	02009KT	R5.	L4.	L4.	30	20	20	X	X	X
4	4/30/2014	0736	1136	0853	1253	N586PU	1	00000KT	23004KT	L23	L4.	L4.	230	40	40	CHECK	X	X
5	5/4/2014	0745	1145	0905	1305	N586PU	1	25004KT	27004KT	L23	L22	L22	20	30	30	X	X	X
5	5/4/2014	0933	1333	1049	1449	N586PU	2	27004KT	35009KT	L28	L4.	L4.	10	230	230	X	CHECK	CHECK
7	5/4/2014	1338	1738	1457	1857	N586PU	1	36009G16KT	03012KT	R5.	L4.	L4.	310	320	320	X	X	X
8	5/4/2014	1650	2050	1807	2207	N586PU	4	02009KT	03008KT	R5.	L4.	L4.	30	20	20	X	X	X
Э	5/7/2014	0733	1133	0848	1248	N586PU	1	08003KT	07006KT	R5.	R9.	L22	30	10	140	X	X	X
C	5/7/2014	1754	2154	1906	2306	N586PU	1	18013G21KT	19008G16	L23	L22	L22	50	40	40	X	X	X
1	5/8/2014	0758	1158	0923	1323	N586PU	1	19006KT	23009KT	L23	L22	L22	40	30	30	X	X	X
2	5/10/2014	1404	1804	1520	1920	N586PU	1	VRB03KT	27010G17KT	L28	L22	L4.	10	50	230	X	X	CHECK
3	5/11/2014	1426	1826	1548	1948	N586PU	2	20008G15KT	21010KT	L23	L22	L22	30	20	20	X	X	X
4	6/17/2014	0950	1350	1111	1511	N586PU	4	22011G18KT	23013G23KT	L23	L22	L22	10	0	0	X	X	X
5																		
5																		

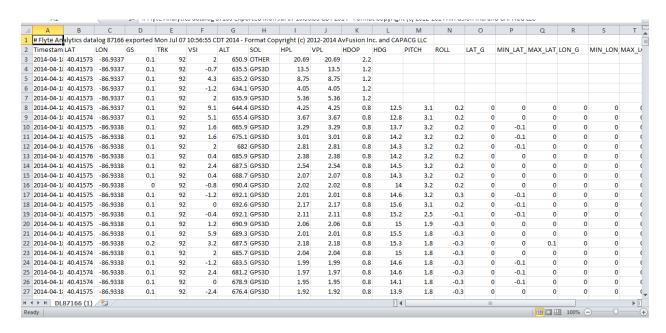
The flight list will look like this:

Now that all of the necessary items are there, the first step is to identify which flight is to be analysed. All of the flights are on the flight list, so one of them should be selected (it may help to do them in order, beginning with the first one).

One must now go into the server, select "detailed list" on one of the SMARTBOX rows that corresponds to the correct airplane, find the corresponding date and time for the selected flight, and click "analyze."



This will open up the data for the individual flight. Once there, one should click "download CSV," which will download all of the raw data from that flight. This file should then be opened, looking similar to this:

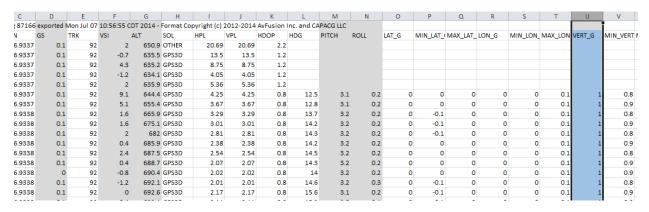


Now open the template and save it as a new file with a name that follows this pattern:

[enough numbers to identify each plane]_[month of flight]-[day of flight]-[year]_[time (in Zulu)]

Example: 86_4-15-14_2148

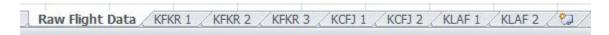
Once that is finished, copy the raw data into the sheet labeled "Raw Flight Data." Then highlight the columns for the information on GPSGS, VSI, ALT, Pitch, Roll, and Vert G. Information will later be taken from these 6 columns and pasted into the other sheets, with one sheet for each approach.



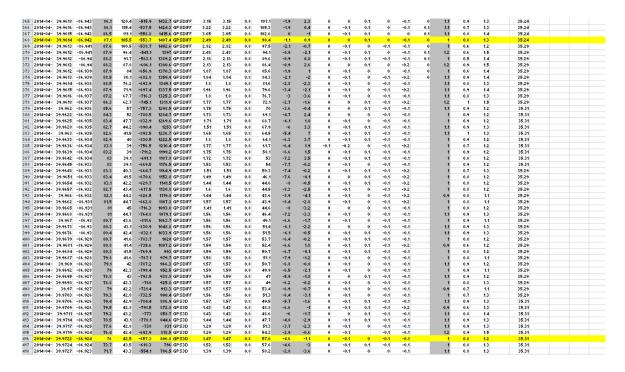
Next, go back to the server data and identify where the landings were made. Identify which at airports the landings were made, and in what order. This can be done by moving the mouse over the data on the left, which will, on the right side, show where the plane was at that point (This method can also be used to determine what direction the plane turned before the approach, which should also be added to the flight list).



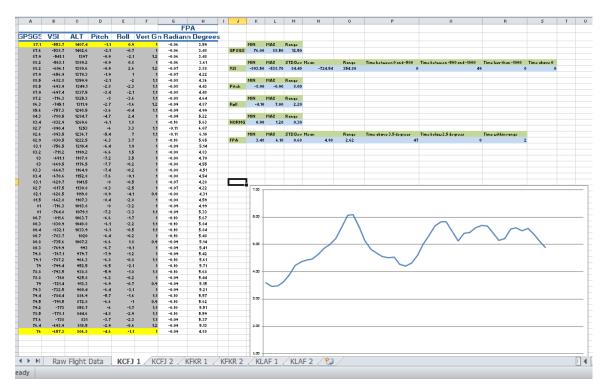
Then rename the sheets so that they correspond to the airport (if there are multiple at one airport, put a number after each one: KLAF 1, KLAF 2, ...).



Next, decide what altitudes will be the cutoff points for each airport and each runway. This is normally from 15 ft above the ground to 600 ft above that (615 ft above ground). Using the altitude column as a guide, go through the raw data and identify what parts fall inside these limits. Highlight the first value below the max and min altitude values. For example, in the picture below, the altitude range was 1411 ft to 811 ft, so each altitude after that was highlighted (1407 and 806). Do this for every approach.

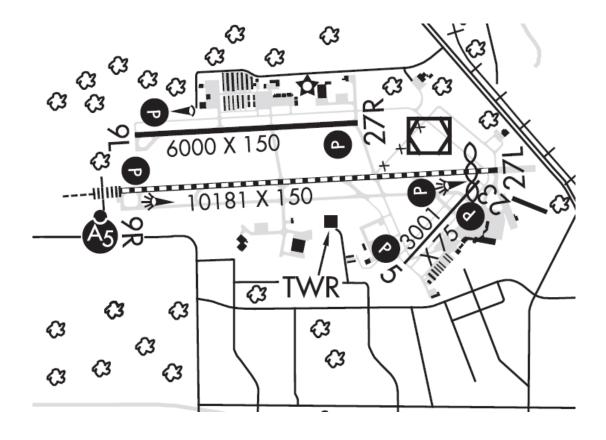


Once this is complete, copy the data from each approach into its designated sheet. The sheet should then automatically calculate the rest of the data. It should look like this:

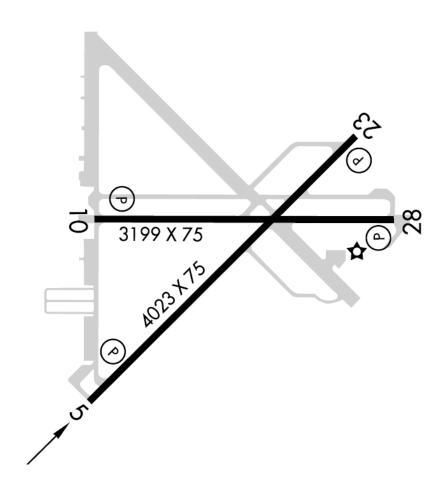


APPENDIX I—AIRPORT ELEVATIONS AND LAYOUTS

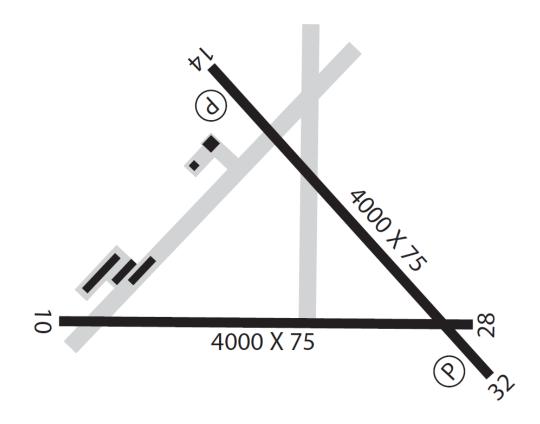
Airport	Runway	Altitude	Range				
Amport	Kuiiway	Aiiiuue	Low	Up			
	9L	31	46	646			
	9 R	32	47	647			
	27L	22	37	637			
KMLB	27R	26	41	641			
	5	25	40	640			
	23	21	36	636			
	Airport	33	48	648			



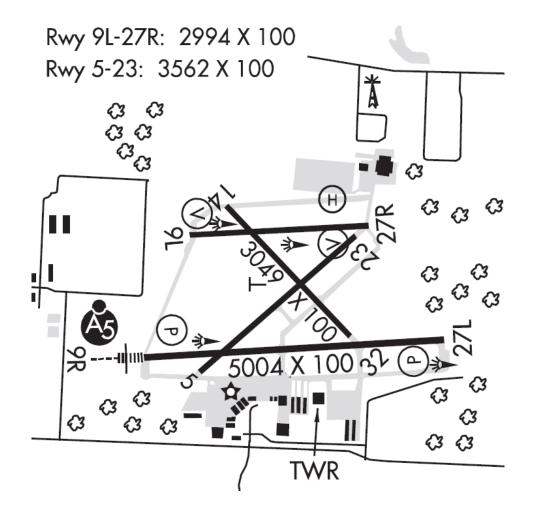
A impout	Dunway	Altituda	Range			
Airport	Runway	Altitude	Low	Up		
	5	18	33	633		
X26	23	21	36	636		
	10	18	33	633		
	28	21	36	636		
	Airport	21	36	636		



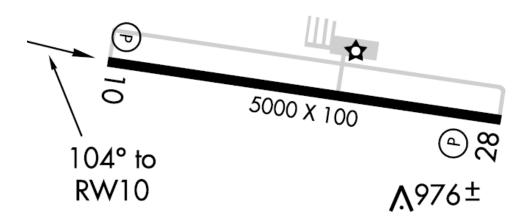
A import	Dunway	Altitude	Range				
Airport	Runway	Aititude	Low	Up			
X59	10	22	22 37 6				
	28	23	38	638			
	14	24	39	639			
	32	23	38	638			
	Airport	26	41	641			



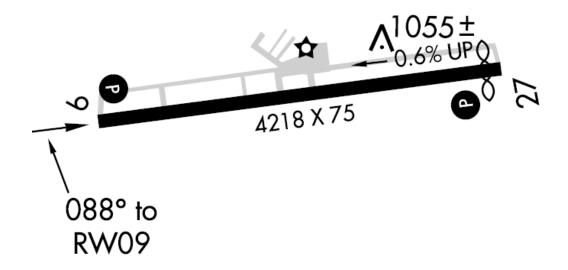
A imp out	Dumyyayı	Altitude	Range			
Airport	Runway	Aiiitude	Low	Up		
	9L	904	1519			
	9R	901	916	1516		
	27L	890	905	1505		
	27R	892	907	1507		
KOSU	5	903	918	1518		
	23	893	908	1508		
	14	900	915	1515		
	32	894	909	1509		
	Airport	906	921	1521		



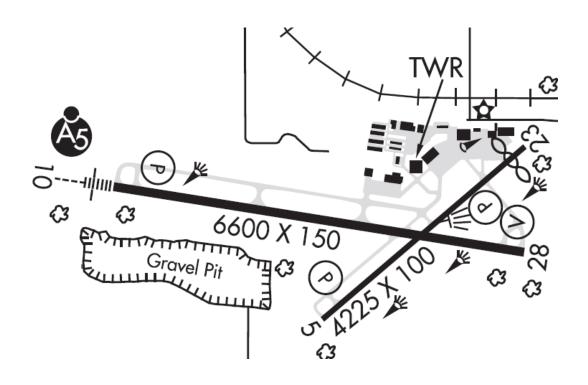
A : at	Dunway	Altituda	ange	
Airport	Runway			Up
	10	945	960	1560
KDLZ	28	945	960	1560
	Airport	945	960	1560



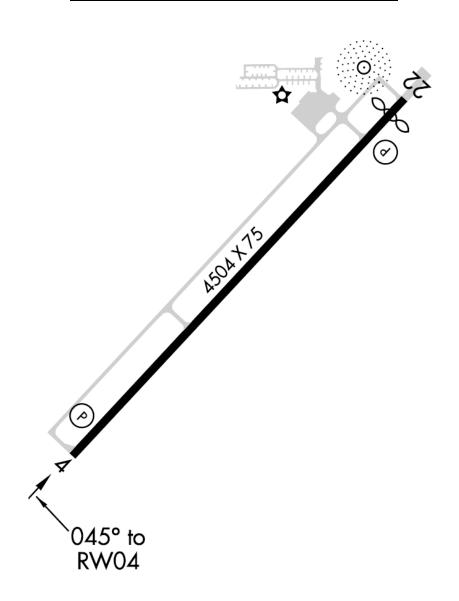
Airport	Dunway	Altitude	Range				
	Runway	Aititude	Low	Up			
KMRT	9	1021	1036	1636			
	27	997	1012	1612			
	Airport	1021	1036	1636			



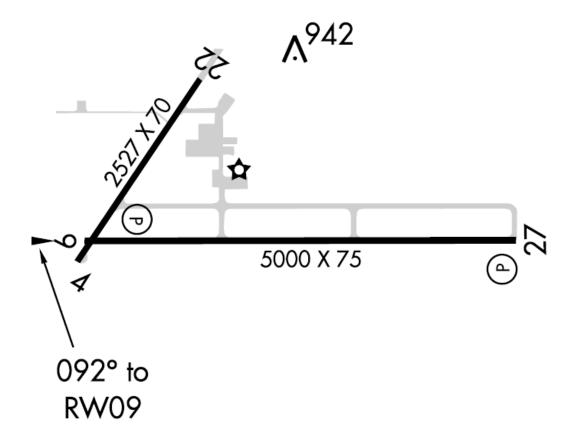
A import	Dunway	Altituda	Range			
Airport	Runway	Altitude	Low	Up		
	5 593		608	1208		
KLAF	10	600	615	1215		
	23	606	621	1221		
	28	598	613	1213		
	Airport	606	621	1221		



Aimont	Dunway	Altitudo	ange	
Airport	Runway	796 811 2 801 816	Up	
	4	796	811	1411
KCFJ	22	801	816	1416
	Airport	801	816	1416



A import	Dunway	Altitude	Range			
Airport	Runway	Amude	Low	Up		
	4	857	857 872 147			
KFKR	22	857	872	1472		
	9	856	871	1471		
	27	861	876	1476		
	Airport	857	872	1472		



APPENDIX J—DATA RECORDER ASSESSMENT

PEGASAS Project 3: Angle of Attack Equipment for General Aviation Operations

Background:

Prior to the initiation of this research project the knowledge concerning the available data parameters was primarily limited to Garmin equipment. It was understood that the available parameters in the Avidyne Entegra system were different in type than the Garmin G1000 but it was not readily apparent that certain parameters are recorded at different rates. This was primarily due to the limited access that the aviation industry has in working with Avidyne systems as the data from the Primary Flight Display (PFD) is encrypted. It was with this knowledge that the original proposal was developed and based upon recent findings it is necessary for us to make modifications to ensure the integrity of the research findings. During the work being completed in Subtask 2A (Determine data recording capabilities of aircraft in University Fleets) it was determined that the data recording capabilities of the various equipment with the Avidyne Entegra and the G1000 avionics platforms is different enough in the record rate of various parameters to create potential issues in the merging of the data for analysis purposes.

Of particular concern is the record rate of the Latitude and Longitude of the aircraft. These parameters will be necessary to determine the position of the aircraft along various stages of the traffic pattern to compare the flight characteristics of the various study groups. With 4 seconds of time between captures it creates too much of a difference in data to be able to potentially combine results across the three universities.

Following are the capture rates for the Avidyne Entegra with the G1000 comparison listed in the right column.

Avidyne Entegra Digital Data (FIT & OSU)

AhrsAndRateData	,	Recorded 5 times/second (Higher than G1000)
	magHeading	
	pitch	
	roll	
	lateralAcceleration	
	rateofTurn	
	Roll Rate [deg/sec]	
	Pitch Rate [deg/sec]	
	Yaw rate [deg/sec]	
	Long Accel [m/s^2]	
	Lat Accel [m/s^2]	
	Norm Accel [m/s^2]	
AirData timestamp		Recorded once per second (Same as G1000)
	altitude [ft]	
	baroCorrectedAlt	
[ft]		
	altitudeRate	
[ft/min]		
	trueAirspeed [kts]	
	indicatedAirspeed	
[kts]		
	airspeedTrend	
	densityAltitude	
FlightDirectorData		Recorded once per second (Same as G1000)
	apAnnunciators	
	fdPitch	
	fdRoll	
	logicStates	
PriNavDetails		Recorded once every 4 seconds (Lower than G1000)
	ActiveCourse [deg]	
	ActiveBearing [deg]	
	HdiDeviation [%]	
	VdiDeviation [%]	
	DesiredCourse [deg]	
	HdiSource	
	VdiSource	

PriNavDisplayBlockText		Recorded G1000)	once	every	4	seconds	(Lower	than
	mGroundTrack	31000)						
[deg]								
	DistanceToWpt							
[nm]								
	DtkOrBrg [deg]							
VhfFreq								
	EteInSeconds [sec]							
	NeedleTextType							
[enum]								
	NxWptID							
GpsPositionAndTimeDa	GpsPositionAndTimeData		once	every	4	seconds	(Lower	than
	mLongitude [deg]							
	mLatitude [deg]							
	UtcDate							
[mm:dd:yyyy]								
	UtcTime [hh:mm:ss]							
	GroundSpeed [kts]							
EngineData		Recorded G1000)	once	every	6	seconds	(Lower	than
	manPresL [InHg]							
	oilPresL [Psi]							
	fuelflowL [Gph]							
	tachL [RPM]							
	oilTempL[DegF]							
	percentPowerL							
	coolTempL [DegF]							

Garmin G1000 Recorded Parameters (Garmin Perspective)—All Recorded once
per second
Local Date
Local Time
Total Flight Time
Latitude
Longitude
Altimeter Setting
Altimeter Setting
Altitude Above Sea Level
Outside Air Temperature
Indicated Airspeed
Ground Speed
Vertical Speed
Pitch
Roll
Lateral Acceleration
Normal Acceleration
Heading
Track
Voltage 1
Voltage 2
Amperage Meter 1
Engine Fuel Flow
Engine Oil Temperature
Engine Oil Pressure
Engine Manifold Pressure
Engine Rotations per Minute
Cylinder 1 - Head Temperature
Cylinder 2 - Head Temperature
Cylinder 3 - Head Temperature
Cylinder 4 - Head Temperature
Cylinder 5 - Head Temperature
Cylinder 6 - Head Temperature

Cylinder 1—Exhaust Gas Temperature
Cylinder 2—Exhaust Gas Temperature
Cylinder 3—Exhaust Gas Temperature
Cylinder 4—Exhaust Gas Temperature
Cylinder 5—Exhaust Gas Temperature
Cylinder 6—Exhaust Gas Temperature
GPS Altitude
True Airspeed
Horizontal Situation Indicators
Course
Navigation Frequency 1
Navigation Frequency 1
Communications Frequency 1
Communications Frequency 2
Horizontal Course Deviation Indicator
Deflection
Vertical Course Deviation Indicator
Deflection
Wind Speed
Wind Direction
Distance to Waypoint
Bearing to Waypoint
Magnetic Variation
Autopilot
Rollm
Pitchm
RollC
PitchC
GPS Calculated Vertical Speed
GPS Fix
Vertical Alert Limit
Vertical Alert Limit
Horizontal Protection Level WAS
Horizontal Protection Level FD
Vertical Protection Level WAS
Vertical Protection Level FD

Another issue that has arisen is that Avidyne encrypts the data that comes from the PFD. Avidyne has provided the technical support needed to decode the data from the PFD for our use, but the software programs from past projects that have analyzed the data aren't currently equipped to handle the Avidyne PFD data. This will require software to be written which was not a subtask that was anticipated in the project and it is unknown exactly how long it will take to develop the ability to analyze the data.

Stand-Alone Data Recorder:

An option is available that would record a standardized set of data points that would serve for the main analysis capability and the data from the Garmin G1000 and Avidyne Entegra systems could be incorporated for those parameters that would provide additional analysis capability without compromising commonality and generalizability. The unit can be installed as a minor alteration and only requires a logbook signoff if the unit is not connected to aircraft power. The data below are recorded in the stand-alone unit.

AvConnect Smart Box [™]	HDG
DataSet	PITCH
Timestamp(UTC)	ROLL
LAT	LAT_G
LON	MIN_LAT_G
GS	MAX_LAT_G
TRK	LON_G
VSI	MIN_LON_G
ALT	MAX_LON_G
SOL	VERT_G
HPL	MIN_VERT_G
VPL	MAX_VERT_G
HDOP	RPM

Summary Options:

The options below (in no particular order) reflect the potential directions that could be taken and are presented to the FAA for analysis and decision making purposes.

Option 1: Acquire the AvConnect Smart BoxTM which will allow the research team to have a commonality of data across all three aircraft platforms. This will eliminate the digital data from being a restriction to the blending of the data for analysis. The consistent parameters will be used as a standardized platform for determining the degree of stability during approach for the various participant groups.

Option 1 anticipated effects: Increase in budget, ability to maintain timeline and ability to combine data.

Option 2: Continue with the current analysis capabilities and there is a likely possibility that the data from the Avidyne units will be too granular on certain parameters to be able to conduct a robust analysis. In addition, the data from the Avidyne and the Garmin units with different parameters will not be able to be combined for assessment which would reduce the generalizability of the research findings.

Because of the inexperience of the analysis team in using the PFD data from Avidyne, it is possible that the software modifications necessary for using the PFD data would take longer than expected in the scope of the project. This could potentially result in either research findings coming only from the aircraft equipped with the G1000 avionics platform (which would reduce generalizability) or an extension in the completion date of the project.

Option 2 anticipated affect: Reduction in generalizability, reduction in data to be analyzed, potential extension in timeline for full analysis capability but with reduction in generalizability likely.

The decision was made to pursue Option 1 and the data included within this report reflects that decision.

APPENDIX K—AOA DEVICE DIAGRAMS

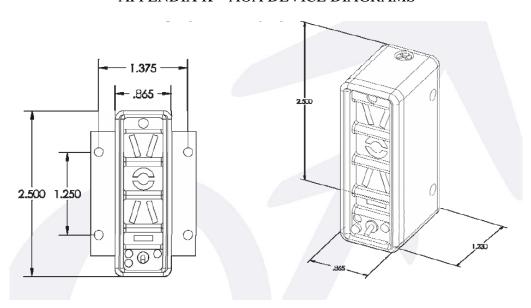


Figure K-1. Legacy Display Dimensions

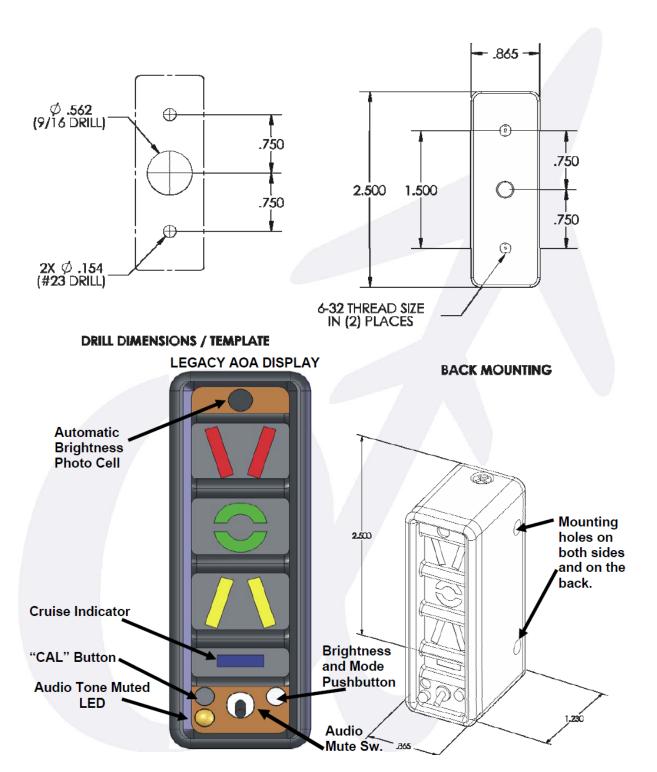


Figure K-2. Flush Panel Mounting (Purdue Cirrus Aircraft)

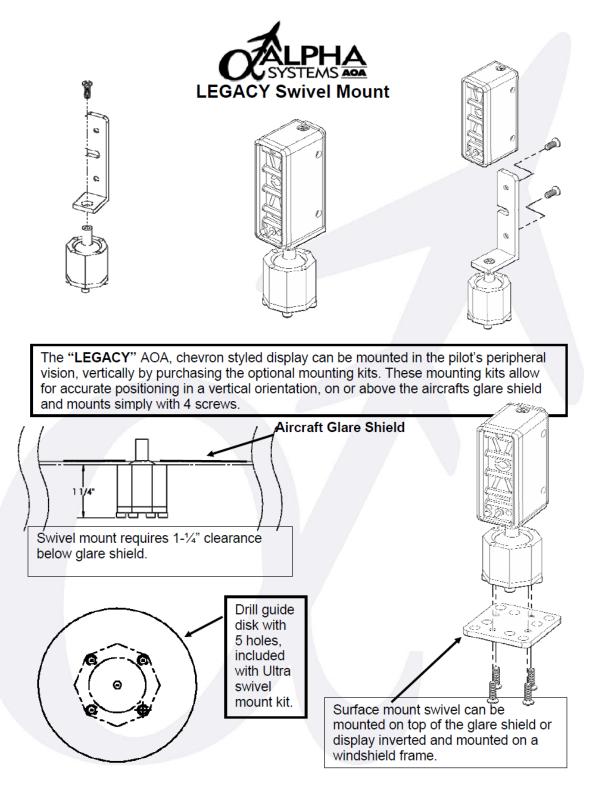


Figure K-3. Glare Shield Mounting (OSU and FIT Piper Aircraft)

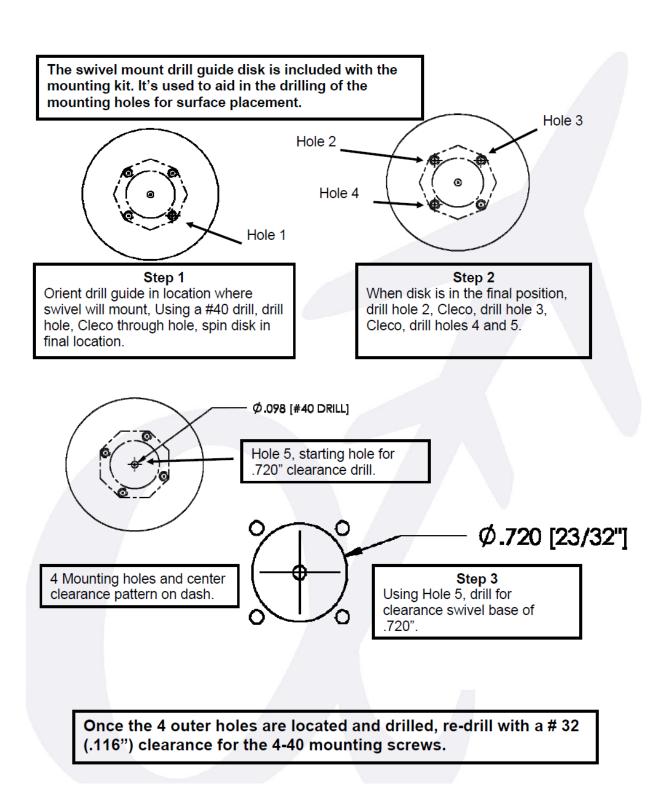


Figure K-4. Glare Shield Mounting (OSU and FIT Piper Aircraft)



Figure K-5. AOA Interface Module

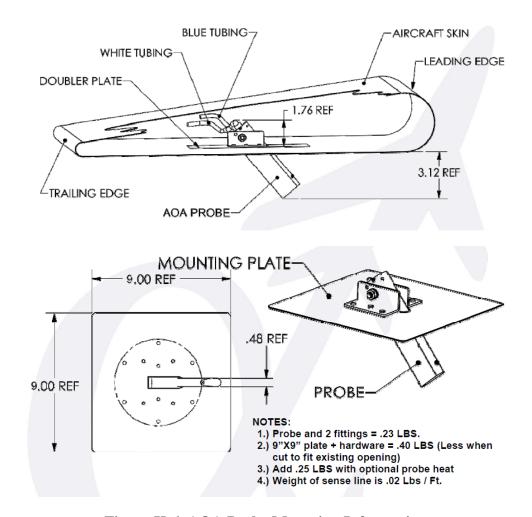


Figure K-6. AOA Probe Mounting Information

APPENDIX L—APPROACH ANALYSIS FACTORS, RESULTANTS, AND CODES

Factor/Resultant	Label	Description
SumFPA	Sum Flight Path Angle	The sum of the variation of the flight path angle for the last 30 seconds of the approach
Participant	Participant	The number of the participant in the study used to facilitate confidentiality
Date	Date	Date of the Evaluation Flight
Time	Time	Time of the Evaluation Flight
University	University	Code representing each university (1-3)
EvalGRP	Evaluation Group	Code representing the group to which the participant was randomly assigned
LdgOrder	Landing Order	The order of landing of each approach (1-6)
Pwr	Power Off or On	Code representing if the landing is a power-off or power-on landing
EduDate	Education Date	The date of the AOA education
EduInst	Education Instructor	The instructor that provided the AOA flight education to the participant
EvalPilot	Evaluation Pilot	The safety pilot that sat in the right seat during the evaluation flight
EduToEval	Education to Evaluation	The length of time (in days) between when the education flight and evaluation flight were conducted
WindDir	Wind Direction	The direction of the wind as reported in the METAR
WindSpd	Wind Speed	The speed of the wind as reported in the METAR
Gust	Gust	Code representing whether or not the winds were gusting during an approach as reported in the METAR
Aircraft	Aircraft	Code representing the type of aircraft that was flown during the approach
DispUse	Display Use	Code representing if the participant used the display as a primary or secondary reference
FreqUse	Frequency of Use	Code representing the frequency with which the participant referenced the display
FltTime	Flight Time	The amount of flight time of the participant
VASI	Visual Approach Slope Indicator	Code representing if there was any type of visual guidance present for reference on the approach
Twnd	Tailwind	Code representing if a tailwind situation was present during the base to final turn
Airport	Airport	Code representing the airport where the approach was conducted
Runway	Runway	The number of the runway for the approach
TurnDir	Direction of Turn	Code representing the direction of turn
AOALocation	AOA Location	Code representing the location of the AOA display

The legend below describes the codes that were used in the data processing

	Aircraft		
1	Warrior		
2	Arrow		
3	SR-20		

University	
1	FIT
2	OSU
3	Purdue

Direction of Turns		
1	Left	
2	Right	

Wind Gust	
0	No Gust
1	Gust

Visual Approach Guidance		
0	No Visual	
1	Visual	

	Tailwind Condition		
0	No Tailwind		
1	Tailwind		

Power	
1	Power On
0	Power Off

Location of Display	
0	Below Dash
1	Above Dash

Education Instructor		
1	Jones	
2	Bloss	
3	Spence	
4	France	
5	Kieffer	
6	Borsa	
7	Dillman	
8	Cardoza	
9	Peden	
10	White	
11	Callender	
12	Solomon	

	Kind of Device Usage	
1	Primary Instrument	
2	Secondary Instrument	
3	Not Used	

Frequency of Use		
1	Never	
2	Rarely	
3	Sometimes	
4	Often	
5	All of the time	

Airport	
1	KFKR
2	KCFJ
3	KLAF
4	KMLB
5	X26
6	X59
7	KOSU
8	KMRT
9	KDLZ

Evaluation Pilot		
1	Jones	
2	Bloss	
3	Spence	
4	France	
5	Kieffer	
6	Borsa	
7	Dillman	
8	Brynjolfsson	
9	Cardoza	
10	Peden	
11	White	
12	Callender	
13	Solomon	
14	Knight	
15	Rice	



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COMPARISON OF THREE ANGLE OF ATTACK (AOA) INDICATORS: A USABILITY STUDY
Ву
Camilo Jimenez
A Thesis Submitted to the College of Arts and Sciences in Partial Fulfillment of the Requirements for the Degree of Master in Science in Human Factors and Systems

Embry-Riddle Aeronautical University Daytona Beach, Florida November 2013

COMPARISON OF THREE ANGLE OF ATTACK (AOA) INDICATORS: A **USABILITY STUDY**

by

Camilo Andres Jimenez

This Thesis was prepared under the direction of the candidate's Thesis Committee Chair, Dr. Albert Boquet, Professor, Daytona Beach Campus; and Dissertation Thesis Committee Members Dr. Dahai Liu, Professor, Daytona Beach Campus; and Dr. Michael Wiggins, Professor, Daytona Beach Campus; and has been approved by the Thesis Committee. It was submitted to the College of Arts and Sciences in partial fulfillment of the requirements for the degree of

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ABSTRACT

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Title: COMPARISON OF THREE ANGLE OF ATTACK (AOA) INDICATORS: A

USABILITY STUDY

Institution: Embry-Riddle Aeronautical University

Degree: Master in Science in Human Factors and Systems

Year: 2013

Angle of Attack (AOA) is an important aeronautical concept used to understand the performance status of an aircraft during different flight stages. The Federal Aviation Administration (FAA) has indicated the importance of developing and encouraging the use of affordable AOA based systems to increase inflight safety. Embry-Riddle Aeronautical University's flight department decided to install AOA indicators in its fleet of Cessna 172S, to increase safety and to help student pilots better understand this important concept. This paper presents a review of AOA, visual display design principles, and usability. This experimental study examined three different AOA indicators provided by the flight department. The goal was to conduct a usability study in order to understand which of these indicators was better suited for student training. Instructor pilots were used as participants in a series of flights, in which they were asked to perform different maneuvers in which using AOA indicators was thought to help increasing stall awareness and performance. At the end of each flight participants were asked to complete a series of surveys (including an adaptation of the system usability scale) and to provide comments in order to understand their preferences related to AOA indicators. The analysis of the data shows significant differences between the indicators. Discussion of the results and recommendations for future studies are also covered.

TABLE OF CONTENTS

Review Committee Signature Page	iii
Abstract	iv
List of Tables	vii
List of Figures	viii
Introduction	1
Significance of the Study	6
Purpose Statement	7
Hypotheses	7
Limitations and Assumptions	8
Definition of Terms	8
List of Acronyms	9
Review of the Relevant Literature	10
Angle of attack	10
Usability	12
Methods	20
Research Approach	20
Sample	20
Apparatus and Materials	21
Design and Procedures	22
Sources of the Data	25
Data Collection Device	25
Instrument reliability and validity	25
Treatment of the Data	26
Results	27
Discussion, Conclusion, and Limitations	38
Discussion	38
Conclusion	45
Limitations	48
References	51

Appendices

A	Approximate AOA Indications for Each Flight Maneuver	56
В	Informed Consent Form	58
C	Pre-Flight Questionnaire	61
D	Post-Flight Questionnaire	67

LIST OF TABLES

Table 1 Mean and Standard Deviation for SUS	8.
Table 2 Mean and Standard Deviation for Visual Representation	8
Table 3 Pairwise Comparisons for Visual Representation	9
Table 4 Mean and Standard Deviation for Enhanced Performance	9
Table 5 Pairwise Comparisons for Enhanced Performance	0
Table 6 Mean and Standard Deviation for Enhanced Stall Awareness	0
Table 7 Pairwise Comparisons for Enhanced Stall Awareness	1
Table 8 Mean and Standard Deviation for Crosschecked Indicator During Maneuvers 3	1
Table 9 Mean and Standard Deviation for Indicator would Enhance Students' Performance 3	2
Table 10 Ranks for Crosschecking the Indicator helped in Flying a More Stable Approach on Final (Normal Approach and Landing)	2
Table 11 Ranks for Crosschecking the Indicator helped in Flying a More Stable Approach on Final (Short Field Approach and Landing)	3
Table 12 Ranks for Crosschecking Indicator Enhanced Landing Performance (Normal Approach and Landing)	
Table 13 Ranks for Crosschecking Indicator Enhanced Landing Performance (Short Field Approach and Landing)	4
Table 14 Overall Satisfaction Ranks	4
Table 15 Observer A * Observer B Comments Crosstabulation	6

LIST OF FIGURES

Figure 1. Relationship of lift to AOA.	11
Figure 2. The three AOA indictors preselected by the flight department for the proposed study. vertical bar, horizontal, bar, and legacy indicators.	
Figure 3. Interrater agreement by indicator type separated by type of comment.	37
Figure 4. Interrater agreement on the instrument location in the cockpit by indicator	38
Figure 5. Location of the AOA indicators in relation to the airspeed tape on the G1000 and standalone airspeed indicator.	44

Introduction

Angle of attack (AOA) is an important concept used to understand basic aerodynamics principles in aviation, as well as to understand some aspects of an aircraft's performance capabilities (Boeing, 2000). Angle of attack, in its simplest form, could be defined as the angle at which the aircraft's wing chord lines meet the relative wind (the direction of the airflow with respect to the airfoil) (Flach, Patrick, Amelink, & Mulder, 2003; Federal Aviation Administration, 2008). In most military and commercial aircraft, there is either a dedicated instrument that shows AOA, or a warning stall system that, even though it does not explicitly depict AOA information, uses this aeronautical concept to warn pilots of a potential stall. In general aviation (GA) the use of AOA indicators is almost nonexistent and most GA aircraft lack such an indicator. Even though the concept of angle of attack has been around since the first years of aviation (Langewiesche & Collins, 1972; Aarons, 2006), and is currently widely used by military pilots, especially naval aviators (Boeing, 2000; Dunn, 2011; Aarons, 2006), its importance among commercial and general aviation pilots has been undervalued or simply ignored due to the lack of knowledge and/or training on the value of the information a dedicated AOA indicator can provide to airmen (Aarons, 2006; Flach et al., 2003). One of the reasons why many pilots do not value angle of attack is because, even though at some point during their flying career they have been exposed to this concept and its relation to the lift curves, AOA is usually displaced by the airspeed as a primary indicator of performance (Aarons, 2006). Flach et al. (2003) mentioned that during a landing simulation task, experienced pilots seemed to be more interested in final approach speeds rather than angle of attack. Pilots are trained to use airspeed as a source of performance data, and when airspeed is available to the pilot, AOA should only be used as a supplementary or advisory source, but never as a primary source of performance data

(Aarons, 2006, Boeing, 2000). Even though airspeed is used as a primary source of information for pilots to measure the aircraft's capabilities, it is important to note that "a stall can occur at any airspeed, in any attitude, at any power setting" (FAA, 2000, p.1); the FAA's Supplement # 1 to the upset recovery training aid (2008) mentions that even though an airplane is in a descending pattern with ample airspeed, the wing surface could potentially stall if the AOA is greater than the stall angle for the wing setting. A fully integrated AOA indicator can warn pilots of a potential stall regardless of the aircraft's airspeed, attitude, and power setting (Dunn, 2011). It is important to note that even though an AOA indicator may be useful at different flight stages, it is most valuable during those stages in which the aircraft is at an airspeed and at an angle of attack close to stall (e.g. during final approach, go around maneuvers, and take off) (Hoadley & Vanderbok, 1987; Boeing, 2000; Dunn, 2011, Federal Aviation Administration, 2000). Despite the importance that the aviation community has given to airspeed over AOA, the Federal Aviation Administration (FAA) has stressed; a) that it is important to train GA pilots on the concept of AOA and its potential benefit in understanding aircraft performance capabilities, and b) the importance to manufacture AOA indicators that can be afforded by the GA community (FAA, 2012). This new interest in training pilots on the use of dedicated angle of attack indicators and making these instruments easily available to them is due to the fact that at least 40% of the accidents in GA between 2001 and 2010 were related to loss of control-in flight (LOC-I) (FAA, 2012). LOC-I is defined as "an extreme manifestation of a deviation from intended flightpath," including stalls and spins (International Civil Aviation Organization (ICAO), 2013, p. 13). For this reason, the FAA's general aviation steering committee (2012) recommended that in order to reduce the risk of potential stalls resulting in LOC-I related accidents, the general aviation community should install and use AOA systems to aid pilots to

identify aircraft stall margins. In the commercial aviation community, LOC-I is a serious concern as well. Boeing (2011) reported that during the time period covering the years 2001 through 2010, twenty commercial jet flight accidents were related to LOC-I (accounting for 23% of all commercial jet accidents worldwide during this time period). Jacobson (2010) pointed out that LOC-I accidents have generated attention in the aviation community, not only because of the high number of accidents, but also because of the high number of fatalities they produce; the author also reported that "more than half of LOC-I events result in an accident and more than half of those accidents are fatal" (p.7). A review of the reports involving LOC-I accidents during the period 1987-2009 conducted by Ancel and Shih (2012) revealed that over 10% of accidents in the U.S. were LOC-I related, which, at the same time, produced more than 50% of the fatalities in commercial airline accidents. The analysis of the accident data revealed that around 20% percent of these accidents were due to flight crew errors. Boeing (2011) reported that LOC-I related accidents ranked as the principal contributor of fatalities in accidents involving commercial jets (1,841 [or 36.78%] out of 5,005 fatalities worldwide). On a report created for the National Aeronautics and Space Administration (NASA), Jacobson (2010) reported that 81% of commercial aircraft accidents that were categorized as LOC-I, occurred during flight stages in which the aircraft was fairly close to the ground where chances to react are limited due to the aircraft's low altitude. This same report also mentioned that aerodynamic stalls are a significant contributor to LOC-I related accidents.

As it was mentioned before, several organizations, including the FAA, have stressed the importance of training pilots on procedures that help to minimize the conditions that could result in a loss of control in flight situations. For this purpose, some of the mitigation options they suggest include the installation of safety devices that can detect unsafe conditions and warn

pilots of the presence of such hazards (e.g. AOA based systems); training pilots on how to deter, detect, and react to hazardous conditions that could trigger a LOC-I situation (e.g. reaching stall margins); and the implementation of standardized safety procedures to be applied during emergency situations (FAA, 2000; Jacobson, 2010). The FAA (2000) stressed on the importance of flight instructors being capable of giving stall training to future pilots. At the same time, the FAA warned that a stall cannot be avoided unless the aircraft's AOA is reduced. For this reason, a dedicated instrument that can inform pilots of the aircraft's current AOA and how close the aircraft is from stalling should be considered of great importance. Due to the benefits that an understanding of angle of attack has on avoiding LOC-I incidents and accidents, exposing student pilots (SP) to the AOA concept and making it a meaningful aspect of their training should be considered a top priority. Embry-Riddle Aeronautical University (ERAU), as a leader in aviation, has decided to install AOA indicators in the cockpit of its Cessna 172 Skyhawk (172S) fleet to help students better understand AOA from an applied and more practical perspective. Teaching ERAU student pilots this important concept could have a direct impact on the improvement of air safety, as ERAU student pilots will be future commercial pilots and/or flight instructors, and the knowledge they acquire during their training can be later passed on to other future pilots.

The importance of introducing SPs to the AOA concept in order to increase flight safety has been discussed in this paper. Another fundamental aspect is the design of the AOA indicator chosen to teach SPs. It is important that the instrument used to teach and get SPs familiarized with AOA comply with certain design characteristics. Wickens, Lee, Liu, and Gordon-Becker (2004), discussed the importance of visual displays and their characteristics. One of the important features that would make a display user friendly includes the discriminability of the

elements presented by the display; in the case of AOA indicators, it is important that an indicator clearly informs the pilot when the aircraft is in a high, low, or optimum AOA. Another important characteristic includes the principle of the moving part or the dynamics of the information presented by the display, which means that those moving elements presented on the display match the mental model and expectations of the user (Roscoe, 1968). In this particular case, it is important that the information presented by the AOA indicator matches the pilot's expectations, helping them to react in a proper way and in a timely manner to the information provided by the instrument.

As it was previously stated, the flight department at ERAU decided to install AOA indicators in order to better train its SPs. The flight department preselected three different types of AOA indicators. In essence, they all provide the same information, but the way the information is presented to the pilot differs (vertically vs. horizontally, many round lights vs. few lights and different symbols). The department needed to select one of these three indicators in order to be installed in its fleet of Cessna 172S. The flight department was interested in knowing which indicator was the best option to train ERAU's SPs. The current investigation evaluated the differences of these three types of AOA indicators. In essence, this was an applied usability study in which subjective measures were used to assess the differences between the three AOA indicators that were pre-selected by the Flight Department and their usefulness as a teaching tool. The final purpose of the study was to determine which indicator could most benefit the training of ERAU's student pilots regarding the importance of AOA and its relationship to the lift curves.

The three AOA indictors were manufactured by Alpha Systems, Inc. The first indicator is a vertical bar indicator, the second is a horizontal bar indicator, and the last one is a Legacy indicator (which is also a type of vertical indicator). Some important differences exist in the way

the information is presented to pilots. The differences between these indicators will be explained in more detail in the methods section of this paper. It is important to note that the preselected indicators were not fully integrated into the aircrafts' systems. This means that the indicators were not able to recognize different trim configurations during different flight stages. Therefore, the instruments were calibrated to a specific configuration. Specifically, the pilots had to learn and memorize different light combinations presented by the AOA indicators according to different trim configurations of the aircraft in order to identify the proper AOA for any given maneuver.

Significance of the Study

Since the university's flight department decided to install AOA indicators in the Cessna 172S fleet, the present study will have a direct impact on the university's flying community. Making sure that the proper AOA indicator was selected could greatly benefit both safety and training for the university's SPs. A better training will translate to the pilots' future professional career, enhancing air safety in general by producing better qualified pilots and instructor pilots (IPs) capable of making better informed decisions while inflight situations required them to react to unexpected conditions. The study asked the opinion of IPs to determine which instrument they considered was the best option to help train their student pilots. The study also asked them about different possibilities for instrument placement inside the cockpit.

Statement of the Problem

The flight department decided to install AOA indicators in their fleet of Cessna 172S. In order to determine which indicator was the most adequate option, the human factors department was asked to conduct a usability study using instructor pilots to test the instruments in a series of

inflight maneuvers and provide feedback about each indicator. By the end of the study, the flight department was expecting to have enough data in order to decide which indicator was the most suitable for SP training.

Purpose Statement

The purpose of the present study was to help the university's flight department to make an informed decision about the most suitable AOA indicator to install in their fleet of planes used to train SPs. This was a usability study in which subjective measures were used to determine which indicator IPs consider to be the most suitable for SP training. At the same time, the study tried to determine the best location for the AOA indicator inside the cockpit.

Hypotheses

For this study there were three basic hypotheses that were developed and tested during the experiment, these statements are related to pilot's preferences:

- H_11 : There is a significant difference between the indicator that presents AOA information in a horizontal fashion and indicators that present AOA in a vertical fashion.
- H_12 : There is a significant difference between the vertical bar indicator and the Legacy indicator.
- H_13 : The current location where the AOA indicator is placed (to the left of the magnetic compass on the dashboard) will be disliked by IPs.

Limitations and Assumptions

There were several limitations to the proposed study. The researchers had no control over the type of AOA indicators that were preselected by the flight department, these indicators were preselected by the university's flight department alone without previous consultation with the investigators. The flight department provided all participants for the study, thus the investigators were unable to randomly select from the instructor pilot pool.

Definition of Terms

Angle of Attack Angle at which the aircraft's wing chord line of the wing

meets the relative wind (FAA, 2000, p.1).

Chord line A straight line drawn through the profile of the wing

connecting the extremities of the leading edge and trailing

edge (FAA, 2000, p.1).

Loss of Control Inflight An extreme manifestation of a deviation from intended

flightpath (ICAO, 2013, p. 13).

Relative Wind The direction of the airflow with respect to the airfoil.

Spin A controlled or uncontrolled maneuver in which the aircraft

descends in a helical path while flying at an angle of attack

greater than the critical AOA (FAA, 2000, p.5).

Stall A loss of lift and increase in drag that occurs when an

aircraft is flown at an angle of attack greater than the angle

for maximum lift (FAA, 2000, p. 1).

Trim/Configuration Refers to employing adjustable aerodynamic devices on the

aircraft to adjust forces so the pilot does not have to

manually hold pressure on the controls (FAA, 2008, p. 2-

8).

List of Acronyms

ADI Attitude Display Indicator

AOA Angle of Attack

ERAU Embry-Riddle Aeronautical University

GA General Aviation

FAA Federal Aviation Administration

HUD Heads Up Display

ICAO International Civil Aviation Organization

IP Instructor Pilot

LOC-I Loss of Control-in Flight

MCA Minimum Controllable Airspeed

NASA National Aeronautics and Space Administration

SME Subject Matter Expert

SP Student Pilot

Review of the Relevant Literature

Angle of attack

A general explanation of AOA and its importance in aviation safety was presented in the introduction of the study. In this section, a more detailed description of the concept will be provided in order to create a better understanding of the principles governing angle of attack and how it relates to aircraft performance. The reason why AOA is an important concept to understand aircraft's performance is related to lift. In other words, the AOA should be high enough to let airflow over and under the wing in order to produce lift. As the wing's AOA increases, the pressure difference between the upper and lower sections of the wing will be higher (FAA, 2012; Sadraey, 2013). If the AOA is too high, a separation of airflow from the wing is produced; this separation of airflow causes the wing to stall (FAA, 2000). If the AOA is not reduced, the stall could develop into a spin. Figure 1 depicts the relationship between AOA and lift at a constant speed. As it can be seen, lift increases as the angle of attack increases to approximately twenty degrees; any angle higher than that will cause the airfoil, or part of it, to stall. Sadraey (2013) explained that most airfoils stall at angles between twelve to sixteen degrees. Stall angles are influenced by different factors such as type of wing, configuration, and contamination of the airfoil (e.g. ice buildup). It is important to note that even though wing type and contamination are important factors that influence AOA stall margins, it is wing configuration that is of the most interest for the present study. Boeing (2000) mentioned that lift and stall margins change as the airfoil configuration changes. For instance, the position of flaps and spoilers affect the angle at which the airfoil stalls. When flaps are extended, they increase the wing's curvature and area, this at the same time increases lift, but the stall AOA is less because the wing cannot sustain the same lift levels and the airflow separates earlier from the upper portion of the wing. Spoilers, on the other hand, have the opposite effect; they reduce lift but

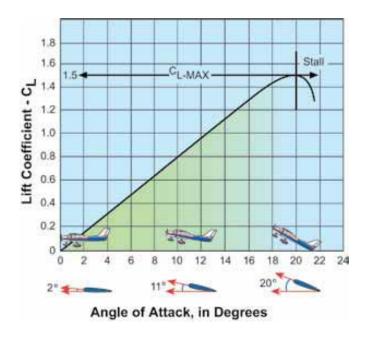


Figure 1. Relationship of lift to AOA. Adapted from Instrument Flying Handbook (FAA, 2012).

increase stall AOA. In order to recover from a stall (regardless of wing trim), the AOA must be reduced to a point in which the airfoil can generate enough lift again. If AOA is not reduced, the chances of recovering from the stall are virtually nonexistent.

As it has been stated before, the landing and takeoff phases of flight are critical because the aircraft performs at speeds and AOA close to stalling (Hoadley & Vanderbok, 1987). For this reason, it is important that SPs learn how to react to situations in which the aircraft stalls during one of these critical stages. Training maneuvers designed to teach SPs how to recover from stalls include power-on stalls and power-off stalls. Power-on stalls simulate takeoff/climb-out conditions and configurations, while power-off conditions simulate normal approach to landing conditions and configurations (FAA, 2000). A dedicated AOA indicator could help students to

better understand AOA and stall margins. At the same time AOA indicators can aid pilots to better understand the aircraft's performance capabilities, regardless of airspeed, trim, and load factors (Alpha Systems, 2010). Angle of attack indicators should comply with a number of characteristics that facilitate both the learning process and the integration of the instrument with the overarching system. In other words, the selected AOA indicator should be usable.

Usability

It is important to understand that the tools with which humans interact should not only be functional, but also usable. Usability can be defined as the degree to which a system is easy to use by the intended operator, or how user friendly such a system is (Wickens et al., 2004). Usability studies focus on the assessment of the difficulties that users encounter when interacting with products in applied settings. At the same time, usability studies also try to find ways to improve the manner users interact with products (Chamorro-Koc, Popovic & Emmison, 2009). Usability studies are of great interest because it is essential to understand the interaction between humans and systems (Ziegler & Kortum, 2012). This is very important in aviation because the use of poorly designed devices at the usability level is more hazardous, since pilots depend on avionics to fly their aircraft in a safe manner (Hamblin, Miller & Naidu, 2006). It is important that aviation information systems not only comply with regulations, but also provide reliable information in a user-friendly manner (Schvaneveldt, Beringer & Leard, 2003). Another reason why the use of user-friendly avionics is important is because the operation of an aircraft is a complex task that requires the pilot to distribute its attention to different sub-tasks, such as communication, monitoring of systems, and of course, operation of the aircraft. In the specific case of AOA indicators, it is important that such a device not only presents the information in an

accurate fashion, but also does it in a way that aids pilots to react to the information depicted by the indicator in a timely manner using as few cognitive resources as possible (Zhang, 1997).

In visual displays such as AOA indicators, certain characteristics should be taken into consideration when evaluating the usability aspects of the device. Wickens et al. (2004) discussed the characteristics that an optimally designed visual display should have; they presented these characteristics as principles of usability design. Some of these principles include legibility: the consideration of features such as contrast, illumination, and visual angle at which the display is located from the operator's line of sight. Redundancy: a good display should be able to express the information more than once, redundant information is better when different sources are used to get the operator's attention (i.e. combination of visual and aural sources of information). Discriminability: the information presented by the display should be clearly discernible from the information presented on other displays, for instance the elements used for any given display should be clearly differentiable from the elements used for other displays in order to eliminate confusion. Pictorial realism: a display ideally should look like the variable it represents. Congruency of dynamic information (principle of the moving part): this principle refers to the need of having elements in the display that moves in accordance with the direction that is compatible with the mental models and expectations of the user. Elicitation of top-down processes: refers to the importance of a display to provide information that is in synchrony with the expectations of the operator. Minimization of information access costs: refers to the importance of having displays that aid the pilot in processing and integrating information from multiple displays in a way that helps the user to move selective attention when the task demands him/her to do so. Consistency: this principle refers to a display providing reliable information in a constant format whenever the information is transmitted to the operator. Predictive aiding: the

need to design displays that can effectively predict what is going to happen and that can transmit this information to the user, prediction is important because it can support performance while replacing cognitive resources with pure perception. Wickens et al. (2004) also emphasized the importance of replacing memory with visual aids. In the case of AOA indicators, the system should reduce the need for the pilot to memorize important information critical for the operation of the aircraft. This is a critical point because, as it has been mentioned before, the operation of an aircraft is a demanding complex task. Consequently, displays that work as memory aids help to reduce the number of cognitive resources used by the pilot allowing for safer and more efficient flight.

Besides the principles explained above, there are some other characteristics that are important to take into consideration in the design of usable visual displays. It is clear that poorly designed systems are deployed every day. Time after time, we see the outcome of using systems that are poorly designed and possess low levels of usability. These poorly designed and unusable systems are difficult to operate, and users tend to have a difficult time trying to figure out how to use these complicated systems. Training users/operators on how to use systems low in usability tend to be complicated, expensive and sometimes futile. As a consequence of a poor design and low levels of usability, the system will more likely be misused or disused, forcing users to keep their current working methods (Maguire, 2001; Chamorro-Koc et al., 2009). Maguire (2001) discussed the benefits of designing usable systems. The first benefit is increased productivity: a user friendly system allows users to concentrate in the task rather than figuring out how to operate the system. The second benefit is error reduction: eliminating inconsistencies, ambiguities, and other design faults will effectively reduce human error due to poorly designed systems. The third benefit is the reduction of training and support needed to generate adequate

performance levels, as a usable system is capable of reinforcing learning and reducing the time needed to train people on how to operate and effectively interact with a tool or system. The final benefit is improved acceptance: users will be more likely to use and trust a system that presents information in a format that is easy to understand and that supports the user's mental models. Trust is an important feature of a usable system. Lee and Nass (2010) explained that trust in relation to technological systems can be defined as the level of confidence the operator has in the system, particularly when the achievement of a goal in an uncertain situation is necessary. Acemyan and Kortum (2012) discussed the relationship between usability and trust. They explained that lack of trust in a system causes significant problems for the system's user, especially when a system is designed to support the user's decision-making process. When a system is not trusted, the operator may refuse to use it and instead, it will find different sources to achieve a goal. In this aspect, Acemyan and Kortum pointed out that if an operator does not trust a system, the user may take three different approaches. The first one is avoiding the system, the second one is limiting the interaction with the system, and the third one is using the system until a better system is provided. At the same time, if a system is perceived as reliable, the operator will trust it, depend on it, and use it frequently. In the study conducted by Acemyan and Kortum on trust and the usability of technological systems, participants had to rate their level of trust and perceived usability on popular systems such as ATMs, DVRs, GPS devices, and software systems such as Microsoft Office. Results of the study showed a linear correlation between usability and trust. Higher scores of perceived usability of the system translated into higher levels of trust. This relationship is even stronger when the user is given no choice and is required to use a specific system. This is an important finding because there are many circumstances in which operators have no choice but to interact with the tools that have been

provided to them to execute a task. This is exactly the case in flying an aircraft. Pilots usually don't have the option to pick among a selection of gauges, controls, and displays. They need to use the system that is installed in the aircraft's cockpit. The goal should be to design and install instruments that pilots can perceive as usable, in order to increase their level of trust in the systems and subsystems provided to them to operate an aircraft.

It was discussed earlier in this section how a visual display should match the mental models of the operator in order to enhance performance. Tlauka (2004) explained that the visual relationship between displays and controls should be considered in their spatial functional relationship and that a compatible display-control arrangement could enhance performance and increase user satisfaction. In other words, a display should aid operators to enhance their ability to respond to a stimulus, reducing the stimulus-response time by being in accordance with the controls needed to perform the task. This is an important aspect in aviation, especially when it comes to displays that show information relevant to AOA. When an airfoil is close to stalling, the display will warn the pilot that the airplane is about to or that it is already stalling. The only way to recover the aircraft from a stall is by reducing the AOA. If the airfoil has already stalled, a reduction in the AOA will necessarily translate into a loss of altitude (FAA, 2000). An adequate stimulus response time in a stall situation is critical, especially when the aircraft is in close proximity to the ground where any loss of altitude can be hazardous. In the implementation of an AOA indicator for the school's fleet, it was important that the chosen instrument was an AOA indicator that not only would help pilots to react faster, but that would also indicate in which direction the controls should be applied. It is not sufficient that the display warns the pilot of a potential stall; a usable display should aid the pilot to apply controls in an effective manner while lowering the usage of cognitive resources. Korblum, Hasbroucq, and Osman (1990)

proposed what they called a dimensional overlap model. This model claims that when a stimulus-response ensemble shares a number of characteristics, the stimulus will activate an automatic response thanks to the features shared by both the stimulus set and the response set, thus reducing not only reaction times, but also increasing the probabilities of a correct response. When the stimulus sets and the response sets do not share characteristics, response times may be slower and error prone. In a series of experiments performed by Eimer (1995), it was found that participants' reaction times when a cue (arrow) indicating in which direction a target letter would appear on a computer screen were faster compared to situations in which the cue alerted the participant of the appearance of the target letter but not of its potential location on the screen. These series of experiments indicated that cues that effectively alerted the participant of the direction in which the letter would appear on the screen, elicited automatic responses. These findings were in accordance with Korblum et al.'s (1990) dimensional overlap model. In a different study conducted by McDougall, Curry, and Brujin (2001), participants were presented with a series of problem-solving tasks. To solve the problems participants had to resort to a series of functions. These functions were represented by a series of icons. Participants were exposed to one of three different types of icons: the first set presented icons that depicted concrete information, the second one presented abstract information, and the last set used arbitrary information that was not connected with the functionality of the icons. Results of the study showed that performance was best for those who used concrete icons, followed by those who used abstract icons. Nevertheless, as the number of trials increased, the significant performance differences between the three sets of icons disappeared. Even though this study reveals that performance is influenced by the level of exposure to the icon set, this study does not show how performance is affected by a secondary task and how concreteness may or may not aid operators in decision making. However, the authors of the study suggested that concrete icons are more useful when an immediate understanding of the icon is necessary, such as in emergency situations. A different study by Geiselman and Osgood (1992) in which non-pilot participants were exposed to three different types of attitude display indicators (ADI), showed that those participants who were exposed to attitude displays that showed concrete information needed significantly less numbers of trials to reach acceptable performance levels than those exposed to a heads up display (HUD) that showed attitude information in an abstract manner.

It is important to understand that AOA indicators are not considered primary sources of information regarding aircraft performance, even though such an indicator can increase safety. There are many different instruments and cues outside the cockpit that provide information to pilots to notify them on the current operational condition of the aircraft. In this sense, pilots need to distribute their attention to all different kind of cues in the environment. Zhang (1997) referred to distributed cognitive tasks, such as flying an aircraft, as a task that requires operators to process the information coming from the external environment and integrate it with information retrieved from internal interpretations in a dynamic manner. In this sense, Zhang argued that external representations are picked up through perceptual processes, while internal representations come from cognitive processes that involve schemas, mental images, and neural networks. To perform distributed cognitive tasks, it is necessary that the information from internal and external representations are integrated and exchanged, not only in a dynamic manner but in an integrative way. In this aspect, it is important to understand that visual displays for complex tasks should allow operators to switch between focused attention and divided attention whenever needed. Parasuraman and Davies (1984) discussed the importance that these two types of attention have on performance. While focused attention allows operators to fixate and process

certain characteristics of a display, divided attention allows operators to integrate the information perceived from different sources. The goal with divided attention and complex tasks in properly designed displays is to create subsystems (individual displays) that allow operators to integrate these sources of information while maintaining efficient levels of performance (Parasuraman & Davies, 1984; Zhang, 1997; Tlauka, 2004). Bennet and Flach (1992) explained that in integrated tasks, attention must be distributed among different information sources that need to be considered in order to reach a decision. It is important then that when designing displays not only the type of information transmitted to the operator should be considered, but also how this information will be presented. Woods (1991) discussed the importance of designing not only for data availability but also designing for information extraction. Systems that have been designed only considering data availability usually force the operator to maintain the data in the memory, while, at the same time, forcing them to retrieve information from long term memory, causing an exhaustion of limited cognitive resources. Thus, displays that replace memory with perception are considered to improve performance because they do not use the cognitive resources involved in information processing (Bennett & Flach, 1992). As stated by Hall, Shattuck and Bennett (2012), "The ultimate goal is to design interfaces that (a) are tailored to specific work demands, (b) leverage the powerful perception-action skills of the human, and (c) use powerful interface technologies wisely." (p. 166). Thus, an AOA indicator that facilitates the crosscheck of instruments should be considered of high importance. It has been argued that introducing new instruments in the cockpit only adds to the already high workload experienced by pilots while operating an aircraft. However, a dedicated AOA indicator that complies with good usability characteristics can increase a pilot's awareness of an aircraft's performance at any given point,

without interfering with the continuous and dynamic examination of other instruments inside the cockpit.

Methods

This was a usability study that employed subjective measures to ask participants about their opinion on the three different AOA indicators that were preselected by the flight department. By the end of the study, the experimenters expected to have enough information to aid the flight department to choose one of the three instruments. The experiment was conducted in the operational environment in which pilots perform their work on a daily basis. Proper steps were taken to avoid biases by both the experimenter and the participants.

Research Approach

This was a within subjects experimental study in which participants were exposed to three different types of AOA indicators. Participants were asked to fill out a number of surveys and provide feedback on each of the AOA instruments they had used during the experiment.

Sample

Ten instructor pilots (IP) (9 male and 1 female) that worked at ERAU participated in the study, the average age of the participants was 22.3 (SD = 3.2). The average total number of hours as pilots for the participants was 424 (SD = 111.3), the average experience as IPs in hours was 141.5 (SD = 120.7). None of the participants had experience as military pilots, and none of the participants had previous practical experience with AOA indicators. These participants were selected by the flight department. The experimenter was subject to work with IPs selected by the flight department at ERAU. Participants were compensated at the same rate they usually are when they work for the university as IPs.

Apparatus and Materials

Three Cessna 172S equipped with the Garmin G1000 glass flight deck were used for the study. Each one of these aircraft had installed one of the three preselected AOA indicators (see figure 2). The three AOA indicators were manufactured by Alpha Systems, Inc. The first aircraft was equipped with a Ultra 2.50" bar indicator installed vertically (L: 2.50", W: 0.75", D: 1.00"); the second one with a Ultra 2.50" bar indicator installed horizontally (L: 0.75", W: 2.50", D: 1.00"); and the third aircraft had the Legacy indicator (L: 2.50", W: 0.87", D: 1.25") installed vertically. Both bar indicators consisted of a series of lights that were aligned either vertically or horizontally; each of these indicators had a total of 16 round lights (5 red, 1 blue, 6 yellow, and 4 green). The legacy indicator had fewer lights than the vertical indicator (1 red chevron, 2 green semicircles, 1 yellow chevron, and a blue line). The vertical bar and Legacy indicators were installed approximately 3 inches to the left of the magnetic compass. The horizontal bar indicator was aligned with the magnetic compass and it was placed on the instrument panel, approximately 2 inches below the magnetic compass.



Figure 2. The three AOA indictors preselected by the flight department for the proposed study. vertical bar, horizontal, bar, and legacy indicators.

Some differences exist in the way these indicators displayed information about AOA. For instance, during slow flight and landing flare, the bar indicators (both horizontal and vertical) showed all red lights plus the blue light on. On the other hand, the Legacy indicator showed the complete green doughnut. For cruise climb and final approach, the bar indicators displayed all red, one blue, and all yellow lights, while the Legacy indicator displayed the bottom half green doughnut and yellow chevron. During a stall warning, the bar indicators displayed all red lights, while the Legacy indicator displayed the red chevron and the top half of the green doughnut (see Appendix A for a complete list of indications according to the type of maneuver/flight stage).

An informed consent form (see Appendix B) was created for the study and it was distributed to the participants before the experiment began. A pre-flight questionnaire (see Appendix C) designed to collect demographic information, as well as previous experience using AOA indicators, was used prior to the experimental portion of the study. In order to capture the participants' opinions on the usability of the AOA indicators, a post-flight questionnaire was developed. This questionnaire included an adaptation of the Systems Usability Scale (Brooke, 1996) for the purposes of this study. A series of surveys were created in order to ask IPs their opinions about the following topics: visual representation and location of the instrument inside the cockpit, effect of the AOA indicator in performing maneuvers, and advantage of the instrument for pilot training (see Appendix D).

Design and Procedures

This was a within subjects study. Each participant was exposed to all three AOA indicators. In order to reduce learning bias and carryover effects, the presentation of the instruments was counterbalanced.

The study was divided into four different sessions and the study had an approximate duration of two weeks. The first portion was an informative/training session. Participants were scheduled to appear at the flight department in order to be briefed on the purpose of the study. At this point participants filled out and signed the informed consent (Appendix B), a copy of the informed consent was provided to participants for their records. After the briefing, participants filled out the first portion of the pre-flight questionnaire (Appendix C). After participants answered questions about demographics and previous experience with AOA indicators, they received a one hour training session. The training consisted of a brief explanation of the AOA concept and an introduction to the functions embedded in the indicator (such as buttons and dials). Participants were provided with a copy of the approximate indications form, which told pilots what information the instrument would show on each of the flight maneuver they would be performing during the experimental portion of the study (see Appendix A). The training session and all the training material was designed and provided by the flight department. At the end of the training session, participants were encouraged to ask any questions regarding the instruments or what to expect while using the indicators during the experimental flights. After the training session, participants filled out the portion of the pre-flight questionnaire to rate the effectiveness of the training received. After questions were answered, the pre-flight questionnaires were collected and participants were told that they would receive a flight schedule via e-mail during the following days in order to begin the three experimental flights.

In the first experimental session, participants received a copy of the post-flight questionnaire that they would fill out right after the completion of the first session. Each of the experimental sessions had an approximate duration of an hour. The flight was divided into five different stages in which participants were to use the assigned AOA indicator to aid them in

performing each maneuver. The five maneuvers (stages) selected for this study were: slow flight, power-on stall, power-off stall, normal approach and landing, and short-field approach and landing. The reason why these five maneuvers were selected for the study is because AOA indicators are more useful in warning pilots of possible aerodynamic stalls during the takeoff and landing phases of flight. During takeoff and landing, the pilot needs to maneuver the aircraft under a high AOA and low airspeeds. Slow flight is a maneuver used to show SPs the flight characteristics and the amount of control they would have when the aircraft is at a minimum flying speed. Power-on stall is a maneuver performed at high altitude that simulates a takeoff using the appropriate aircraft's trim and power conditions for this stage of flight. Power-off stall is a maneuver performed at high altitude that simulates a landing using the aircraft's appropriate trim and power conditions during a landing procedure. These two maneuvers are used to train pilots on proper stall recovering techniques. Short field approach and landing is a maneuver that requires pilots to approach the runway at a high rate of descent while maintaining a low airspeed; this maneuver is performed when runways are relatively short and/or an obstacle is on the final approach path to the airstrip. After each participant completed this first flight, they filled out the first post-flight questionnaire and they dropped it off at the office of the university's assistant chief flight instructor. This same procedure was used for flights two and three of the experimental stage. After completion of the three flights, participants were thanked for their participation in the study and were dismissed from the experiment. Participants were told that they could contact the experimenter in case they had any questions, concerns or if they wanted to know the results of the study.

Sources of the Data

The data collected during this study was of a qualitative nature; all the data was subjective (with the exception of the demographics questionnaire). This data was divided into two sections. First, a number of items that had been developed specifically to ask participants about the ability of the instrument to assist them on performing the five flight maneuvers that were selected for this experiment and how they thought the indicators could help training SPs. These items had been developed using seven point Likert scales. An adaptation of the SUS developed by Brooke (1996) was also used to ask pilots about their opinion on the usability of each instrument. The second source of data was the comments pilots wrote on the survey about their opinions on each AOA indicator.

Data Collection Device

The pre-flight questionnaire was an instrument designed for this study that collected data about participants' demographics, previous experience using AOA indicators, and their opinion of the usefulness of an AOA indicator for student training. The post-flight questionnaire was divided into two sections; an adaptation of the System Usability Scale (Brooke, 1996) and a survey that asked participants about the usefulness of the instrument for each of the five maneuvers. This survey also asked participants about their opinions about the chosen location of the instrument in the cockpit and how beneficial they thought the instrument would be for SP training.

Instrument reliability and validity.

The SUS has been used extensively to measure a wide range of products and services including, websites, computer hardware, voice systems, mobile applications, among others (Kortum & Bangor, 2013). According to Bangor, Kortum, and Miller (2009), the SUS has been

used in over 206 studies; they also mentioned that this survey is an easy and quick way to collect usability data. At the same time, the survey has been shown to be effective in surveying participants about the usability of a variety of technological systems. The last item of the post-flight questionnaire was developed by Bangor, Kortum and Miller (2008) and was adapted for this study to ask participants about their overall experience with the indicator; this is a seven point Likert type of question that ranges from "worst imaginable" to "best imaginable."

The second section of the post-flight questionnaire asked participants to rate the usefulness of the instrument in aiding them to perform the five maneuvers, and the usefulness of the instrument in helping training SPs. This survey was developed for this study by a subject matter expert (SME) with extensive military flight experience and the use of the AOA. The SME also chose the five maneuvers to be used in the experiment. This survey has not been validated but it was expected that the results of this survey would correlate to the answers provided by the participant in the SUS.

Treatment of the Data

The SUS was scored according to the guidelines provided by Brooke (1996); for items 1, 3, 5, 6 and 8, the score contribution is the scale position minus 1 (with a maximum score contribution of 4 per item). For items 2, 4, 7 and 9, the score contribution is 5 minus the scale position. The sum of the scores was then multiplied by 2.77 to obtain the overall score of the SUS. The SUS ranges from scores of zero (not usable at all) to one hundred (most usable).

The second portion of the post-flight questionnaire was composed of items that used Likert scales. Even though the data collected in this portion was also qualitative, because of the numerical values assigned to each point in the scale, it was possible to analyze this data using quantitative methods. For the purposes of this study, a repeated measures ANOVA was used to

test the experimenter's hypotheses related to differences between the three indicators; a Friedman's Rank test for correlated samples was also used to analyze the data.

All comments about the indicators were coded and divided into four categories; positive, negative, mixed, and other comments. Consideration was taken on the type of feedback provided by each participant (positive or negative); the number of positive and negative comments for each category was then summed up for each indicator.

Results

The different subjective scales containing Likert items were analyzed using a repeated measures analysis of variance (ANOVA), which assumes the data is continuous and normally distributed. Likert (1932) recommended using a parametric data analysis approach on composite scales, he pointed out that surveys containing five point scale items or more tend to follow a fairly normal distribution, and that the sum of the numerical scores of individual items in the scale should be obtained for each participant before analyzing the data. The Friedman's rank test for correlated samples was used to analyze some individual items that were of especial interest for the study. This technique assumes that samples are not continuous and not normally distributed, and it can be thought of as the non-parametric alternative to the repeated measures ANOVA. This test is normally used when analyzing individual items of a scale containing nonparametric data, such as Likert items.

The first scale that was analyzed was the adaptation of the system usability scale (SUS) composed of 9 Likert type items. In this scale the minimum possible score is 0 and the maximum possible score is 100. Table 1 shows the mean and standard deviation for each AOA indicator.

Table 1
Mean and Standard Deviation for SUS

		Std.	
	Mean	Deviation	N
Horizontal	45.69	27.58	10
Vertical	61.11	24.25	10
Legacy	71.11	19.07	10

A repeated measures ANOVA was first employed to investigate if significant differences between the groups existed. Results indicate that when using a repeated measures ANOVA with a Greenhouse-Geisser correction, the mean scores for SUS were not statistically different F(1.14, 10.27) = 3,58; p > .05. The next analysis conducted was related to the visual representation of the indicator. This section of the survey was composed of 3 items with a total maximum score of 21. Once again a repeated measures ANOVA was conducted first, followed by the Friedman's rank test for correlated samples. Table 2 shows the mean score and standard deviation for each indicator.

Table 2
Mean and Standard Deviation for Visual Representation

	,	· ,	
	Mean	Std. Deviation	N
Horizontal Bar	10.11	3.85	9
Vertical Bar	15.78	4.94	9
Legacy	17.78	2.11	9

The repeated measures ANOVA with a Greenhouse-Geisser correction shows there is a significant difference between the mean scores for visual representation; F(1.79, 14.34) = 7.39, p < .05. A pairwise comparison of the means using the Bonferroni correction showed that there

was a significant difference between the horizontal bar indicator and the legacy indicator, all other comparisons were not significant (see Table 3).

Table 3
Pairwise Comparisons for Visual Representation

Indicator		Mean Difference	Std. Error	Sig.
Horizontal Bar	Vertical Bar	-5.67	2.27	.11
	Legacy	-7.67	1.68	.01
Vertical Bar	Horizontal Bar	5.67	2.27	.11
	Legacy	-2.00	2.19	1.00

The section of the survey related to the indicators ability to enhancing IPs' personal performance was also analyzed following the procedures shown above. The maximum possible score for this section was 35. Table 4 shows the mean and standard deviation for each indicator.

Table 4

Mean and Standard Deviation for Enhanced Performance

Mean and Standard Deviation for Enhanced Lefformance				
	Mean	Std. Deviation	N	
Horizontal Bar	17.22	7.43	9	
Vertical Bar	21.22	6.26	9	
Legacy	22.33	6.18	9	

The repeated measures ANOVA with a Greenhouse-Geisser correction showed a significant difference between the mean scores for enhanced performance; F(1.27, 10.21) = 4.73, p < .05. A pairwise comparison of the means using the Bonferroni correction showed a significant difference between the horizontal bar indicator and the vertical bar indicator, all other comparisons were not significant. It is important to note that the mean difference between the horizontal bar indicator and the Legacy indicator (not significant) is greater than the mean difference between the horizontal bar and the vertical bar indicator (significant). This inability to

find a significant difference between the horizontal bar and the Legacy indicator is believed to have occurred due to the difference in variance between these two sample sets (see table 5).

Table 5
Pairwise Comparisons for Enhanced Performance

		Mean Difference (I	J) Std. Error	r Sig.
Indicator				
Horizontal	Vertical Bar	-4.00	1.04	.01
Bar		-4.00 -5.11	2.25	
	Legacy			.16
Vertical Bar	Horizontal	4.00	1.04	.01
	Vertical	-1.11	1.74	1.00

A similar analysis was performed on the section that asked IPs about how they thought the indicators enhanced their awareness of how close the aircraft was to a stall during the maneuvers. This section was composed of five Likert items and the maximum possible score for this section was 35. Table 6 shows the mean score and standard deviation for each indicator.

Table 6
Mean and Standard Deviation for Enhanced
Stall Awareness

		Std.	
	Mean	Deviation	N
Horizontal Bar	19.50	7.06	10
Vertical Bar	23.40	5.98	10
Legacy	24.70	5.54	10

The repeated measures ANOVA with a Greenhouse-Geisser correction showed a significant difference between the mean scores for enhanced performance; F(1.70, 15.32) = 6.48, p < .05. A pairwise comparison of the means using the Bonferroni correction showed that there was a significant difference between the horizontal bar indicator and the vertical bar indicator

and between the horizontal bar and the legacy indicators. No significant difference was found between the vertical bar and legacy indicators (see Table 7).

Table 7
Pairwise Comparisons for Enhanced Stall Awareness

Indicator		Mean Difference	Std. Error	Sig.a
Horizontal Bar	Vertical Bar	-3.90	1.26	.04
	Legacy	-5.20	1.78	.05
Vertical Bar	Horizontal	3.90	1.26	.04
	Legacy	-1.30	1.42	1.00

Another section of the survey asked IPs about how often they crosschecked the indicator during the maneuvers, this section was composed of 5 items with a maximum possible score of 35. Table 8 shows the mean score and standard deviation for each indicator. The repeated measures ANOVA with a Greenhouse-Geisser correction showed there was a significant difference between the mean scores for crosschecked indicator during maneuver; F(1.25, 8.77) = 5.29, p < .05. A pairwise comparison of the means using the Bonferroni correction was unable to identify any significant differences between the three indicators.

Table 8
Mean and Standard Deviation for
Crosschecked Indicator During Maneuvers

		Std.	
	Mean	Deviation	N
Horizontal Bar	18.00	6.78	8
Vertical Bar	22.62	6.07	8
Legacy	23.75	6.86	8

The final section of the survey asked IPs if they thought that SP's crosschecking the indicator would help them enhancing their performance during maneuvers. This section was also

composed of five items with a maximum possible score of 35. Table 9 shows the mean score and standard deviation for each indicator. The repeated measures ANOVA with a Greenhouse-Geisser correction showed there was a significant difference between the mean scores for enhanced performance; F(1.37, 10.98) = 5.29, p < .05. A pairwise comparison of the means using the Bonferroni correction was unable to identify any significant differences between the three indicators.

Table 9
Mean and Standard Deviation for Indicator would Enhance Students' Performance

	Mean	Std. Deviation	N
Horizontal Bar	18.78	8.24	9
Vertical Bar	22.56	6.17	9
Legacy	24.11	5.64	9

Five individual Likert items were also analyzed using the Friedman's rank test for correlated samples. The first item asked participants if crosschecking the indicator helped them to fly a more stable approach on final during normal approach and landing. This seven point Likert item ranged from, 1 strongly disagree, to 7 strongly agree. The Friedman's rank test for correlated samples showed there wasn't a significant difference between the sample ranks; $\chi_F^2(2) = 4.22$; p > .05. Table 10 shows the mean ranks for this item.

Table 10
Ranks for Crosschecking the Indicator helped in Flying a More Stable Approach on Final (Normal Approach and Landing)

	Mean Rank
Horizontal Bar	1.56
Vertical Bar	2.06
Legacy	2.39

The second item asked participants if crosschecking the indicator helped them to fly a more stable approach on final during short field approach and landing. This seven point Likert

item ranged from, 1 strongly disagree, to 7 strongly agree. The Friedman's rank test for correlated samples showed there wasn't a significant difference between the sample ranks; $\chi_F^2(2) = 2.85$; p > .05. Table 11 shows the mean ranks for this item.

Table 11
Ranks for Crosschecking the Indicator helped in Flying a More Stable Approach on Final (Short Field Approach and Landing)

	Mean Rank
Horizontal Bar	1.78
Vertical Bar	1.83
Legacy	2.39

The third item asked IPs if crosschecking the indicator enhanced their landing performance during normal approach and landing. This was also a seven point Likert item like the ones described above. The Friedman's rank test for correlated samples showed there was a significant difference between the sample ranks; $\chi_F^2(2) = 11.08$; p < .01. Table 12 shows the ranks for this particular item.

Table 12
Ranks for Crosschecking Indicator Enhanced Landing Performance (Normal Approach and Landing)

	Mean
	Rank
Crosschecking this Horizontal AOA indicator enhanced my landing performance	1.33
during normal approach and Landing	
Crosschecking this Vertical AOA indicator enhanced my landing performance	2.00
during normal approach and landing	
Crosschecking this Legacy AOA indicator enhanced my landing performance during	2.67
normal approach and landing	

The fourth item asked IPs if crosschecking the indicator enhanced their landing performance during short field approach and landing (seven point Likert item). The Friedman's

rank test for correlated samples showed there was a significant difference between the sample ranks; $\chi_F^2(2) = 8.82$; p < .05. Table 13 shows the ranks for this particular item.

Table 13
Ranks for Crosschecking Indicator Enhanced Landing Performance (Short Field Approach and Landing)

	Mean
	Rank
Crosschecking this horizontal AOA indicator enhanced my landing performance	1.56
during short field approach and landing	
Crosschecking this Vertical AOA indicator enhanced my landing performance	1.83
during short field approach and landing	
Crosschecking this Legacy AOA indicator enhanced my landing performance during	2.61
short field approach and landing	

The final item asked participants about their overall satisfaction with the indicator (worst imaginable to best imaginable) using a seven point Likert item. Friedman's rank test showed a significant difference between the indicators; $\chi_F^2(2) = 6.06$; p < .05. Table 14 shows the ranks for this item. Through a visual inspection of the ranks it can be concluded that there was a significant difference between the horizontal bar and legacy indicators.

Table 14

Overall Satisfaction Ranks

	Mean Rank
Horizontal Bar	1.40
Vertical Bar	2.25
Legacy	2.35

Another important aspect of the data collected during the study was the comments that participants provided during the experimental stage of the study. As it was explained before, IPs had the option to provide their own thoughts for each of the items on the post-flight

questionnaire. It is important to clarify that participants were not required to provide comments, this was an option provided to them in case participants felt the need to support their answers while using the Likert type items. There were a total of five hundred seventy six comments collected during the study. There were one hundred sixty three comments about the horizontal bar indicator, two hundred twenty one about the vertical bar indicator, and one hundred ninety two comments for the legacy indicator. Two raters coded independently each comment into one of four different categories; Positive, negative, mixed, and other comments. Examples of positive comments include: "[it] would help in setting proper climb angle after recovery" or "good location and representation, the lights are easy to understand." Examples of negative comments include: "hard to integrate into scan" or "the indications are not that simple. May require frequent review for students." Examples of mixed comments include: "I like the number of red lights. Like counting down until stall, but so many yellow and green, too complex, sometimes all light up during/after maneuvers which is just distracting" or "it really helped for landings, not so much slow flight/stalls." Examples for other comments include: "gusty crosswinds made crosschecking hard" or "Flew slow flight at MCA [minimum controllable airspeed] and got different indications from published. Flew at published indications and airspeed was 10 knots above MCA [minimum controllable airspeed]." A Cohen's Kappa was used to analyze interrater reliability. The interrater reliability for the observers was found to be Kappa = 0.80, p < .001, 95%CI (0.759, 0.842). Table 15 shows the cross-tabulation of all the comments between observers. This table shows the number of comments in which both observers agreed on for each

Table 15
Observer A * Observer B Comments Crosstabulation

			Observer B				
			Positive	Negative	Mixed	Other	Total
Observer A	Positive	Count	244	5	14	8	271
		Expected Count	123.3	84.7	38.1	24.9	271
	Negative	Count	6	160	8	3	177
		Expected Count	80.5	55.3	24.9	16.3	177
	Mixed	Count	10	13	59	5	87
		Expected Count	39.6	27.2	12.2	8.0	87
	Other	Count	2	2	0	37	41
		Expected Count	18.6	12.8	5.8	3.8	41
Total		Count	262	180	81	53	576
		Expected Count	262	180	81	53	576

category, the expected value for each category (chance), and the number and type of comments in which both raters disagreed on. The number of comments in which both raters agreed on was then separated according to the type of indicator. Thus, for the horizontal bar indicator, both raters agreed on 147 of the 163 comments. The comments were divided as follows; 62 positive, 60 negative, 19 mixed, and 6 other. For the vertical indicator, raters agreed on 189 of the 221 comments. The comments were divided as follows; 88 positive, 63 negative, 23 mixed, and 15 other. For the Legacy indicator, raters agreed on 164 of the 192 comments provided by the participants. The comments were divided as follows; 94 positive, 37 negative, 17 mixed, and 16 other. Figure 3 shows the interrater agreement by indicator type. As it can be seen on this figure, the Legacy received the highest number of positive comments and the lowest number of negative comments, followed by the vertical bar indicator. The horizontal bar indicator had the highest number of negative comments.

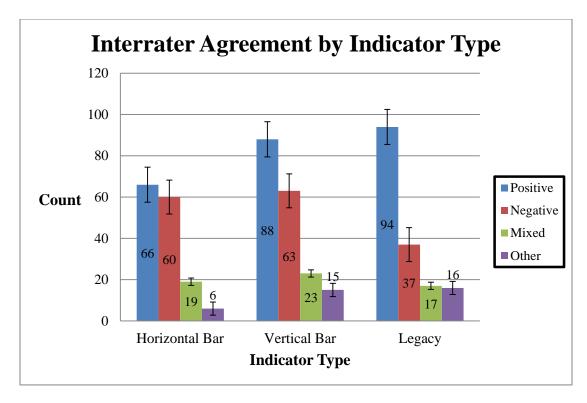


Figure 3. Interrater agreement by indicator type separated by type of comment.

Comments regarding the present location of the indicator were also analyzed. Figure 4 shows how these comments were distributed by type. It is important to note that there were a total of forty three comments analyzed; raters agreed on 37 of those comments. The comments were distributed as follows; 17 positive, 17 negative and 3 mixed. Once again the indicator that received the highest number of positive comments and the lowest number of negative comments was the legacy indicator. The horizontal bar and the vertical bar indicator had the same number of negative comments. Finally, the vertical bar indicator had the lowest number of positive comments.

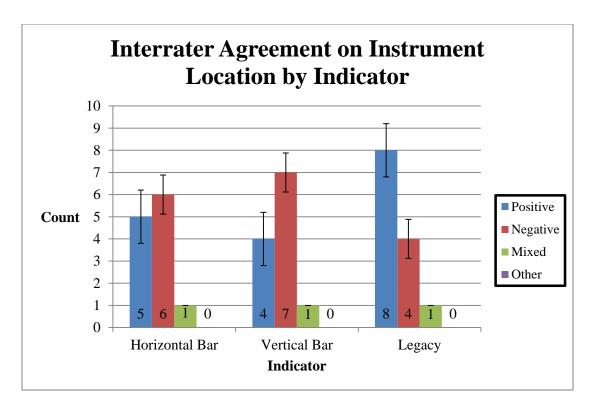


Figure 4. Interrater agreement on the instrument location in the cockpit by indicator.

Discussion, Conclusion, and Limitations

Discussion

The results of the present study allowed the researchers to test three hypotheses. The first hypothesis stated that there was a significant difference between the indicator that presents AOA information in a horizontal fashion and indicators that present AOA in a vertical fashion. As it can be concluded from the statistical analysis of the data collected, it is clear that pilots overall preferred vertical AOA indicators (vertical bar and/or Legacy indicator) over the horizontal bar indicator. Significant differences between the horizontal bar indicator and at least one of the vertical indicators were found on six of the eleven statistical analyses (comments are not included on this count). The significant differences were found for visual representation (Legacy), Enhanced performance (vertical bar), enhanced stall awareness (vertical bar and

Legacy), enhanced landing performance for normal approach and landing (Legacy), enhanced landing performance for short field approach and landing (Legacy), and overall satisfaction with the indicator (Legacy). It is important to note that the horizontal bar indicator had the lowest score on all of the subsections of the post-flight questionnaire, including the system usability scale (SUS) in which it only achieved a mean score of 45.69 compared to the legacy indicator which had a mean score of 71.11, and the vertical bar indicator with a mean of 61.11. The results of the statistical analysis of the Likert items on the post flight questionnaire are in accordance with the number of positive versus negative comments that the participants gave to each type of indicator. The horizontal bar indicator received the lowest number of positive comments (66) compared to the Legacy indicator (94) and the vertical bar indicator (88). Reading the type of positive and negative comments about each indicator, it was evident the reasons why participants liked vertical indicators better than the horizontal bar indicator; when commenting about the horizontal bar indicator, one of the participants stated "when pitching for angle of attack we use the vertical plane. Horizontal display counter-intuitive." Another participant commented "total negative transfer of learning, horizontal indication has no relevance to pitch." In contrast, some of the comments about the vertical indicators support the idea that the indicator should match the pilot's mental expectations. One of the participants commented about the Legacy indicator that "as pitch (should hopefully be) is in the vertical axis, the AOA indicator felt more "naturalized." Another participant commented about the vertical bar indicator stating, "the vertical bar represents the vertical force making it simple to understand." These comments are in accordance with some of the design principles discussed earlier on this paper. The principles of pictorial realism and the principle of congruency of dynamic information, where Wickens et al. (2004) discussed the importance of designing displays that comply with the mental models and

expectations of the operator, this includes having realistic visual representations of the information that is intended for the operator. These comments are also in accordance with the importance of designing visual displays that take into consideration the display-control arrangement (Tlauka, 2004). As it was mentioned several times on the comments, pilots liked the vertical displays better because they were in accordance with their mental expectations. Also, because the way the controls need to be applied in order to increase or decrease AOA is vertically (by pulling or pushing the yoke control). A horizontal bar indicator violates both, the mental models and expectations of the pilot and the idea of a synchronized display-control arrangement; while the horizontal bar indicator is providing information about angle of attack in a fashion that violates mental models, the pilot is expected to apply the controls in a vertical fashion while looking at indications displayed horizontally.

The second hypothesis stated that there was a significant difference between the vertical bar and legacy indicators. The statistical analyses do not show any significant difference between these two indicators. It is important to note that for the eleven sections of the post-flight questionnaire that were analyzed, the Legacy indicator obtained the highest mean scores and the smallest standard deviations on all of the repeated measures analyses. On the Friedman's rank test for correlated samples, the Legacy indicator ranked higher than the vertical indicator on eight of the sections (visual representation, enhanced performance, would enhance students' performance, helped in flying a more stable approach on final (normal approach/landing and short field approach/landing), enhanced landing performance (normal approach/landing and short field approach/landing), and overall satisfaction. The Legacy and vertical bar indicators had the same rank on two of the sections (system usability scale, and enhanced stall awareness). The vertical bar indicator achieved a higher rank in only one of the categories (crosschecked indicator

during maneuvers). The number of positive comments also favors the Legacy indicator (94) when compared to the vertical indicator (88). The number of negative comments for the Legacy indictor is almost half of the total number of negative comments for the vertical indicator (37 versus 63). When reading the comments about both indicators, most of the negative comments for the vertical indicator refer to the high number of lights used for each of the indications. Some examples include: "too many lights to be able to quickly scan," and "need to count all lights to be on glidepath, very sensitive." One of the comments that best reflects how most participants felt about the vertical bar indicator's light arrangement and indications was provided by one of the participants when asked about his overall experience with the indicator, the participant stated that "the indicator uses too many lights and can be distracting, especially on takeoff and climbout. Also when transitioning from cruise to higher AOA, the sudden illumination of all 16 lights from just one green would grab my attention, which I did find distracting." Negative comments about the Legacy indicator were not as consistent as for the vertical indicator. Few participants complained about the symbols and the number of lights on the indicator. Some examples include: "Colors/symbols less intuitive compared to light bar indicator," "not as accurate as other ones (due to the limited number of indications)," and "hard to integrate. Stall horn works just fine." This last participant produced twenty two of the thirty seven negative comments for the legacy, his comments concentrated on how hard it was to integrate the indicator into the visual scan, and how much easier it was for him to just listen to the stall warning horn. On the other hand, positive comments for the vertical indicator concentrated on the fact that the indicator was easier to understand and more intuitive than the horizontal bar indicator; some examples include: "the vertical bar represents the vertical force making it simple to understand," and "unlike horizontal, vertical makes more sense." Some other positive

comments emphasized on the ability of the indicator to help participants to perform maneuvers in an efficient manner, and to support decision-making. Some examples include: "I felt more confident with a higher AOA and slower airspeed during final approach," and "complemented maintaining slow flight." For the Legacy indicator, positive comments in general focused on the simplicity of the indications and the discriminability of the lights displayed on the indicator (chevrons and doughnut) compared to the multiple bulbs on the bar indicators. Some examples include: "Very simple, clean, and quick to read," "with different symbols, it was much easier to see critical AOA in peripheral vision," and "Intuitive. Easy to understand and interpret. Few large symbols are much easier to use than many lights in close proximity." As with the vertical bar indicator, many positive comments about the Legacy indicator also referred to the indicator's ability to support decision making and improve performance. Some examples include: "allows me to know I am on speed quickly without having to look down at airspeed," and "if the normal indication [green doughnut] wasn't there, I knew something had changed (alt, airspeed)." Most participants commented on how useful the Legacy indicator was during landings. Some of the comments that best describes what participants thought about the instrument during these landing maneuvers include: "Helps to not overcorrect on pitch changes, keep the ball [green doughnut] and the airplane lands super smooth," and "in these landings I was less apprehensive about my slower airspeeds during final approach, I also knew I was doing it correctly because of the green doughnut." For comments regarding the overall experience with the indicator (in which all participants commented), independent raters agreed on 6 positive comments for the Legacy indicator versus 1 positive comment for the vertical indicator. Both indicators received one bad comment; for mixed comments, the Legacy indicator received 2 comments versus 5 for the vertical bar indicator. Even though the statistical analyses failed to support our hypothesis that

there was a significant difference between the vertical bar and the Legacy indicator, the high number of negative comments received by the vertical bar indicator suggests that participants felt more comfortable performing maneuvers (especially final approaches and landings) with the Legacy indicator.

Our third hypothesis stated that the current location where the AOA indicator is placed, to the left of the magnetic compass on the dashboard (vertical bar and Legacy indicators) and below the magnetic compass (horizontal bar indicator) would be disliked by IPs (see figure 5). One item on the post flight questionnaire asked participants if the particular AOA indicator's physical location in the cockpit facilitated a crosscheck of AOA. This was a seven point Likert item that ranged from strongly disagree to strongly agree. The horizontal bar indicator received 3 negative ratings (below 4 on the Likert Scale), 1 neutral rating (4 on the scale), and 6 positive ratings (5 or higher on the scale). The vertical bar indicator received 1 negative rating, and 8 positive ratings. The Legacy indicator received 1 negative rating and 9 positive. This means that across indicators, participants acknowledged that the indicators' current location facilitated the crosscheck of AOA. On the other hand, the analysis of the comments indicated that there was a high number of negative comments (see figure 4). It is interesting to see how the vertical bar indicator received the highest number of negative comments and the lowest number of positive comments. While the comments for the Legacy indicator seems to be consistent with the ratings it received on the Likert item discussed above. The comments for the horizontal bar indicator seem also to be somehow inconsistent with the ratings received on the Likert item. When

reading the type of negative comments provided by the participants for this specific item, most



Figure 5. Location of the AOA indicators in relation to the airspeed tape on the G1000 and standalone airspeed indicator.

pilots only talked about minor modifications to the current location of the instrument. For instance, a participant commented about the vertical bar indicator's location "would like to see the indicator right next to mag compass." This is a minor modification from the indicator's current location, since the instrument is located no more than three inches from the magnetic compass. This same participant commented on the horizontal bar indicator's location "too far from magnetic compass." Once again, the horizontal bar indicator is located no more than two inches below the magnetic compass. Another participant commented about the location of all three indicators "Integrated in G1000 would be a lot better than a standalone instrument." Only one of the participants suggested a significant change on the positioning of the instrument in the cockpit, this participant stated that the indicators "should be aligned with AS [airspeed] tape" (see figure 5). This is an interesting comment as the airspeed tape is on the left side of the G1000

display on the pilot's side of the cockpit. The researchers of this study believed that participants would not like the current location of the instrument because traffic patterns are usually performed turning to the left. As stated by the FAA (2013), "If not otherwise authorized or directed by the tower, pilots of fixed-wing aircraft approaching to land must circle the airport to the left." These types of maneuvers require pilots to check for other aircraft in the area while checking the aircraft's position in reference to the runway (which is normally to their left). For these reasons, the researchers of the present study hypothesized that the present location of the indicators would be disliked by the participants and that they (or at least some) would suggest the indicator to be installed on the left side of the dashboard as it would facilitate the crosscheck with the airspeed tape and the outside scan of traffic in the pattern while maintaining awareness of the aircraft's position in reference to the runway.

Conclusion

The present study was intended to find the difference between three different angle of attack indicators. The multiple analyses of the data and the comments allowed the researchers to reach several conclusions about the usability of the three preselected indicators. It can be concluded that vertical indicators are better representations of AOA, because they support the expectations and mental models of pilots. The horizontal bar indicator is not intuitive and it can create confusion, especially for SPs who do not fully understand all the aeronautical concepts related to operating an aircraft. Even though the statistical analysis didn't show a significant difference between the vertical bar and the Legacy indicator, it can be concluded according to the comments provided by the participants of the study, that the Legacy is a simple tool that aids pilots to perform landing maneuvers better than the vertical bar indicator. The reason why the Legacy indicator seems to be a better instrument is because it relies more on perception than in

higher order metal processes. While the Legacy indicator displays few lights and different shapes, the vertical bar indicator relies on a series of 16 lights that push pilots to count the number of red lights remaining to know how close they are to stalling. The Legacy indicator on the other hand, shows fewer indications; a red chevron and the upper half of the green doughnut would warn pilots of a potential stall, also the red chevron pointing downwards tells pilots that the AOA should be decreased by lowering the nose in order to avoid a stall. The Legacy's visual layout seems to be in accordance with compatible display-control arrangements discussed by Tlauka (2004) and with Korblum et al.'s (1990) dimensional overlap model; which claims that when a stimulus-response ensemble shares a number of characteristics, the stimulus can trigger an automatic response due to the similarities between the stimulus and the mental expectations of the operator. On the other hand, some pilots commented on the vertical bar indicator during the stalls and slow flight maneuvers; that they liked counting the lights or seeing the lights disappear as they were approaching the critical AOA until stalling. This exercise (counting lights) requires the utilization of multiple cognitive resources, including memory. This would indicate that during these types of maneuvers in which the aircraft is several hundred feet above the ground, pilots can afford to count lights in order to know when a stall would happen; they would have plenty of time to react in order to recover the aircraft from the stall without worrying about hitting the ground. This same approach (counting lights) is both inefficient and dangerous while performing landings because pilots cannot waste time or cognitive resources on counting lights in order to figure out the aerodynamic status of the aircraft. During landings pilots need to be aware of multiple cues inside and outside the cockpit. As a matter of fact, some of the participants commented on how they decided to disregard the vertical bar indicator while landing. On the other hand, the Legacy indicator received positive comments about its ability to

assist pilots during landings. This is because the few indications and the different shape of the symbols on the display can effectively inform pilots of the aerodynamic status of the aircraft. A green doughnut indicates pilots that the aircraft is in an optimal AOA, while the red and yellow chevrons inform pilots of whether the AOA is too high or too shallow, there is no counting lights involved, just perception; a red chevron pointing downwards tells pilots to decrease AOA, a yellow chevron pointing upwards tells the pilot that the AOA is too shallow, and a full green doughnut tells the pilot the aircraft is in a safe aerodynamic attitude. As for the location of the indicator inside the cockpit, it is unclear whether or not pilots favored the present location. As it was seen in the discussion section, both bar indicators received a high number of negative comments, while the Legacy indicator received a high number of positive comments and very few negative ones. It is important to remember that the type of negative comments for the indicators only mention minimum modifications to the present location of the instrument. It can be speculated that the reason why participants favored a central location of the instrument rather than a leftward position was because perhaps, they disregarded the indicator during most parts of the traffic pattern, and only focused on it during final approach and landing when the aircraft was already aligned with the runway's centerline. Perhaps this central position of the indicator helps pilots to concentrate on the widening of the runway while they are preparing for landing, while crosschecking the AOA indicator without having to shift their eyes away from the runway. This same reasoning could be applied to slow flight and stalls; pilots didn't necessarily need to scan for traffic by looking to the left of the aircraft, and while performing the maneuvers they were looking forward and outside the cockpit. This would explain the high ratings on the Likert item that asked participants about the current location of the instrument inside the cockpit.

Nevertheless, the difference in the number of positive and negative comments for the location suggests there might be a relationship between indicator type and its location in the cockpit.

Based on the analyses of the data collected throughout the study and visual display design principles and theoretical background discussed in this study, the researchers of the present paper believe that the Legacy indicator is the most usable indicator in comparison with the Ultra 2.5" bar indicators (vertical and horizontal). The results show a significant difference between the Legacy indicator and the horizontal bar indicator in six of the eleven analyses, including overall satisfaction with the indicator. Even though the statistical analyses did not show a significant difference between the vertical bar indicator and the Legacy indicator, the difference in the number of negative comments between these two indicators (66 for the vertical bar vs. 37 for the Legacy), and the nature of the positive comments for the Legacy indicator, indicates that participants, in general, preferred the latter indicator. This preference is more evident during landings. While the Legacy indicator received many positive comments on its ability to support decision making during landings, the vertical bar indicator was disregarded for most pilots during this maneuver. It is important to note that AOA indicators are most usable in flight phases in which the aircraft is at high AOA and low airspeeds (e.g. during landings). For this reason the researchers of this study believe the Legacy indicator should be the instrument to be installed in the university's fleet of Cessna 172S.

Limitations

The present study has a number of different limitations that should be addressed in future studies. The first limitation that we encountered was the small number of participants provided by the flight department. If a larger subject pool had been made available from the same pilot population, the probabilities of finding significant differences between the AOA indicators in the

SUS scale would have been highly probable. The second limitation we encountered was the nature of the sample, participants were relatively inexperienced IPs. Maybe using experienced IPs could help to clarify if there is a significant difference between vertical indicators; at the same time, more experienced participants could have a different opinion about the location of the indicator in the cockpit. Perhaps a study with a larger sample that combines both types of pilots could help to clarify differences between experienced and inexperienced IPs. Another limitation of the present study was the type of data collected. Due to time limitations, our study was constrained to collect subjective data. Future studies should consider using objective measures. For instance, it is possible to collect flight data from the fleet of Cessna 172S. This data, if properly analyzed, could help researchers understand if there is a clear relationship between indicator preference and performance. Another important limitation of the study was the location of the indicator in the cockpit; it would be interesting to manipulate the location of the instrument in order to see if participants blindly agree with the location of the instrument, or if on the other hand, they suggest a different location for the instrument based on their past experiences and aviation knowledge. Finally, it would be interesting to have the students' perspective on AOA indicators. A study using SPs would help researchers better understand the preferences and needs of SPs while using AOA as part of their training.

As for the tools used in the present study, there are a few recommendations for future research. First, future studies that use the SUS are encouraged to use the format that was developed for the present study. More importantly, future studies should include the ten items on the original SUS instead of nine items as it was used for the present study. Researchers of the present study consider that the selected maneuvers used for the flights were appropriate as they are directly related to AOA. Future studies should incorporate these same five maneuvers and the

corresponding sections of the post-flight questionnaire to test the usability of AOA indicators.

Overall, we consider that the post-flight questionnaire designed for the present study was an appropriate tool to test for differences between the indicators. Researchers interested in conducting usability studies on AOA based systems should use the post-flight questionnaire as a base to develop a strong testing tool that could eventually be validated.

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APPENDIX A

Approximate AOA Indications for Each Flight Maneuver

Approximate Indications

Phase of Flight	Legacy Indication	Bar Indication	
Taxi	No lights	No lights	
Max Angle Climb	Bottom half green doughnut	All red, one blue, and two yellow	
Cruise Climb	Bottom half green doughnut and yellow chevron	All red, one blue, and all yellow	
Cruise	Blue bar	One green	
Slow Flight	Complete green doughnut	All red and one blue	
Stall warning	Red chevron and top half green doughnut	All red	
Stall	Red chevron	Some red	
Final Approach	Bottom half green doughnut and yellow chevron	All red, one blue, and all yellow	
Landing Flare	Complete green doughnut	All red and one blue	
Landing Touchdown	Red chevron and top half green doughnut	All red	

APPENDIX B

Informed Consent Form

Usability Testing of Angle of Attack (AOA) Indicators

Principal Investigator: Dr. Albert Boquet

Research Assistants: Camilo Jimenez and Claas Tido Boesser,

jimenec4@my.erau.edu boesserc@my.erau.edu

Embry-Riddle Aeronautical University Human Factors Laboratory 600 S. Clyde Morris Blvd. Daytona Beach, FL 32114

Purpose of the study

You are participating in a usability study. The purpose of this research is to collect data on a series of three flights, each flown with a different type of AOA indicator, in order to assess which type of AOA indicator is best suited for installment on the fleet of Cessna 172s at Embry-Riddle.

During the sessions, you will perform a series of predetermined maneuvers while referencing an AOA indicator. At the end of each flight, you will fill out a post-flight questionnaire, providing feedback on the usability of the AOA indicator during flight, and in particular during the predetermined maneuvers.

Through this study, you will have a unique opportunity to help us enhance overall flight safety and the flying experience of our aviation community.

Risks associated with the study

The risks associated with this study are the same as what you face in everyday activities as an instructor pilot. There are no known additional risks to those who take part in this experiment. Flights will always be conducted with another instructor pilot acting as the safety pilot

Compensation

You will be compensated for your flying duties the same way that you would during regular flying sorties at Embry-Riddle. There will be no additional compensation but your feedback will have a direct impact on future instrumentation of Embry-Riddle's fleet of aircraft and student pilot training.

Participation

Your participation in the study is voluntary; you should only take part in this study if you want to volunteer. You should not feel that there is any pressure to take part in the study. You are free to participate in this research or withdraw at any time.

Confidentiality

We will collect data through a series of questionnaires at the end of each flight and a one-time questionnaire before you begin the flight series. We will keep your personal records private and confidential. Any information collected during this study will only be used for scientific purposes. We may publish the results of this study. If we do, we will not include your name. We will not publish anything that would let people know who you are or how you are connected to this study.

Other questions, concerns, or complaints

If you have any questions, concerns or complaints about this study, or experience an adverse event or unanticipated problem, contact Dr. Albert Boquet, albert.boquet@erau.edu.

If you would like to know the results of this study please contact any of the researchers listed on page one of this form.

Statement of Consent

I acknowledge that my participation in this research experiment is entirely voluntary and that I have the freedom to withdraw from the study at any time. I have been informed about the general scientific nature of the research. If I choose to withdraw from the study, I shall be compensated for the amount of time that I invested into the experiment.

Participant's name (print):	
Signature of participant:	Date:
Experimenter:	Date:

APPENDIX C

Pre-Flight Questionnaire

AOA Pre-Flight Questionnaire

	Demographics					_
1.	Last four digits of your ERAU ID number					
2.	What is your age?		у	ears		
3.	What is your gender?		Male	Ш	Female	
4.	Rating currently held					
5.	How many years have you been working as a instructor pilot?	у	ears			
6.	Total number of flight hours as an instructor pilot					
7.	Total number of flight hours (including those before becoming an instructor)					
8.	Of the total flight hours, approximately how many hours were flown with a "glass-cockpit	"?				
9.	Have you flown in the military?		☐ Yes		□ No	
	9a. Number of hours flown in the military	7				
	9b. Type of aircraft flown in the military					
10	. How many hours per week (on average) do y work as an instructor pilot?	ou				
11	. How may years have you worked as an instructor pilot for ERAU?		у	ears		

General

		Agree
omments:		
	rience with AOA indicators prior t	o your training on A(
ndicators at Embry-R	tiddle:	
In a simula	ator (high-fidelity or home compu	
No Experience		High Experience
	During actual flight	·
No Experience		High Experience
omments:		
		
always thought that a viation aircraft	an instrument showing AOA shou	ld be installed in gen
Strongly Disagree		Strongly Agree
omments:		

	Slow-Flight	
Not at all		Extremely
omments:		
	Power-On Stalls	
Not at all		Extremely
omments:		
	Power-Off Stalls	
Not at all		Extremely
omments:		
	Normal Approach and Landing	
Not at all	Normal Approach and Landing ⊝ ⊜ ⊛ ⊕ ⑤ ⑥ ⑦	Extremely
		Extremely
Not at all Comments:		Extremely
	Short-field Approach and Landin	

I think that using an AOA indicator can improve my performance during the

4.

following maneuvers

Instructor Pilots

1. I think that using an AOA indicator could be especially beneficial for student pilot training during the following maneuvers

	Slow-	Flight	
Not at all	\ominus \ominus \otimes \circ	9 9 6 7	Extremely
Comments:	1		
	Power-0	On Stalls	
Not at all	\ominus \ominus \otimes \circ	9 9 6 7	Extremely
Comments:			
	Power-0	Off Stalls	
Not at all	\ominus \ominus \otimes \circ	9 9 6 7	Extremely
Comments:	-		
	Normal Approa	ich and Landing	
Not at all	\ominus \ominus \otimes \circ	9 6 7	Extremely
Comments:			
	Short-field Appro	oach and Landin	<u> </u>
Not at all		a s 6 7	Extremely
Comments:			

Overall Comments:		

APPENDIX D

Post-Flight Questionnaire

AOA Post-Flight Questionnaire

1. Last four digits of your ERAU ID number

AOA indicator flown (please circle)

Horizontal (Light-bar)



Vertical (Light-bar)



Vertical (Legacy)



General System Usability Scale

	Strongly Disagree		Θ	⊜	*	4	(5)	Strongly Agree
Com	ments:							
				0.4				
I fou	nd usage of this p Strongly Disagree	particul	ar A	.OA i	mdic ⊛	ator ④	unnece ⑤	Strongly Complex Strongly Agree
Com	ments:							
I tho	ught this particu	lar AOA	linc	licat	or w	as ea	asy to u	se
I tho	ught this particu Strongly Disagree	lar AOA	\ inc	licat	or w ⊛	as ea	sy to u	se Strongly Agree
	Strongly	lar AOA						Strongly

Strongly Disagree	(∋ (*	4	(5)	Strongly Agree
Comments:							
I found this particu	ular AOA ind	dicat	tor t	o be	e a w	ell-inte	grated representation
Strongly Disagree	(∋ (⊛	4	(5)	Strongly Agree
Comments:							
I w <u>ould learn the</u> u	ise of this p	artic	cular	· A0	A in	dicator	quickly
Strongly Disagree	(∋ (⊛	4	(5)	Strongly Agree
Comments:							
Comments:							

	Strongly Disagree	Θ		⊛	4	(5)	Strongly Agree
Com	ments:						
I felt	very confident us	ing this p	artic	ular	AOA	indicator	
	Strongly Disagree	Θ		*	4	⑤	Strongly Agree
Com	ments:						
I wil	l need a lot of time	e before e	ffecti	ively	usin	ıg this par	ticular AOA ind
	Strongly Disagree	Θ	⊜	*	4	3	Strongly Agree
	ments:						
Com	inches.						

Visual representation and location

Strongly Disagree		Strongly Agree
Comments:		
This particular A(a v <u>isual represen</u>	OA indicator's orientation (horizon tation of AOA	ital/vertical) was well s
Strongly Disagree		Strongly Agree
Comments:		
This particular Aocrosscheck of AO	OA indicator's physical location in t	the cockpit facilitated a
Strongly Disagree		Strongly Agree
Comments:		

4. If you could place this particular AOA indicator anywhere in the cockpit, given the rough cockpit layout below, please outline the position where you would like the indicator to be placed. If you are 100% satisfied with the current position, leave blank.

Note: You can mark anywhere on the dashboard or free space on the instrument panel. Please outline the AOA indicator.



Comments:			

Maneuvers

I think that crosschecking this particular AOA indicator enhanced my personal performance on the following maneuvers
 Slow-Flight

	Not at all	Θ		*	4	(5)	6	7	Extremely	
Со	mments:									
									·	
			Pov	ver	-Or	St	alls			
	Not at all		<u> </u>		4				Extremely	
Co	mments:								-	
			Pov	ver	-Of	f St	alls	3		
	Not at all	Θ	\Rightarrow	*	4	(5)	6	7	Extremely	
Со	mments:									
		Normal	An				ad I	anding		
	Not at all		Ap ⊜		(4)			Landing (7)	Extremely	
Co	mments:									
		Short-fie	ld A	nn	rna	ch:	and	l Landin		
	Not at all								Extremely	
Co	mments:									

This particular AOA indicator enhanced my awareness of how close the aircraft is to 2. a stall at all times during the following maneuvers **Slow-Flight** ⊝ ⊜ ⊛ ④ ⑤ ⑥ ⑦ Not at all Extremely Comments: **Power-On Stalls** Not at all \ominus \ominus \otimes \oplus \odot \odot \bigcirc Extremely Comments: **Power-Off Stalls** Not at all \ominus \ominus * 4 5 6 7Extremely Comments: Normal Approach and Landing Not at all \ominus \ominus \otimes \oplus \odot \odot Extremely Comments: **Short-field Approach and Landing** Not at all Extremely \ominus \ominus \otimes \oplus \odot \odot \odot

Comments:

3. During the following maneuvers, I crosschecked this particular AOA indicator

		S	lov	v-Fl	ligh	ıt		
Not at all	Θ	\Rightarrow	*			6	7	Very frequently
Comments:								
		Pov	ver	-Or	ı St	alls	6	
Not at all	Θ		€	4	(5)	6	7	Very frequently
Comments:								
		Pov	ver	-Of	f St	alls	5	
Not at all	Θ	\Rightarrow	*	4	(5)	6	7	Very frequently
Comments:	1							
	Normal	Аp	pro	acl	h aı	nd l	Landin	ng
Not at all	Θ		*	4	(5)	6	7	Very frequently
Comments:								
	Short-fie	ld A	рр	roa	ch	ano	d Land	ing
Not at all	Θ					6		Very frequently
Comments:	•							

]		
Stroi Disag			Strongly Agree
Comments:			
	Sr	nort-field Approach and Landin	g
Stroi Disag			Strongly Agree
Comments:			1
		ig this particular AOA indicator er e following maneuvers	ihanced my la
oerformance Stroi	e during th		Strongly
performanco	e during th	e following maneuvers Normal Approach and Landing	
performance Stroi Disaş	e during th	e following maneuvers Normal Approach and Landing	Strongly Agree
Stroi Disaş Comments:	e during th	e following maneuvers Normal Approach and Landing	Strongly Agree
performance Stroi Disaş	e during the state of the state	e following maneuvers Normal Approach and Landing	Strongly Agree

I feel that crosschecking this particular AOA indicator helped me in flying a more

4.

Instructor Pilots

Strongly Disagree		Strongly Agree
Comments:		
think this particular	AOA indicator can improve studer	nt's conceptual
Strongly Disagree		Strongly Agree
Comments:		
would integrate this	particular AOA indicator in my tra	nining of student
Strongly		Strongly Agree
Disagree		
Disagree Comments:		

enhance student pilot training during the following maneuvers **Slow-Flight** Not at all \ominus \ominus * 4 5 6 7Extremely Comments: **Power-On Stalls** Not at all \ominus \ominus \otimes \oplus \odot \odot \bigcirc Extremely Comments: **Power-Off Stalls** Not at all \ominus \ominus * 4 5 6 7Extremely Comments: Normal Approach and Landing Not at all \ominus \ominus \otimes \oplus \odot \odot Extremely Comments: **Short-field Approach and Landing** Not at all Extremely \ominus \ominus \otimes \oplus \odot \odot \odot Comments:

I think student's crosschecking of this particular AOA indicator could particularly

4.

Overall satisfaction

1. Overall I would rate my experience with this particular AOA indicator as:

Worst	Awful	Poor	Fair	Good	Excellent	Best
Imaginable						Imaginable

Overall Comments:					

AD A 039223



A STUDY OF LIGHTPLANE STALL AVOIDANCE AND SUPPRESSION

David R. Ellis

Flight Research Laboratory
Aerospace and Mechanical Sciences Department
Princeton University
Princeton, N. J. 08540



Final Report February 1977

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.



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FEDERAL AVIATION ADMINISTRATION
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Washington, D.C. 20590

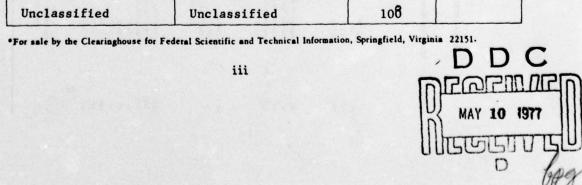
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TABLE OF CONTENTS

			Page
Ι.	INTR	ODUCTION	1
	A. B.	BACKGROUND THE PRESENT STUDY	1 1
11.	THE	STALL-MUSH ACCIDENT RECORD - A SUMMARY	5
	A. B. C.		5 6 6
III.	HIGH	ANGLE OF ATTACK FLIGHT CHARACTERISTICS	10
	A. B.		10 11
IV.	CONT	ROL FORCE CONSIDERATIONS	13
	A. B. C.		13 13 17
V.	TRIM	CHANGES	19
VI.	STAL	L WARNING	20
	A. B. C. D.		20 20 21 21
VII.	PERF	ORMANCE AS A FACTOR	23
VIII.	THE	OUTLOOK FOR PROGRESS	25
		AWARENESS OF THE PROBLEM IMPROVING THE PILOT IMPROVING THE AIRPLANE	25 25 26
IX.	CONC	LUSIONS	29
х.	SUMM	ARY OBSERVATIONS	32
XI.	REFE	RENCES	33
APPENDI	ХА	AN ANALYSIS OF SINGLE-ENGINE LIGHTPLANE STALL ACCIDENTS (1965-1973)	A 1
APPENDI	ХВ	TYPES OF ACCIDENTS	B 1
APPENDI	хс	AIRCRAFT GROUPS	C 1
APPENDI		SUMMARY OF STALL BEHAVIOR	
APPENDI	X E	STALL-RELATED PORTIONS OF FAR PART 23	E 1
APPENDI	X F	THE IN-FLIGHT SIMULATOR	F 1
APPENDI	Y C	RIBI IOCRADHY	G 1

LIST OF ABBREVIATIONS AND SYMBOLS

ALL	Fatal plus non-fatal accidents
AR	Accident rate
CG	Center of gravity
C _L max	Maximum lift coefficient
${}^\delta_{\mathbf{f}}$	Flap deflection, degrees Drag, 1b
D_{α}	Drag due to angle of attack derivative, $1/m$ ($\partial D/\partial \alpha$) ft/sec ² /rad
D _V	Drag due to airspeed derivative, 1/m (\delta D/\delta V), 1/sec
FATAL	Fatal accidents only
FAR	Federal Aviation Regulations
F _s	Longitudinal control force, 1b (commonly called "stick force")
F _s /n	Maneuvering force gradient, 1b per g
g	Gravitational acceleration, ft/sec ²
I _y	Moment of inertia about pitch axis, slug-ft ²
kt y	Knots
L _a	Lift due to angle of attack derivative, $1/m (\partial L/\partial \alpha)$, $ft/sec^2/rad$
Lv	Lift due to airspeed derivative, 1/m (\partial L/\partial V), 1/sec
m	Mass, slugs
mph	Miles per hour
М	Pitching moment, ft-1b
Mα	Pitching moment due to angle of attack derivative, $1/I_y$ ($\partial M/\partial \alpha$), rad/sec ² /rad
M. a	Pitching moment due to angle of attack rate derivative, $1/I_{y}(\partial M/\partial \alpha)$, 1/sec
MŮ	Pitching moment due to pitch rate derivative, $1/I_{v}$ ($\partial M/\partial \dot{\theta}$), $1/\sec$
M _V	Pitching moment due to airspeed derivative, 1/I y (\partial M/\partial V), rad/sec ² per ft/sec
n	Load factor, g units
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
R/C	Rate of climb, ft/min.
R/S	Rate of descent, ft/min.

T	Thrust, 1b
TOTAL	Total of all accident types
T _v	Thrust due to airspeed derivative, $1/m (\partial T/\partial V)$, $1/sec$
v _i	Indicated airspeed, mph or kt
Vs	Stall airspeed, mph or kt
V _{trim} or V _o	Trim airspeed, mph or kt
α	Angle of attack, degrees or radians
ά	Angle of attack rate, deg/sec or rad/sec
ė	Pitch rate, deg/sec or rad/sec

SECTION I

INTRODUCTION

A. BACKGROUND

Although the 1903 flight at Kitty Hawk was a magnificent accomplishment, the Wright Brothers were far from being competent pilots at that point. It was not until September of 1904 that the first full circle was performed, and well into the 1905 flying sessions they were still encountering frequent out-of-control situations (References 1 and 2). In one recorded case, Wilbur inadvertantly shut off the engine and in the ensuing confusion allowed the machine to nose up and stall; the impact caused considerable damage but no injury. In time, the need for a nose-down control input to unstall the wing was recognized, and diving for recovery from what we now term high angle of attack situations became part of their flying technique.

Despite the passing of over seventy years of powered flight, during which the phenomenon of stalling has been studied rather extensively (as a quick scan of the Bibliography will confirm), aviation has experienced a continuing stall-related accident problem. Periodically, major efforts have been directed toward the development of "safe airplanes." In the late 1930's, NACA activities in this area led to several production lightplanes with considerably improved low speed flight characteristics compared to previous designs. The level of research and development activity at any given time seems to depend on how clearly everyone perceives that the accident record is not acceptable and that simple remedies, especially those which depend upon enhanced pilot awareness and capability, won't entirely suffice. This is evident in the recent surge of military R&D in the stall/spin area (Reference 3).

In the general aviation case, renewed research activity has come largely as a result of NTSB Report AAS-72-8, "Special Study - General Aviation Stall/Spin Accidents 1967-1969" (Reference 4). The report pointed out that although the stall/spin accident record had shown a marked improvement over the immediate post-war years (for 1945 through 1948, stall/spin accidents accounted for 48% of all fatal accidents; for the period 1967 through 1969 this dropped to 22%), the stall-related accident still accounted for a large portion of the fatalities and injuries in general aviation. Considering the projected size and growth rate of general aviation, an improvement in the record would clearly be required to prevent an accompanying increase in injuries and fatalities.

Among the recommendations of the NTSB report were several which urged the FAA, together with NASA, to conduct studies and evaluations which would point to areas of design, equipment, and operation which might bring about an improvement in the stall/spin accident record. At the time (1972) NASA was already deeply involved in light airplane spin research (Reference 5). The study reported here represents an FAA response to the NTSB recommendation in the area of stall and mush accidents.

B. THE PRESENT STUDY

The existence of a continuing history of stall/spin accidents tends to be somewhat perplexing to anyone deeply involved in airplane design and certification, or pilot training and licensing, because seemingly reasonable efforts have been made to prevent such occurrences. Specifically, the following might be noted:

Stall and spin characteristics which are accepted as "normal" can
usually be achieved in an airplane through well-known design
approaches and aerodynamic features (although a good deal of

"cut-and-try" testing may be required).

 The Federal Air Regulations require all certificated lightplanes to exhibit clear and distinctive stall warning, and to respond to normal use of the controls in such a way that neither excessive altitude nor dangerous attitudes are encountered during stalls and recoveries; spin recovery must always be possible with normal technique.

 Student pilots are instructed intensively in stall recognition and recovery (though spin training is not required) and must successfully demonstrate this knowledge before being issued a

private license.

If stalls are not inherently dangerous, and if all pilots know how to recognize and recover from them, then one must seriously question why so many stall-related accidents continue to occur. The evidence suggests that although the items listed above might adequately cover intentional stalls and spins, they do not adequately cope with the case of an unintentional stall—one encountered while the pilot is intent on accomplishing some other maneuver, particularly at low altitude.

Unintentional Stalls. In focusing attention on this matter of unintentional stalls, the interactions between the following factors would

seem to be important:

· Performance characteristics at low speeds

· Handling qualities at low speeds

· Pilot behavior in low speed flight situations

The performance characteristics which are significant here are those related to the takeoff and landing environment and to accelerated flight conditions (steep turns, pull-ups), where the pilot may be so intent upon achieving a desired flight path that precise control is not exercised. For example, if climb performance is particularly sensitive to being at the proper speed, or sensitive to flap deflection, then it is possible to imagine how lack of attention to those factors could contribute to the pilot's stalling the airplane in the process of trying to clear an obstacle.

The handling qualities factors are those which influence the ability to fly the airplane precisely and safely at low speeds. The near-stall and post-stall behavior of the airplane are most important, of course; lateral controllability, pitching behavior, change of characteristics with power and flaps, and effects of sideslip come to mind as significant factors. However, in seeking factors which will lead a pilot from a normal flight condition into an unintentional stall, the "feel" characteristics — the stick force and position gradients — would appear to warrant special attention, since they help determine how well speed and angle of attack can be controlled.

Finally, and perhaps most important, it is necessary to consider the pilot's likely behavior in order to understand and evaluate airplane characteristics with respect to inadvertant stalls. In a stressful situation, can be recognize the onset of a stall and apply quick recovery action?

The record indicates that too often he can't, but the reasons for this are not clearly evident. However, some possible influencing factors may be listed: poor state of knowledge stemming from inadequate basic training or lack of familiarity with the type of airplane or type of flying; or insufficient current experience, especially in stalls, slow-flight maneuvering, and maximum performance operations. Even given adequate knowledge and practice, a pilot may still have the problem of "ground shyness," the tendency to be intimidated by the proximity of the ground to the point of not using the recovery techniques which he has mastered at high altitude.

The Research Program. The research reported here represents an effort to illuminate, at least in a preliminary way, the ways in which the various factors mentioned above relate to the accident record of recent years:

Three main elements were involved in the study:

TASK 1 -

An analysis of stall-related accidents.

• TASK 2 -

Flight evaluations of production airplanes.

· TASK 3 -

In-flight simulation experiments.

TASK 1 - Accident Analysis. This first element of the program consists of an extensive analysis of stall-related accidents for the period 1965-1973, using data from NTSB coded magnetic tapes. The aim was to obtain an overview of the circumstances and conditions surrounding this type of accident, and to identify those airplanes with distinctly low and high frequency of involvement.

The bulk of this task was performed under subcontract by Aircraft Safety Consultants, Inc., of Palo Alto, California. Section II of the report contains a summary of the results; a detailed version is given in Appendix A, with supporting material in Appendices B and C.

TASK 2 - Flight Evaluations. The following airplanes were selected for evaluation in the program:

- · Bellanca Citabria 150
- · Cessna 182 Skylane
- · Cessna 150
- · Cessna 177 Cardinal
- · Grumman American Yankee AA-1
- Grumman American Trainer AA-1B
- Piper Cherokee 140

Task 1 findings weighed heavily in the selection of the various airplanes, and the list contains examples with both very good and very poor stall accident records. It was felt important to include commonly used trainers (the Cessna 150 and Cherokee 140 in particular) regardless of their records. Local availability became a final factor. The Grumman American Trainer was not originally on the list, since it was a 1974 model and did not figure in the records used for the Task 1 accident analysis. It was included in order to assess possible improvements in stall behavior over the AA-1 attributable to its modified wing leading edge.

The evaluations themselves were largely qualitative assessments of low speed handling and stall characteristics, with simple measurements being made where possible. The aim of the experiments, it must be emphasized, was not to gather data for the purpose of checking compliance with regulations, but rather to provide orientation and background in this area of unintentional stalls. Section III of the report deals with general observations of the low speed handling of the seven Task 2 airplanes, while more detailed comments are contained in Appendix D. Other results of a topical nature, such as control force characteristics and stall warning are covered in separate sections of the report.

Task 3 - In-Flight Simulation Experiments. The third element of the study made use of the Navion in-flight simulator described in Appendix F. Special features were incorporated in the control system to permit simulation of the essential features of the stall break (a lift loss and nosedown pitching moment) while retaining a reasonable stall margin in the basic vehicle. Various stall warning devices, including horn, stick shaker, and angle of attack indicators could be selected. The basic Navion aerodynamic characteristics are reasonably typical of this class of airplane, and were retained for the "baseline" configuration about which variations were made. Values of the longitudinal stability derivatives for a 70-kt reference condition are listed at the end of Appendix F.

Here the major objective was to explore in a generalized way the interactions between performance and handling characteristics and the piloting task. (It is important to note that typical lightplane characteristics were simulated, but particular airplanes were not.) The usual format of the experiments called for circuits of the airfield with a 75 kt approach and a touch-and-go landing followed by a 70 kt (maximum angle) climb and turn. On the downwind leg the evaluation pilot was asked to perform a lowaltitude 360° or 720° circle about an object on the ground using outside references. At various points in the pattern he would perform intentional stall and control abuses. Appropriate measurements, such as control activity, airplane motions, and flight path time histories were recorded by means of telemetry. Formal evaluations were carried out by one Princeton and one FAA pilot; various other FAA and industry pilots were exposed to the stall simulation and stall warning devices.

Testing in this phase was somewhat limited in scope and extent, but did serve to demonstrate the effectiveness of in-flight simulation for studies of pilot/airframe behavior in the high angle of attack flight regime. The results are discussed in Sections IV, V, and VI of the report.

SECTION II

THE STALL/MUSH ACCIDENT RECORD - A SUMMARY

In this section the material contained in Appendix A - AN ANALYSIS OF SINGLE-ENGINE LIGHTPLANE STALL ACCIDENTS (1965-1973) is summarized to provide background and orientation for the later sections of the report. The analysis is based mainly upon a review of domestic accidents involving 31 different (by make and model) lightplanes selected according to the following criteria:

· Single-engine fixed wing design

· Used primarily for purposes other than crop control

At least 500 active in the U. S. in 1973

Of the 30,606 total accidents reviewed for the group of 31 aircraft (listed separately in Appendix B and referred to collectively as Group 32 in the analysis) 3,467 were due to stall, spin, spiral, or mush. As noted in Section I, the primary emphasis is placed on the stall and mush cases. The data were obtained from two sources:

· NTSB accident records, primarily from coded magnetic tapes

· FAA estimates of hours flown for each make and model

A. ACCIDENT DISTRIBUTIONS

Accident Rates. For the nine years of the study, there were 3,467 stall-related accidents for the group of 31 airplanes (no crop control usage included) of which 1,029 were fatal. This amounted to 29% of the total fatal accidents of all types, and 11% of all accidents. Fatal stall accidents occurred at a rate of about 0.35 per 100,000 flight hours; the combined stall, spin, spiral, and mush fatal accident rate was about 0.7 per 100,000 hours.

Type of Operator. The operator in most of the cases (over 50%) is a private owner; this is followed by fixed-base operator (a little over 20%), flying club (slightly less than 10%), corporate/executive and flying

school (a little less than 5% each).

Kind of Flying. Pleasure flying accounts for 63% of all stall and mush accidents and 68% of the fatal stall occurrences. This may be compared with the distribution for total accidents of all kinds, where pleasure flying is involved in 55% of the cases.

Instructional flying is being done in 18% of the stall and 14% of the mush accidents; by comparison, 21% of all accidents of all types

involve instruction.

Phase of Flight. The most common flight phase for stall accidents is the so-called "in-flight" phase, which encompasses essentially everything except takeoff and landing. Of the fatal stall cases, 63% occur in this in-flight phase, 15% in takeoff, and 21% in landing. Most of the fatal inflight accidents are associated with acrobatics, buzzing, and low passes, and relatively few occur in climb to cruise, normal cruise, and descent operations. The pre-stall maneuver is not known in many cases, but an analysis of 48 fatal stall accidents occurring in 1973 indicated that 60% involved turning and 85% involved turning and/or climbing.

A mush type accident is most likely to occur during takeoff.

Conditions of Weather and Light. Stall and mush accidents are essentially good weather phenomena, with 96% of the stall and 99% of the mush cases happening in VFR weather; more than 90% of all such accidents

occur during daylight hours.

Pilot Experience. Accidents of all types, including stall and mush accidents, tend to happen most frequently to pilots with low total time, low time in type, and to young pilots. Unfortunately, the distribution of experience for all flying done on the airplanes of Group 32 is not available, so the factor of exposure level (that is, who does the most flying) cannot be evaluated directly. However, it is possible to compare stall and mush accidents with a more random type, the "true" engine failure accident (where the engine failure was not due to a pilot error, such as fuel mismanagement), with the following result: pilots with less than 500 hours total flying time or 100 hours in type are more likely to have a stall or mush accident than a true engine failure accident; with more experience in either category the engine failure accident is more likely.

There is insufficient information available at this point to evaluate other important factors such as how much the pilot's experience was recent, and how much dual instruction he had received in the particular type of

airplane involved in the accident.

Stall Warning Indicator. One-third of the stall accidents and one-half of the spin accidents of the group for which data are available involved airplanes which did not have stall warning indicators. One interpretation of this result is that some of the accidents might have been avoided if such a device had been installed; another suggests that since accidents continue to happen with standard stall warning systems installed, serious consideration should be given to their improvement.

B. CAUSES AND FACTORS

The NTSB has the responsibility for determining the "probable cause" of each accident, and has established some 860 codes for the purpose. The same codes may be cited as "factors"; the two terms are formally defined as follows:

CAUSE: Had the condition or event been prevented, the accident would not have occured.

FACTOR: A related condition or event, the omission of which would not necessarily have prevented the accident.

The most common cause cited for stall accidents is, "Pilot in command failed to obtain or maintain flying speed." It must be assumed that the statement means that the stall angle of attack was reached or exceeded, and the flight path was adversely affected. At any rate, the citation clearly implies that the pilot is at fault, and is listed in 91% of stall accidents and 76% of mush accidents. When the pilot is not cited for failure to "obtain or maintain flying speed," some other pilot error is almost always found in stall accidents. This is discussed further in Appendix A.

C. RESULTS FOR INDIVIDUAL AIRCRAFT

In this section accident patterns for individual makes and models are compared with the patterns for the 31 airplanes taken as a group (Group 32, Appendix C). A Chi-square statistical test is applied to determine whether

the observed differences and the sample size are sufficiently large to make the finding significant.

Accident statistics for the 31 individual airplanes and for Group 32 are shown in Table II-1. Crop control flight hours and accidents are excluded; the accident rates shown are per 100,000 flight hours. The term TOTAL is used to indicate that accidents from all causes are being considered; ALL refers to the sum of fatal and non-fatal accidents.

TABLE II-1. TOTAL ACCIDENT STATISTICS FOR 31 SINGLE-ENGINE AIRCRAFT (1965 - 1973)

CD	CHOPT	TOTAL ACCIDENTS		HOURS	TOTAL ACCID. RATE		RELATIVE TO GR.#32; CHI-SQUARE			
GR.	SHORT		The state of the s	X 10 ⁵						E
#	NAME	FATAL	ALL	X 10	FATAL	ALL	FATAL		ALL	
1	AERON.11	18	162	3.595	5.01	45.06	+98%	Н	+112%	VH
2	ERCOUPE	49	505	13.727	3.57	36.79	+41%	Н	+73%	VH
3	YANKEE	35	194	6.060	5.78	32.02	+128%	VH	+50%	VH
4	B-23	63	789	25.505	2.47	30.94	-2%		+45%	VH
5	BONANZA	342	1840	105.359	3.25	17.46	+28%	VH	-18%	VL
6	BELLANCA	27	216	6.517	4.14	33.14	+64%	Н	+56%	VH
7	CITABRIA	162	1293	35.386	4.58	36.54	+81%	VH	+72%	VH
8	C-140	61	991	24.944	2.45	39.73	-3%		+87%	VH
9	C-150	387	4290	284.885	1.36	15.06	-46%	VL	-29%	VL
10	C-170	64	712	21.541	2.97	33.05	+17%		+55%	VH
11	C-172	343	2723	192.896	1.78	14.12	-30%	VL	-34%	VL
12	C-175	36	261	12.884	2.79	20.26	+10%		-5%	
13	C-180	68	853	31.933	2.13	26.71	-16%		+25%	VH
14	C-182	214	1872	104.616	2.05	17.89	-19%	L	-16%	VL
15	C-185	20	196	9.359	2.14	20.94	-15%		-2%	
16	C-206	33	319	21.948	1.50	14.53	-41%	L	-32%	VL
17	C-210	102	755	32.960	3.09	22.91	+22%	Н	+8%	H
18	C-177	48	478	14.852	3.23	32.18	+28%		+51%	VH
19	MOONEY	193	1185	56.566	3.41	20.95	+35%	VH	-2%	
20	NAVION	63	304	10.094	6.24	30.12	+147%	VH	+41%	VH
21	CUB	96	635	19.051	5.04	33.33	+99%	VH	+56%	VH
22	PA-12	21	296	9.171	2.29	32.28	-9%		+52%	VH
23	PA-18	119	751	26.694	4.46	28.13	+76%	VH	+32%	VH
24	TRIPACER	160	1687	55.552	2.88	30.37	+12%		+43%	VH
25	COMANCHE	200	1398	49.117	4.07	28.46	+61%	VH	+34%	VH
26	CHEROKEE	459	3674	204.634	2.24	17.95	-11%	L	-16%	VL
27	CHER-6	65	401	23.886	2.72	16.79	+8%		-21%	VL
28	LUSCOMBE	59	731	11.088	5.32	65.93	+110%	VH	+210%	VH
29	TAYLORCR	51	339	8.404	6.07	40.34	+140%	VH	+89%	VH
30	SWIFT	33	255	3.280	10.06	77.74	+298%	VH	+265%	VH
31	STINSON	48	501	10.069	4.77	49.76	+89%	VH	+134%	VH
32	GR.#32	3639	30606	1436.573	2.53	21.30	0		0	

Percentage numbers in the two right hand columns indicate how high or low the individual airplane accident rates are compared to the group mean which appears in the bottom line. For example, the Stinson (Group 31) has a total fatal accident rate of 4.77 per 10⁵ hours, which is 89% higher than the mean rate of 2.53 per 10⁵ hours. The VH, VL, and L symbols are Chisquare "flags" which indicate that the rates are "very high" or "very low," or "high" or "low" compared to the group mean. The V designator indicates that the result has less then 0.1% probability of ocurring by chance; for the H or L cases the probability of a chance result is less than 5%.

There are large observed differences in the accident rates shown in Table II-1 (by a factor of 20 in some cases), and a high incidence of

flags, which reflects a very large data base.

Figure II-1 presents these same results graphically. The ratio of stall and mush fatal accidents to total accidents is shown as a function of total fatal accident rate. The result for summary Group 32 is indicated by the dark circle and dashed lines; thus an airplane plotted into the lower left quadrant has both a percentage of stall/mush accidents and a total fatal accident rate lower than the group mean.

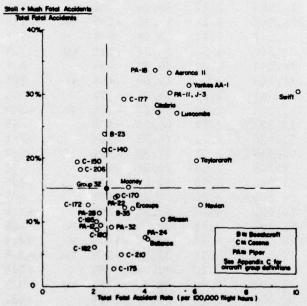


Figure II-1. Fatal Accidents for Individual Airplanes.

A final comparison is afforded by the results shown in Table II-2, which was assembled using the information from Table II-1 (which is the same as Table 15 of Appendix A) and Table 16 of Appendix A. The latter gives the stall, spin, spiral, and mush accident count for each of the airplanes and for the group as a whole. Here the various aircraft are ranked according to formulae which weight fatal accidents ten times more heavily than non-fatal ones. RANK 1 is based on accident rates, RANK 2 on percentage of total accidents represented by stall and mush. In both cases the individual rates and percentages have been compared with those for Group 32 and tested with a Chi-square technique.

The airplane with the best stall/mush safety record according to RANK 1 is the Cessna 182 and

its accident rates are very low compared to the group mean. The two ranking systems show a high degree of correlation, the top three and bottom nine airplanes being the same in both (with one exception, the Taylorcraft), although in different order. Most of the airplanes near the bottom of the list are older designs; exceptions are the Cessna 177 and Grumman American Yankee, which are both relatively recent.

TABLE II-2. TWO STALL/MUSH RANKING SYSTEMS FOR 31 SINGLE-ENGINE AIRCRAFT (1965 - 1973)

RANK 1: Ranked According to (10 x FATAL Rate + ALL Rate) RANK 2: Ranked According to (10 x FATAL % + ALL %)

			EITHE	R ST	ALL OR	MUSH	AS FIRS	T OR	SECOND A	CCID	ENT TYPES:
	GR.	SHORT	ACC	IDEN	T RATES	:	%	OF T	OTAL		
RANK1	#	NAME:	FATAL		AI	L	FATAL		ALL		RANK2
1	14	C-182	0.12	VL	0.60	VL	6.1%	VL	3.4%	VL	3
2	17	C-210	0.15	VL	0.43	VL	4.9%	L	1.9	VL	2
3	12	C-175	0.08	VL	1.86	VL	2.8%		9.2%		1
4	15	C-185	0.21	L	0.96	VL	10.0%		4.6%		8
5	13	C-180	0.19	L	1.47	VL	8.8%		5.5%		6
6	16	C-206	0.27		0.68		18.2%		4.7%	L	19
7	11	C-172	0.23		1.24		12.8%		8.8%		15
8	27	CHER-6	0.25		1.05		9.2%		6.2%		7
9	26	CHEROKEE	0.25		1.32		11.3%	L	7.3%	VL	11
10	9	C-150	0.26		1.50		19.4%		10.0%	Н	20
11	6	BELLANCA	0.31		1.23	VL	7.4%		3.7%	L	4
12	25	COMANCHE	0.31		1.34	L	7.5%	L	4.7%	VL	5
13	5	BONANZA	0.40		1.28	Н	12.3%		7.3%	L	12
14	22	PA-12	0.22		3.38		9.5%		10.5%		9
15	24	TRIPACER	0.40		1.75		13.8%		5.7%	VL	16
16	19	MOONEY	0.53		1.61	VL	15.5%		7.7%		18
17	2	ERCOUPE	0.44		3.13	VH	12.2%		8.5%		13
18	10	C-170	0.42		3.71	Н	14.1%		11.2%	Н	17
19	8	C-140	0.52		3.45	VH	21.3%		8.7%		22
20	4	B-23	0.59		3.25	VH	23.8%		10.5%		23
21	31	STINSON	0.50		4.67	VH	10.4%		9.4%		10
22	20	NAVION	0.79	Н	2.68		12.7%		8.9%		14
23	18	C-177	0.94	VH	5.93	VH	29.2%	Н	18.4%	VH	26
24	7	CITABRIA	1.24	VH	5.54	VH	27.2%	VH	15.2%	VH	25
25	29	TAYLORCR	1.19	VH	7.62	VH	19.6%		18.9%	VH	21
26	23	PA-18	1.50	VH	5.17	VH	33.6%	VH	18.4%	VH	31
27	28	LUSCOMBE	1.44	VH	6.49	VH	27.1%	Н	9.8%		24
28	21	CUB	1.52	VH	8.29	٧H	30.2%	VH	24.9%	VH	28
29	3	YANKEE	1.82	VH	5.94	VH	31.4%	Н	18.6%	VH	29
30	1	AERON.11	1.67	VH	8.07	VH	33.3%	Н	17.9%	VH	30
31	30	SWIFT	3.05	VH	15.24	VH	30.3%	Н	19.6%	VH	27
	32	GR.#32	0.389		1.92		15.36%		9.02%		

SECTION III

HIGH ANGLE OF ATTACK FLIGHT CHARACTERISTICS

The discussion in this section centers on the general behavior of the airplanes tested in connection with TASK 2 of the study. The aim will not be to cover each in detail, but rather to point out common characteristics and important variations; a summary of the observed characteristics for each airplane is given in Appendix D. As noted in the introduction, the following airplanes were evaluated.

- · Cessna 182 (1972)
- Cessna 150 (1972)
- Piper Cherokee 140 (1971)
- Cessna 177 "Cardinal" (1975)
- Bellanca Citabria 150 (1974)
- Grumman American Yankee AA-1 (1968)
- Grumman American Trainer AA-1B (1974)

In view of the period covered by the accident analysis, 1965-1973, it would have been desirable to sample a range of model years. Unfortunately this was not possible, and several of the airplanes may differ from the models which figured in the statistics. Perhaps the most important case is the Cessna 177, which in the version flown had more power (180 vs 150 HP) and a modified airfoil compared to early production airplanes. The Cessna 182 also had a wing leading edge with increased radius and camber compared to pre-1970 versions.

A weight and balance check was carried out for each airplane; fuel and ballast adjustments were made to achieve the weight and CG conditions listed below. Control surface travel was checked to determine compliance with specification limits (all did conform, with the exception of the Cessna 150, which had slightly more down elevator travel than called for).

Test Conditions. The test conditions concentrated on cases which would highlight differences between configurations, and combined the following:

- · Power maximum or idle
- Flap 00 or full down
- Center of Gravity Near aft or forward limit at takeoff gross weight
- Straight flight and 200 Banked Turns
- · Coordinated (ball-centered) and rudder-free flight

It should be noted that these are not necessarily either the conditions required for compliance with FAR Part 23 or even conditions which might be routinely encountered in normal operations; the tests, it should be emphasized, were intended simply to provide orientation and background to aid in understanding the overall stall/mush problem.

A. BEHAVIOR NORMS

Acceptable behavior in high angle of attack flight is treated more in qualitative than quantitative terms in the existing regulations and recent literature (References 6, 7, and 8). The pertinent FAR Part 23

requirements (included as Appendix E) concentrate on being able to operate near and through the stall with normal, unreversed control use, with adequate control power to prevent large departures from straight flight; the emphasis is on slow approach to the stall (less than one knot per second), except for accelerated stalls which are to be demonstrated from turning flight with an approach rate of 3 to 5 kt/sec. The regulations do not require that the maximum aerodynamic lift coefficient be attainable, but only that the minimum steady speed at which the airplane is controllable be determined.

B. OBSERVED CHARACTERISTICS

The Docile Case. In the forward CG, power off, wings-level, no sides lip, zero flap case the stall could invariably be described as "docile." If a complete stall could be reached (a pitch break could not be obtained with slow deceleration in the Cessna 150, for example), the elevator could be held full up while bank angle and yaw remained controllable with modest coordinated aileron and rudder inputs. At worst, small-amplitude pitch oscillations ("nose-bobbing") and some lack of aileron effectiveness might be encountered.

Other Cases. Starting with the case above, changing any of the five variables - power, flaps, CG position, bank angle, or sideslip - generally tends to result in degraded behavior. Among the notable effects are those discussed below.

High power or aft CG movement tends to produce lowered stick force gradients, in some cases markedly so. This will be discussed in detail in the next section.

The effects of added power, flap deflection, and rearward CG all generally are in a direction which require down elevator increments to trim to the same initial speed used in the "docile" case above. The result is that more nose-up elevator (starting from trim) is available, and in most cases - especially when all three variations are combined - more control power than is needed to reach a stall is available. This is particularly striking in the case of the Cessna 150. In the "docile" configuration it barely reaches a stall with full up elevator; with combined full power, full flaps, and aft CG, the control wheel position to trim at 70 mph is nearly three inches forward of that for the "docile" airplane (which puts it only about 1/2 inch from the forward stop). Pulling the wheel back to stall finds a pitch break occurring with nearly four inches of aft travel remaining. (This phenomenon was much more pronounced with the flapped high wing airplanes tested than the low wing ones, although this may not be generally so.)

The above situation tends to produce a rather striking change in the character of the stall maneuver. Unless one takes great care in approaching the stall it is quite easy to go beyond C_L, where even small roll or yaw disturbances quickly develop into large motions, and at that point even vigorous aileron and rudder use may not prevent a departure from straight flight. Immediate recovery upon reaching the stall is the key, of course, but the behavior certainly is no longer always "docile."

In all cases tested it was possible to lower the angle of attack sufficiently to recover, but in the case cited above the cumulative trim changes left such a small increment of down elevator available for recovery that it was considered to be only barely adequate; a brisk recovery could be obtained only by reducing power or retracting flap.

The completely uncoordinated stalls might be viewed as unrealistic, but they served to underscore the importance of keeping sideslip near zero at stall entry. Particularly under high power, flap down, aft CG conditions rather violent yaw/roll departures were experienced, usually prior to any pitch break. Perhaps the most docile case observed overall was the Cessna 182, where sloppy control could be maintained (±15° heading excursions, for example) even for the extreme configurations.

Stalls from turns followed the pattern of the wings-level cases, but with somewhat less predictability and more tendency toward rolling; this is undoubtedly the result of a combination of several subtle factors, including deflected aileron and rudder (to counter yaw damping and overbanking tendencies) and uncorrected build-up of sideslip just prior to the break. However, the overriding factor still appears to be whether or not there is enough control power available to exceed C₁.

Three important points should be made to conclude this section:

• The intentional stall maneuver did not appear to be inherently dangerous in any of the seven airplanes. However, many of the extreme cases demand very prompt recognition and recovery action, and use of more elevator than that required to just reach a stall could result in strong departure tendencies.

• The wide range of characteristics which can be encountered in what are generally considered to be "simple little airplanes" is striking. In some quarters this might be regarded as advantageous for in-depth training; in others it causes speculation that many, if not most, pilots don't receive proper training and fly unaware

of the possible extremes in behavior.

No strong systematic correspondence between the statistics of Section II and the flight test observations is apparent at this point. Perhaps the most clear-cut case is the Cessna 182; it is stallable, but considerable physical exertion is usually required, and the post-stall behavior is good. These factors apparently outweigh other unfavorable ones, such as large trim changes, which will be discussed later.

SECTION IV

CONTROL FORCE CONSIDERATIONS

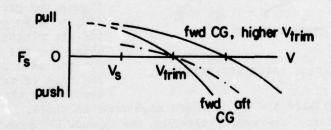
In this section several aspects of control force as they influence low speed operations are considered. The material is based largely upon the TASK 2 testing of seven airplanes, supplemented by in-flight simulation experiments with the variable-response airplane described in Appendix F.

A. BACKGROUND

Control "feel" in the form of a gradient of stick force with airspeed — pull force to slow from trim speed, push force to speed up — is universally regarded as a desirable flying quality, and in fact is required by both civil and military authorities (Reference 6 and 7). The question addressed here is to what degree such forces play a role in stall awareness and avoidance.

B. STICK FORCE vs V

Expected Variation. Most stability and control textbooks (Reference 9 for example) carry a theoretical development which leads to the finding that the variation of control force with speed for conventional, statically stable airplanes should go as shown in the sketch below:



The force variation depends on some built-in parameters such as control gearing, hinge moment and elevator effectiveness coefficients, and the square of the velocity. The intercept of the curve at V=0 is a function of the stick-free static stability, and this varies mainly with center of gravity position (and secondarily with other factors such as power). At any rate, the gradient through trim steepens with forward CG movement, less power, or lower trim speed; flaps may or may not affect the slope, depending on the peculiarities of the aerodynamics.

Measured Variations. Some measured variations from the TASK 2 flight

tests are shown in Figures IV-1, IV-2, and IV-3.

Before considering these results, the following points should be noted:

In keeping with the purpose of providing background and orientation in the area of unintentional stalls, the measurements were purposely kept simple in style and scope, and were not intended to be a basis for checking on FAR compliance. • For stick force and velocity measurements a hand-held force gauge and the standard airplane airspeed indicator were felt to be appropriate. In particular, indicated rather than calibrated airspeed was used, not only because calibrations for the many configurations tested would have been very time consuming and expensive to obtain, but also because the pilot's direct source of information is the indicator; it seems likely that his actions and judgment will usually be based on uncorrected instrument readings.

• Trim (zero stick force) speeds were usually chosen to correspond to a normally-used value; in some cases, as for the Cessna 182, the minimum attainable trim speed for the forward CG, power-off configuration was used throughout for uniformity even though the airplane could be trimmed to lower speeds under other conditions. The minimum speed points shown are at or very near the stall.

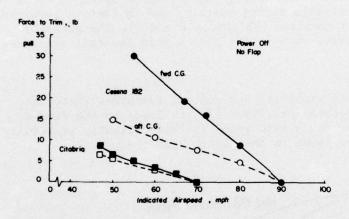


Figure IV-1. Stick Force Variations.

The Citabria, by contrast has a relatively low gradient and force to stall, and little variation with center of gravity position; the feel is qualitatively "spongey" compared to the 182.

Turning to Figure IV-2, the three Cessna airplanes in the program are compared. In the upper half of the figure the previous power-off, no flap points for the 182 are plotted along with those for the 177 and 150 for the same condition. The 150 case is seen to be similar to that of the 182,

but with roughly half the stick force magnitude to stall.

Power-off force characteristics for the Cessna 177 have an unfamiliar look, both due to the small spread for forward and aft CG position and for the upward curvature. The latter is apparently not uncommon for airplanes such as this with stabilator and anti-servo tab. A steep gradient is in evidence and the force level to stall is again substantial.

The lower half of Figure IV-2 presents trim curves for the same three Cessnas, but for the other extreme condition of full power and full flap. Expected behavior is shown in the 177 case, with force levels remaining moderate. The other two show some peculiarities which warrant discussion.

In the case of the 150, both the gradient and the force to stall are drastically reduced. In fact, with aft CG, the airplane can't be trimmed to zero force at the previous 70 mph speed, and only two pounds of pull force will produce a stall; with forward CG the force to stall is still a relatively light 5 lb. Though stable, the gradient is so small as to provide little feel for speed changes.

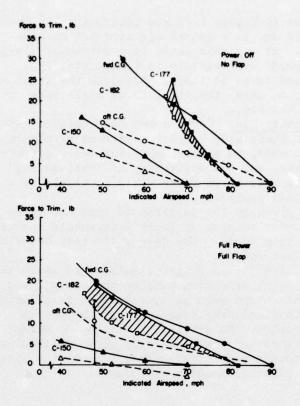


Figure IV-2. Stick Force Variations.

With forward CG the full power, full flap Cessna 182 exhibits its normal, heavy feel. With an aft CG, however, the situation becomes a bit confused, as indicated by one data point at 48 mph with a possible range from 0 to 15:1b; the dotted line suggests a likely change with speed. The problem is one of large trim changes with sideslip, the airplane pitching up for a right slip and down for a left slip (there appears to be some real trim change, but the exact level measured here could be influenced by airspeed errors since the task involved a flapdown, high-power phenomenon, and once identified, it accounts for an observed problem in holding a precise climb speed in that configuration.

Figure IV-3 is the final one in the series and presents results for the Piper Cherokee 140 and the two Grumman American airplanes; together with the Cessna 150 they represent widely used trainers.

Here the conditions have been chosen to display extreme combinations of power, flap, and center of gravity position. Again, the variation in the Cessna 150 curves is striking. The Cherokee displays modest changes, with fairly light stick force evident in the aft CG case.

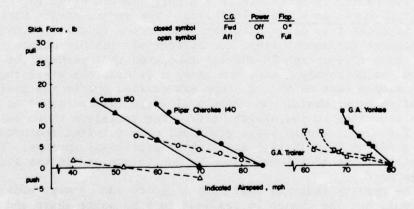


Figure IV-3. Stick Force Variations.

The Yankee and Trainer curves in Figure IV-3 are interesting in their upward curvature which is possibly due to a geared elevator tab or non-linearity in the control linkage. At any rate there is a reasonably large change between the power on and power off cases in indicated stalling speed as well as force gradient and force to stall. Although the gradient is initially shallow in the power-on case, the stick force still ends up being about the same as for the Cherokee.

Stick Force as a Stall Proximity Cue. Perhaps the most notable aspect of these force characteristics is their wide variation between airplanes and, especially in the Cessna 150 case, in a given airplane under different conditions. Given this variability, and the difficulty of "calibrating" the human pilot, it seems unlikely that stick force would in itself be a generally dependable cue as to stall proximity.

However, some attention was given to the question of just how large the force to stall has to be in order to give at least a threshold indication of being well away from the trim speed. The Cessna 150 test described

above demonstrated that 2 1b was not enough.

An experiment was conducted with the in-flight simulator in which the evaluation pilot was asked to fly with attention outside the cockpit and stall the airplane from various maneuvers such as low-altitude turns about a point, turns onto final approach (including overshoots of the center line) and "stretched" final approaches. No artificial warning or buffet was available. The various configurations had generally good longitudinal handling qualities, but force gradient and force increment from trim speed to stall speed were varied. The pilots commented as follows:

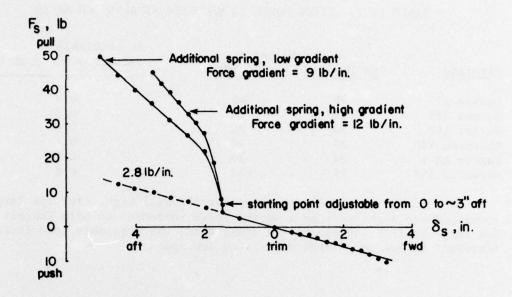
force increment from trim to stall	Comment
2-3 1b	Very light, unsatisfactory cue
10 lb	Good level, satisfactory
17 1b	Heavy, satisfactory

This represents rather limited evidence, but apparently the threshold for force indication is somewhere in the neighborhood of 10 lb.

Stick Force as a Stall Inhibitor. The record of the Cessna 182 at least suggests that large gradients and forces to stall, although perhaps not pleasant for maneuvering, can effectively inhibit unintentional stalling. Recent work (References 10 and 11) indicates that perhaps the force gradient need not be uniformly steep, but steep only near the stall angle of attack.

A simple test of this concept was carried out in the in-flight simulation experiments. An additional spring was attached to the feel system as indicated in the sketch below. The variation shown has a rather light 2.8 lb/in. linear basic gradient; others tested featured a steeper basic gradient (4.8 lb/in.) and lighter additional springs. The nonlinear character of the additional force is due to preload in the short coil springs used.

The results indicate that such a device can be most effective as a deterrent, but the change in gradient must be quite sharp and large, almost in the nature of a "yielding stop"; the variations in the sketch gave this impression. Encountering the change in gradient during the landing was initially quite objectionable, but became less so with practice.



Although the concept has merit, the simple spring-in-the-system approach may not prove practical due to the presence of large and conflicting trim changes from power, flaps, CG shift and ground effect.

C. STICK FORCE TO MANEUVER

Although stick force per g is normally considered to be a handling factor in cruise and relatively high speed maneuvering, measurements of this parameter were made in connection with TASK 2 to determine if it held any significance in the low speed maneuvering case. A sample of the data is shown in the sketch below, and measured values for the power off, flap down case are given in Table IV-1.

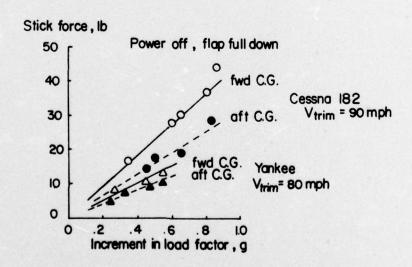


TABLE IV-1. STICK FORCE TO MANEUVER AT APPROACH SPEED

Airplane	F _s /n, 1b CG forward	per g CG aft	Δn available (abrupt pull-up at V _{trim})
Cessna 177	70	65	0.7
Cessna 182	48	30	0.7
Cessna 150	30	25	0.8
Cherokee 140	25	20	0.8
Yankee AA-1	24	20	0.5
Citabria 150	15	12	0.8

Some of the measured values are surprisingly high. For the larger levels, there might well be a useful force increment to help inhibit sudden large control inputs; on the other hand, the available load factor increment is not very large due to the low speed.

SECTION V

TRIM CHANGES

Nose-up trim changes due to power or flap are obvious candidates as factors which might induce an unintentional stall. Table V-1 shows the results of measurements taken on the seven airplanes of TASK 2.

TABLE V-1. STICK FORCE TO HOLD TRIM SPEED, 1b. F ≡ PUSH, A ≡ PULL

	Power	Flap	Sides	lip
Airplane	$Off \rightarrow Max$	$0^{\circ} \rightarrow \text{Full}$	Left	Right
Cessna 182	36 F	34 F	12 A	15 F
Cessna 177	26 F	16 F	9 F	6 A (Power On)
			3 F	5 F (Power Off)
Cessna 150	12 F	11 F	10 F	10 F (Flap 0°)
			2 A	2 A (Flap 40°)
Citabria 150	12 F	(Unflapped)	2 A	1.5 F
G.A. Trainer	8 F	3 A		
Cherokee 140	7 F	2.5 A	8 F	7.5 A
G.A. Yankee	6.5 F	1 A	4 A	6 A

The force levels are seen to be quite large in some cases, requiring prompt trimming action. Some interesting, though not very significant, effects of sideslip are evident, including change in force with direction of sideslip, a factor mentioned in the previous section in connection with the Cessna 182 trim curves.

Not indicated in the table but observed in flight is the fact that the trim changes with either power or flap in the Cessna airplanes are of sufficient magnitude to cause the airplane to stall itself if left unattended. However, only a part of the force shown had to be applied to prevent the stall.

Trim changes due to power were explored briefly in the in-flight simulation phase in connection with aborted approaches and touch-and-go landings, with the findings that almost any level requiring trim action is considered annoying. Forces in the neighborhood of 30 lb were definitely objectionable. However, if adequate control power was available to control the flight path, and if the forces could be trimmed off in a timely manner, even large trim changes were judged to be tolerable.

even large trim changes were judged to be tolerable.

Thus the significance of trim changes in the stall accident picture remains unclear, partly because the airplane with the best accident record exhibits the largest effects. Despite the lack of hard evidence, however, it seems obvious that a large nose-up trim change occurring during a moment of inattention could lead to a stall. Also, factors causing the trim change could result in reduced nose-down control power being available for recovery (as discussed in Section II with respect to the Cessna 150). All in all, it would seem desirable to minimize trim changes if possible.

SECTION VI

STALL WARNING

A. BACKGROUND

The subject of stall warning is clearly central to the study of inadvertent stalls. It was touched upon in the accident analysis of Section II, where it was pointed out that one-third of the stall accidents and one-half of the spin accidents for which data are available involved airplanes which did not have stall warning indicators installed (conversely, two-thirds of the airplanes in stall accidents and one-half of those in spin accidents apparently did have such devices). One way to interpret this finding is that some accidents might have been avoided if a stall warning had been installed in all cases; another interpretation suggests that since accidents continue to happen with standard systems installed, consideration should be given to their improvement.

Federal Airworthiness Standards (Reference 6, § 23.207) call for clear and distinctive stall warning in any normal configuration, in both straight and turning flight. The warning may be either natural (aerodynamic buffet) or artificial, and must provide a speed margin before stall of not less than 5 knots or more than 10 knots (or 15% of stall speed if

that is greater).

Despite the seeming clarity of the regulation, the continuing accident history (including military cases) strongly suggests that the warning of impending stall is not always getting to the pilot in a useful form or time frame. It is not as though the subject has escaped serious attention; the amount of literature directly related to stall warning and warning devices is impressive. Some 30 items of the Bibliography - entries 49 through 77 - address the subject, and indicate that artificial warning systems were in use as early as 1938 (Reference 12), and that research on new devices continues at the present time (References 13 and 14).

B. MEASURED STALL MARGINS

The stall warning observed in the course of the TASK 2 testing was generally unimpressive. All seven airplanes with the exception of the Citabria had articifial warning devices; all gave an aural signal except for the Piper Cherokee 140 which utilized a panel light. In terms of sound quality, the aural warnings in the Grumman American airplanes were the only ones which came through with impressive loudness and clarity; in the Cessnas tested, the sound tended to be soft, intermittent, uninteresting, and, on occasion, absent.

The warning margins observed are shown in the following table.

TABLE VI-1. STALL WARNING MARGINS
Increment Above Indicated Stall Speed, mph

	Power	Flag	o Up	Flap Down's		
Airplane	Setting	Horn	Buffet	Horn	Buffet	
Cessna 182	Off	24	•	22	3	
	On	12	12	22	0	
Cessna 177	Off	12	-	10	-	
	On	10	2	10	-	
Cessna 150	Off	10	-	(?)	-	
	On	7	-	(?)	-	
Citabria 150	Off					
	On	AT REST DA	8		7.50	
Cherokee 140	Off	17	4	3	0	
(Panel Light)	On	16	2	10	0	
G.A. Yankee	Off	5	2	1	1	
	On	4	1	5	1	
G.A. Trainer	Off	10	2	Not Re	corded	
	On	7	0	2	2	

Great variability is apparent between airplanes and between configurations for a given model. The warning on the Cessna 182 is so premature that it is easily ignored; on the other hand, as noted elsewhere, the stall is docile and usually requires considerable physical effort to produce.

Buffet, if present at all, usually occurred too close to the stall to be useful.

C. DESIRABLE SPEED AND TIME MARGINS

The in-flight simulation work (TASK 3) produced the following results which relate to stall warning:

Speed and Time Margin. Pilot commentary indicated the following with regard to stall warning margin for configurations with satisfactory feel characteristics (Section IV) which were trimmed for pattern operations at 75-80 knots and stalled at 60-62 knots:

Stall Warning Horn			
Speed Margin	Comment		
2-3 knots	Too small		
4-5 knots	Marginal		
6-7 knots	Acceptable		

These results are for slow to moderate (3 kt/sec) decelerations, both in straight flight and in turns. One pilot volunteered the comment in one instance that the time interval between warning and stall was simply too short (in that particular run it was between one and two seconds). The time margin aspect unfortunately could not be pursued at any length, but there is other recent work (Reference 15) which suggests that it is a significant factor in need of systematic study.

D. HORNS, STICK SHAKERS, AND ANGLE OF ATTACK INDICATORS

The in-flight simulator was equipped with selectable horn and stick shaker warning systems, and pilots were asked to comment on their relative effectiveness for various configurations and situations. The results simply reinforced the already-known (Reference 16, for example) strong pilot preference for the tactile cue provided by the shaker system.

Angle of attack indicators were available in three styles: dial type in upper left hand corner of the panel, calibrated in % of maximum lift; Navy-style vertical indexer with "chevrons" and "donut," mounted above the panel in the line of vision; and a Safe Flight horizontally-mounted slow-fast speed control unit also mounted above the panel in the line of sight (see Appendix F).

The evaluation pilots were allowed to sample these devices, and although again the results are not extensive, some trends may be noted:

 General aviation pilots are usually unfamiliar with such equipment, and a period of adjustment is required. Any of the three could be utilized effectively with practice.

• As warning devices, such indicators have the shortcoming of requiring the pilot to look straight ahead or even down at the

panel.

• After considerable flying with the combination, one pilot felt that either a horn or stick shaker plus the dial-type unit gave the most effective warning. The horn or shaker furnished a proximity cue, and the indicator provided useful information on whether or not the angle of attack was increasing further, holding steady, or decreasing. This was most helpful in recovery from maneuvers in which large pitch attitude had been reached.

In summary, despite past efforts, the subject of stall warning still appears to warrant a good deal of serious work.

SECTION VII

PERFORMANCE AS A FACTOR

Climb and descent performance of the seven TASK 2 airplanes were measured to determine whether or not an undue sensitivity to speed existed; in particular, it has been suggested that if performance falls off very rapidly as speed decreases, a pilot might be induced to enter a mush condition. As in other TASK 2 measurements, the experiments were designed simply to illuminate this area of concern, and not to provide data indicative of absolute climb performance.

Figure VII-1 presents the results in terms of a ratio between the rate of climb and the maximum observed, or in the power-off case, the ratio between rate of descent and the minimum rate observed. The rates themselves were determined by recording the altitude increment traversed in a steady climb or descent of at least one minute duration. Reasonably smooth, low altitude conditions were sought, but since absolute performance was not of primary interest, the data were not corrected for weight or non-standard conditions. Open symbols represent flap-up cases, darkened symbols flap full down. The small triangles on the plot denote indicated stall speed.

The results indicate a general lack of sensitivity to being moderately off the most favorable speed; even errors as large as 10 mph seldom reduce the rate of climb more than 10%. In most cases the stall must be approached closely before a very large performance decrement is noted.

Flap drag varied notably from airplane to airplane, but only in the case of the Cessna 150 was there a drastic climb performance reduction. However, the accident record suggests that this is not a particularly significant factor in this case.

Finally, the flap down descent cases exhibit an interesting lack of "backside of the thrust-required curve" characteristic, with descent rate tending to lessen with decreasing speed almost to the stall in most instances.

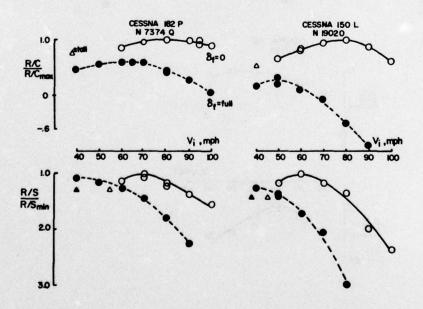


Figure VII-1. Climb and Descent Performance.

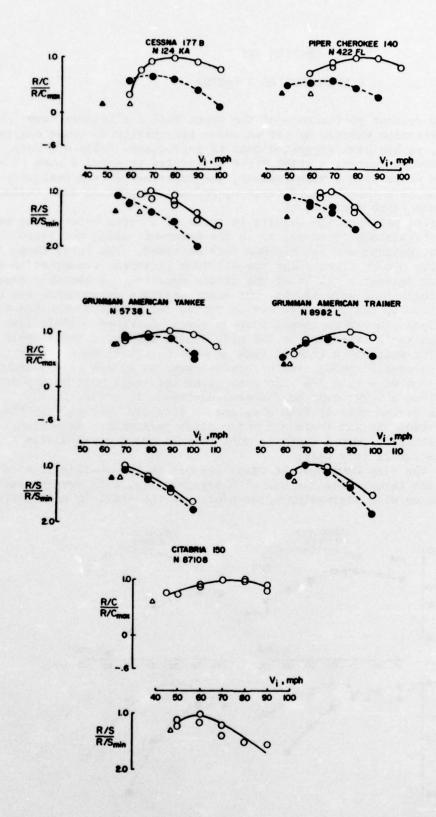


Figure VII-1. Climb and Descent Performance (Continued).

SECTION VIII

THE OUTLOOK FOR PROGRESS

A. AWARENESS OF THE PROBLEMS

Recognition that a problem truly exists is a necessary first step in improving the stall-related accident record; this awareness has been sharpened by the NTSB survey (Reference 4) and reports of military and NASA research activities (References 3 and 5, for example). Hopefully, the present study will serve to bring the problem into better focus and suggest areas which might benefit from further research activity.

The record, as summarized in Section II, is clearly not good. Particularly disturbing are the observed large differences between accident rates for various airplanes, mainly because such differences are not altogether explainable at this point. Although the flight test phase confirmed that substantial differences in flying qualities exist between various makes and models (and between various configurations and flight conditions for a given airplane), it has not been established whether these rank in importance with usage factors such as type of flying and pilot experience. Thus a good deal of work remains to be done in the area of accident analysis for individual makes and models, much in the style of the analysis of the overall group statistics performed for this report, with added attention to details available in the complete files (but not coded on the present tapes). Also, it appears in retrospect that the present analysis may have unduly emphasized fatal accidents, and any new work should give equal attention to the extraction of pertinent information from non-fatal cases as well.

With additional effort in the accident analysis area, it will be possible to assemble a much more detailed picture of the stall-related accident for individual airplanes, and this in turn will enhance our feeling for the relative importance of usage/piloting factors and airplane characteristics.

B. IMPROVING THE PILOT

Although significant gaps exist in the understanding of stall-related accidents, it is possible, on the basis of the work thus far, to suggest several areas which warrant immediate consideration. The extremely high incidence of citation of the pilot as a cause or factor in such accidents (see Section II-B) naturally tends to focus attention on training and proficiency; indeed, industry spokemen tend to emphasize pilot involvement to the point of virtually excluding mention of the airplane itself (Reference 17).

There is evidence which suggests that training in itself cannot eliminate the stall-related accident. Even in the military, with the most extensive training, both initial and recurrent, and where the hazards of high angle of attack situations can be reviewed on a flight-by-flight briefing basis, the stall accident continues to occur. Intensive efforts were put forth in the late 1930's and 1940's to educate pilots to the hazards of the stallable and spinnable airplanes of that time (Reference 18), but it took a new generation of airplane designs to achieve a significant

reduction in stall-related accidents (Reference 19). However, it would appear useful to consider what might be done to take advantage of an enhanced awareness of the stall accident problem with the airplanes presently in the general aviation fleet.

In Depth Training and Open Ratings. The present study suggests that the modern single engine lightplane is probably more complex in terms of stall characteristics than most pilots realize. The observed variations between various makes and models, and between configurations in a given airplane are rather striking, yet the handbook information available to the pilot usually describes the stall behavior simply as "normal." It would appear to be both highly advisable and possible to do the following:

- Make the student pilot aware that all airplanes don't necessarily have the same stall behavior as the one in which he is learning.
- In the course of instruction or check out, require the pilot to be exposed to the complete range of possible behavior (including extremes of center of gravity position).
- Provide a detailed discussion of stall characteristics (and other flight characteristics as well) in a standardized operator's manual.

Although the idea will undoubtedly be resisted in many quarters, the observed variability in flight characteristics, along with operating complexities and lack of cockpit standardization, tend to suggest that the present system of "open" ratings (SEL or all single engine landplanes, for example) should perhaps be replaced with a system which would insure a pilot's being completely familiar with each airplane he flies.

Recurrent Training. With the biennial flight review now established, it seems worthwhile to suggest that it could be used as an avenue of communication to make each pilot aware of the general aviation accident picture, including problems peculiar to the particular airplanes he flies or expects to fly. In the flight phase of the review stalls should receive special emphasis.

C. IMPROVING THE AIRPLANE

It is often suggested that the most effective way of eliminating the stall-related accident would be to make all airplanes stall-proof. This is unrealistic of course, since stalling is sometimes demanded by the mission (training or acrobatics, for example) or by the airplane configuration (many tailwheel landing gear airplanes must be either full-stall landed or "wheel-landed" to prevent bouncing); and moreover, making an airplane stall-proof under all conditions without compromising performance, utility or control system simplicity is invariably difficult.

Recent and ongoing research does indicate, however, that the role of the airframe design in the accident picture bears careful examination (Reference 20). Some avenues for improvement are discussed below:

Improved Stall Warning and Warning Systems. The discussion of Section VI implies quite strongly that much work is needed in the area of stall warning and stall warning systems. In particular, the question of whether or not both time and speed margins are necessary should be answered with definitive experiments, preferably utilizing in-flight simulation so as to explore a usefully wide range of characteristics in a realistic environment.

The superiority of buffet or tactile "buffet-like," warning over aural or visual warning is already well known, and suggests that every reasonable effort should be made during prototype development to provide natural aerodynamic buffeting; also development and application of low-cost, reliable stick shaker devices would appear desirable.

Improved Aerodynamics. New airfoil and wing research holds promise for improved stall characteristics in future designs. The art of optimizing airfoils by use of digital computing is progressing rapidly, and several recent European designs have demonstrated "soft-stalling" charac-

teristics intentionally integrated into the airfoils.

Reference 21 covers the progress of some recent wing design work in this country; an unconventional aerodynamic approach to stall and spin-suppression utilizing a canard configuration is discussed in Reference 22.

Larger Stall Margins with Flight Path Spoilers. Recent experiments with flight path spoilers integrated with the power control reported in Reference 23 indicated that use of such devices allows the airplane to be flown at higher than normal stall margins without suffering landing performance penalties. Also, the need for large flap deflections to steepen the glide path is removed, thus lessening trim changes associated with flap and power and making the go-around maneuver less critical and less conducive to unintentional stalls.

It appears likely that utilization of such devices could lessen the incidence of stall accidents in the approach and go-around flight phases as well as improve the landing accident record. The concept has been successfully demonstrated, but not yet applied to production airplanes.

Control Power Limiting. Limiting pitch control power to a level which makes it difficult or impossible to completely stall the airplane is an approach to the stall problem which is receiving renewed attention after a lapse of many years; this method of stall suppression was seriously advocated some years ago and saw successful use in the Ercoupe and General Skyfarer designs (Reference 19 covers some of the history) and also in a less extreme form in the Stinson 108 and Bellanca Crusair.

The problem is admittedly much more difficult in more recent designs with high power, large flaps, and most significantly, large center of gravity range. However, it is possible to conceive of a system having stops which are adjusted as a function of throttle setting, flap deflection, and trim tab setting, thus providing appropriate maximum elevator deflection under all inflight conditions (the trim control would account for center of gravity position, but unless properly set before takeoff might permit excess up-elevator in that phase).

Other more complex systems which effectively limit the available control power have already been mentioned (References 10 and 11).

Another approach out of the past is that used on the Culver "V" (Reference 24) designed by A. Mooney and produced in the 1946-1948 period; in this case the pilot's stick controlled a very small elevator that permitted only limited maneuvering about a trim point. The trim point was adjustable, of course, and utilized an interconnected stabilizer and flap.

It will probably always be desirable to design a stall and perhaps a spin capability into some airplanes for purposes of training or sport acrobatics; however, it might be seriously questioned again, as it has been in the past, whether or not the airplane which is to be used almost exclusively for cross-country transportation needs ever to be completely stalled.

The use of tricycle gear makes it unnecessary for landing, and the small reduction in attainable lift coefficient inherent in the control-limiting concept does not usually result in large performance penalties (especially if use of advanced airfoils and flight path spoilers is contemplated). For non-aerobatic airplanes, control power limiting possibly represents the most promising method of reducing stall-related accidents.

SECTION IX

CONCLUSIONS

- 1. A detailed statistical analysis of stall and mush accidents for the period 1965-1973 allows the following observations to be made:
 - a. With regard to the circumstances of occurrence:

 Stall and mush accidents happen most often in personal flying (non-commercial pleasure or practice), followed by instructional and business/executive flying.

 Nearly half of all stall and mush accidents happen in the "in-flight" phase, with the remainder divided between takeoff and landing phases. Most of the fatal in-flight phase accidents are associated with acrobatics, buzzing, and low passes; turning prior to stall is involved in a high proportion of the cases.

· Stall and mush accidents happen almost exclusively in daylight

and in good weather.

 The statistics confirm that stall and mush accidents are most likely to happen to pilots with low total time and low time in type. The role of recency of experience was not evaluated.

- b. With regard to cause:
 - The pilot in command is cited as cause in nearly all stall and mush accidents.
 - The most common citation is, "Pilot in command failed to obtain or maintain flying speed."
- c. With regard to airplane make and model:
 - For a group of 31 single engine airplanes, stall/mush accident rates differ by as much as a factor of 20 between best and worst cases.
 - When ranked according to the accident statistics, older (especially pre-1940) designs consistently show up poorly compared to post-World War II airplanes, with a few recent exceptions.
- 2. Flight tests of seven different airplanes revealed the following with regard to general high angle of attack handling and stall characteristics:
 - a. With forward center of gravity, low power, and no flap, generally good behavior was observed for coordinated (no sideslip) stalls. In some cases a complete stall could not be reached, especially in a turn; at worst a pitch break could be obtained but rolling tendencies were controllable and normal recovery technique sufficed.
 - b. Rearward (aft limit) C.G., high (maximum) power, and full flap deflection, singly or in combination tended to degrade the stall behavior. Among the notable effects were the following:

- Lowered stick force gradients compared to (a), in some cases markedly so.
- More control power than that required to reach a stall was available in most cases.
- Rolling and yawing tendencies could be pronounced at the stall, particularly if up-elevator motion was continued. Vigorous use of aileron and rudder often were needed to prevent departure.
- Because of cumulative trim changes, one case of barely adequate down-elevator power for recovery was noted.
- c. Uncoordinated (rudder allowed to float) stalls almost always result in first yaw, then roll before pitching break could be observed. This usually cannot be countered with aileron, particularly in the critical cases (high power, aft C.G., flap down).
- 3. With regard to elevator control force as a factor in providing feel and stall deterrence, the following observations are pertinent:
 - Control force versus velocity characteristics and force to stall varied widely between the airplanes tested. Although the gradients measured were stable in all cases, force levels ranged from a qualitative "very heavy" to "very light."
 - For a given airplane, the force characteristics were highly dependent upon power setting, flap position, and center of gravity position. In some cases the differences between extreme conditions were striking (15 lb pull to stall in one configuration, 2 lb in another); in others, forces changed but remained relatively high at all times.
 - For some airplanes, the measured force gradients are sensitive to sideslipping, and may be different for right and left slips.
 - Owing to the large variations observable in a given airplane, and the difficulty in "calibrating" the pilot, the absolute level of stick force in itself is likely to be unreliable as an indicator of stall proximity; however, large force levels (i.e., in the neighborhood of 20 lb or more) tend to inhibit stalling if they must be held for any appreciable length of time.
 - In-flight simulator experiments tended to confirm that forces
 to stall in the neighborhood of 5 lb are qualitatively "light,"
 and require care in handling, particularly in the absence of
 stall warning.
 - It has been suggested that a marked increase in stick force for the last portion of up-elevator travel would provide a useful stall deterrent; a simulation indicated that in order to be effective, the change had to be quite sharp, and the ensuing gradient relatively large.
- 4. The significance of trim changes in the stall accident remains unclear, but the following points may be noted:
 - Very large nose-up trim changes with either power or flap deflection (more than 30 lb push required to hold trim speed) were measured in one case; if left unattended, the airplane would stall itself. However, in view of this airplane's very good accident record, this is apparently not a significant factor.

- In-flight simulation indicated that even small power-induced trim changes are annoying, but reasonably large magnitudes can be tolerated if sufficient control power is available to prevent serious changes in attitude or flight path, and if the forces can be trimmed off quickly.
- Despite the lack of compelling evidence based on observed handling problems, the possibility of a nose-up trim change causing a stall during a moment of inattention is bothersome; also, the factors causing the trim change could contribute to a problem of having excess elevator control power at the stall. For both of these reasons it appears desirable to minimize trim changes, or to introduce favorable ones.
- 5. Stall warning is clearly an important factor in the stall accident picture. The results of this permit the following observations:
 - A large proportion of stall/mush (and spin) accidents happen in airplanes without artificial stall warning systems. One interpretation of this result is that some accidents might have been avoided if such a device had been installed; another suggests that since accidents continue to happen even with stall warning systems installed, consideration should be given to their improvement.
 - Stall warning on the test airplanes was generally not impressive; the warning margin varied greatly with configuration, and was often so premature as to invite disregard. Aerodynamic buffet, if present at all, often happened too close to the stall to be useful.
 - A time margin as well as a speed margin may be desirable; this
 was qualitatively reinforced in the simulation experiments,
 although the testing was not extensive enough to define the
 minimum time needed.
 - The in-flight simulations found pilots definitely preferring tactile (stick shaker) over aural (horn) warning; this simply adds to similar results produced elsewhere.
 - Angle of attack indicators as warning devices were faulted for requiring the pilot to look inside the cockpit (or at least ahead over the panel), but when used in conjunction with a horn or shaker, they provide a very useful indication of whether the situation was progressing into or away from the stall.
- 6. Maximum power climb and power-off descent performance were measured on the test aircraft to determine whether or not an undue sensitivity to speed existed; in particular, whether slowing the airplane below normal climb speed could result in such a rapid loss of climb rate (or increase in sink rate) as to induce the pilot to enter a mushing or stalled condition. The findings including the following:
 - None of the airplanes showed an undue tendency in this respect; in fact, the power-off, flap down cases consistently showed little or no "backside" characteristic.
 - One airplane did show a very large loss of climb performance with full flap. However, its accident record does not suggest that this is a strong factor.

SECTION X

SUMMARY OBSERVATIONS

- The stall-related accident problem is clearly a serious one, and the large differences between accident rates for various airplanes are disturbing, partly because they are not altogether explainable at this point. It would be very helpful to know the accident patterns, causes, and factors for individual makes and models as well as for the group as a whole; for the most complete picture, this should be assembled by examining the accident files as well as the coded tapes.
- 2. The "simple" single engine lightplane is possibly more complex and varies more from model to model in terms of flight characteristics than many pilots appreciate. It would appear worthwhile to determine whether or not present-day training practice addresses the subject with sufficient depth to justify continued use of "open" pilot ratings.
- 3. Several avenues for improving the stall-related accident record by improving the airplane are available. In brief, they include the following:
 - Use of flight path spoilers to permit the airplane to be flown
 with larger stall margins without suffering landing performance
 penalties. This might also allow use of simpler, small-deflection flaps which would help alleviate trim change and control
 power problems. The concept has been successfully demonstrated,
 but not applied to production airplanes.
 - Application of recent airfoil and wing research. This holds considerable promise for better stall behavior and more straightforward design procedures.
 - Renewed attention to stall warning requirements and stall warning systems. In particular, the question of time margin prior to stall should be addressed.
 - Reexamination of the question (or possibility) of limiting elevator control power for modern lightplane configurations. For nonacrobatic airplanes this may be a most reasonable solution to problems of inadvertant stalls.

SECTION XI

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APPENDIX A

AN ANALYSIS OF SINGLE-ENGINE LIGHTPLANE STALL ACCIDENTS (1965-1973)

This section contains an analysis of stall-related accidents for the nine-year period 1965 through 1973. The primary emphasis is on "stall" and "mush" accidents, with "spin" and "spiral" types not being considered in detail (see Appendix B for definition of accident types, and Reference Al for a more extensive treatment of spin and spiral accidents).

The study is limited to domestic accidents of U.S.-registered aircraft; no air carrier or military accidents are covered. Only fixed-wing power planes with one or two engines are considered, with statistical summaries for individual make and model formed only for single-engine airplanes. Within the above limitations, 41, 577 accidents were subject to review, of which 4,783 were of the stall, spin, spiral, or mush types. For purposes of analysis, crop control accidents were excluded, unless otherwise noted.

A statistical review of 31 aircraft (by make and model) was undertaken, selected on the following basis:

- · Single-engine, fixed-wing configuration.
- · Not primarily used for crop control.
- · At least 500 active aircraft registered in 1973.

These 31 aircraft plus five summary groups were assigned "group numbers" from 1 through 36 (see Appendix C for listing). Selected results are given for these groups, with the most detailed attention being placed on "Group 32," which encompasses the 31 selected aircraft. For "Group 32," 30,606 accidents were available for analysis, or about three-fourths of the total 41,577. Of these, 3,467 were due to stall, mush, spin, or spiral; in statistical terms this is a large data base.

The data for the analyses were obtained from two sources:

- · NTSB accident records, primarily from coded magnetic tapes.
- · FAA estimates of hours flown for each make and model.

It is important to note that the NTSB coded data are not always complete. Most of the important items - such as accident type and cause - are considered mandatory entries on the tapes; certain others - such as runway length and altitude - are optical. Thus quite often statistics must be formed on the basis of reported data rather than on data for all accidents. The accident count itself is believed to be accurate but the details themselves depend upon the quality of the investigation and reporting; hopefully, the large data base will tend to smooth out the anomalies of individual accidents.

Accident rate data (accidents per 100,000 flight hours is the usual definition) are directly dependent upon the FAA estimates. These are primarily based upon owner/operator estimates, and although probably not exact, it seems reasonable to assume that there are no large differences

^{*}Based on material prepared under subcontract by Brent W. Silver, Aircraft Safety Consultants, Inc., Palo Alto, Ca.

in reporting between various airplane makes and models.

SUMMARY GROUP RESULTS

Of the aircraft groups listed in Appendix C, the following five are "summary groups" and will be covered briefly before considering the 31-airplane Group 32 in detail:

Group 32 - Thirty-one single engine airplanes, no crop control accidents.

Group 33 - Crop control accidents only for Group 32 airplanes.

Group 34 - All general aviation fixed-wing aircraft, one or two engines.

Group 35 - All general aviation fixed-wing single engine aircraft.

Group 36 - All general aviation fixed-wing twin-engine aircraft.

The NTSB Stall/Spin Study (Reference A2) found that 22% of fatal accidents were due to stall or spin during 1967-1969. For Group 34 (1967-1973) the precentage is the same. When fatal spiral and mush accidents are added, the percentage grows slightly, to 24.2%. If both first and second accident types are included, then stall, spin, spiral, and mush account for 30.8% of all fatal accidents. These statistics vary only slightly over each of the nine years of the study.

Table Al contains the accident results for each of the five summary groups. Accident types are arranged by columns, with the last column being a total of <u>all</u> accidents, whether stall-related or not. The percentages shown are based on this total. For each group, two rows are given; F (for fatal accidents) and A (for all, nonfatal plus fatal). For example, for Group 34 there were 2,188 stall accidents of which 796 were fatal. For the same group the total number of accidents was 41577 of which 5,320 were fatal.

TABLE A1. ACCIDENT SUMMARY FOR GROUPS #32-#36 (1965-1973)
(% SHOWN IS OF TOTAL)

	F=FATAL	EITHE	R FIR	ST OR	SECO	ND AC	CID	ENT T	YPE:	TOTAL OF	EVERY
GROUP:	A=ALL	STALL		SPI	N	SPI	RAL	MUS	SH	ACCIDENT	TYPE:
32 GR#1-31	F	500	14%	428	12%	42	1%	59	2%	3639	100%
NO CROP	A	1453	5%	597	2%	111	0%	1306	4%	30606	100%
33, GR#1-31	F	33	31%	22	21%	1	1%	1	1%	106	100%
SS. CROP ONLY	A	72	16%	28	6%	5	1%	49	11%	448	100%
34 ALL SINGLE	F	796	15%	690	13%	64	1%	91	2%	5320	100%
AND TWIN	A	2188	5%	936	2%	161	0%	1932	5%	41577	100%
35, ALL SINGLE	F	678	15%	595	13%	54	1%	69	2%	4449	100%
SS'ENGINE G.A	. A	2003	5%	830	2%	147	0%	1803	5%	36950	100%
ALL TWIN	F	118	14%	95	11%	10	1%	22	3%	871	100%
36. ENGINE G.A	. A	185	4%	106	2%	14	0%	129	3%	4627	100%

The percentages in Table Al are seen to be rather uniform over all the groups with the exception of Group 33 (crop control only), where stall

accidents account for more than half of the total. It is notable that the percentages for single and twin-engine aircraft are similar. For the nine years of the study there were 3,079 fatalities from stall-related accidents for Group 34 (singles and twins), or an average of 342 deaths per year.

GROUP 32 ACCIDENT RATES

In this and the following three sections the results for Group 32 (all 31 individual single-engine airplanes, but no crop control accidents) are examined.

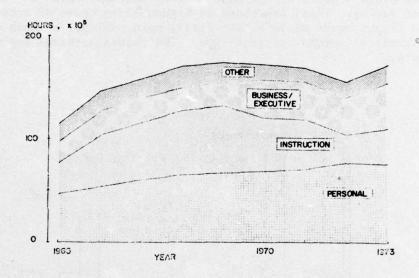


Figure A1. Hours Flown According to Use.

The hours flown by the airplanes in this group are shown in Figure Al for the nine years of the study. The largest component is seen to be personal use (40.7% of the total hours). Personal use if defined as follows:

Personal. Any use of an aircraft for personal purposes not associated with a business or profession, and not for hire. This includes maintenance of pilot proficiency.

The next largest component is instructional flying (29.8% of total hours). This is defined as:

Instruction. Any use of an aircraft for the purpose of formal instruction with flight instructor aboard, or with the maneuvers on the particular flight(s) specified by the flight instructor.

Business/executive, defined below, together account for 18.6% of the total usage.

Business Transportation. Any use of an aircraft not for compensation or hire by an individual for the purpose of transportation required by a business in which he is engaged.

Executive Transportation. Any use of an aircraft by a corporation, company, or other organization for the purposes of transporting its employees and/or property not for compensation or hire and employing professional pilots for the operation of the aircraft.

All other uses (air taxi, "industrial/special," research and development, demonstration, ferry flight, etc.) account for 10.9% of the hours for the group.

The usage figures may be used to form accident rates for the various kinds of flying. These are shown in Figure A2 in terms of accidents per 100,000 flight hours where either stall, spin, spiral, or mush was listed as the first or second accident type. The shaded portions represent fatal accidents.

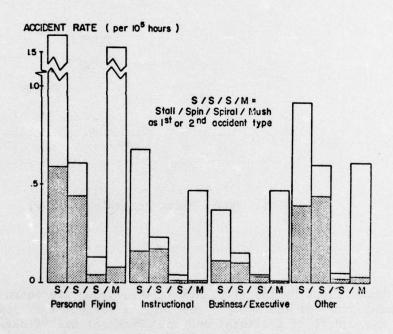


Figure A2. Accident Rate as a Function of Use.

Personal flying clearly has the highest accident rates, with instructional and business flying both significantly better. Within each category stall and spin have the highest rates.

Table A2 gives values for accident rates for all types of usage averaged over the nine years of study. Combined stall, spin, spiral, and mush accidents are seen to give a rate of about 0.7 fatal accidents per 100,000 flight hours; although not shown here, the rates tend to be fairly uniform over the time span.

TABLE A2. FATAL ACCIDENT RATES FOR GROUP 32, 1965-1973 (Either first or second accident types)

Accident Type	Fatal Accidents per 100,000 Hours	Hours per Fatal Accident
STALL	0.348	287,000
SPIN	0.298	336,000
SPIRAL	0.029	3,420,000
MUSH	0.041	2,435,000
STALL + MUSH	0.389	257,000
STALL + SPIN + SPIRAL + MUSH	0.716	140,000
TOTAL OF ALL ACCIDENT TYPES:	2.533	39,500

The inverse of the fatal accident rate is also shown in Table A2. For example, there is an average of 140,000 hours flown between fatal stall, spin, spiral, or mush accidents.

GROUP 32 ACCIDENT DISTRIBUTIONS (STALL OR MUSH LISTED AS FIRST ACCIDENT TYPE)

This section continues the discussion of Group 32 results, but with attention focused on the stall or mush as the first of the two possible accident types (see Appendix B) listed in the accident report. Here comparisons will be made by examining accident distributions rather than rates.

Type of Operator. Accident distributions across types of operators for three categories (stall and mush, spin and spiral, and TOTAL accidents) are compared in Figure A3.

The operator in most cases is a private owner. This is followed by fixed-base operator, flying club, corporate/executive, and flying school. Corporate/executive users have relatively fewer stall and spin accidents than might be predicted on the basis of the group mean.

Kind of Flying. A breakdown of stall and mush accidents by kind of flying is given in Table A3. The percentages shown cumulate down the columns. For example, pleasure flying accounts for 62.6% of all stall accidents for the group (and 68% of fatal stall accidents). This may be compared with the distribution for TOTAL accidents, in which 55.2% occurred in pleasure flying.

For the mush accident, pleasure flying accounts for a percentage of accidents (63.4%) which is similar to that for the stall (62.6%). Instructional flying involves a lower percentage of mush accidents (13.7%) than stall accidents (17.6%) or TOTAL accidents (21.2%).

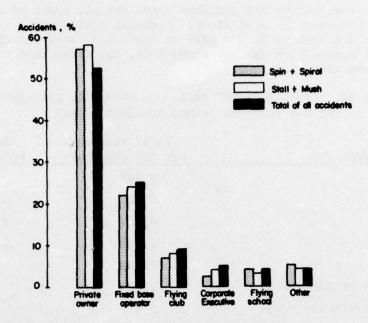


Figure A3. Accident Distributions According to Type of Operator.

TABLE A3. DISTRIBUTION OF ACCIDENTS BY KIND OF FLYING FOR STALL AND MUSH AS THE FIRST ACCIDENT TYPE GROUP #32 (1965-1973) (%s are formed down columns)

	BY	FIRST AC	TOTAL OF EVERY				
	S	TALL	M	USH	ACCIDENT TYPE:		
KIND OF FLYING:	FATAL	ALL	FATAL	ALL	FATAL	ALL	
INSTRUCTIONAL	12.4%	17.6%	7.8%	13.7%	9.5%	21.2%	
DUAL; CHECK RIDE SOLO TRAINING	5.2% 2.6% 4.6%	6.1% 5.6% 5.9%	3.9% 2.0% 2.0%	6.3% 4.3% 3.1%	4.6% 2.0% 2.9%	6.5% 8.7% 6.1%	
NONCOMMERCIAL	75.5%	72.4%	84.3%	78.6%	81.3%	72.6%	
PLEASURE PRACTICE BUSINESS CORPORATE/EXECUTIVE OTHER	68.0% 1.8% 5.4% 0 0.3%	62.6% 2.5% 6.7% 0.2% 0.4%	76.4% 0 5.9% 0 2.0%	63.4% 5.4% 9.6% 0.1% 0.1%	66.2% 1.8% 12.8% 0.2% 0.3%	55.2% 5.2% 11.7% 0.2% 0.2%	
COMMERCIAL	2.6%	2.8%	2.0%	3.8%	3.5%	2.5%	
MISCELLANEOUS FLYING	9.5%	7.2%	3.9%	3.9%	5.7%	3.7%	
TOTAL (DOWN COLUMNS):	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	
(TOTAL NUMBER)	(388)	(1057)	(51)	(1073)	(3639)	(30606)	

Phase of Flight. The distribution of stall, spin, spiral, and mush and TOTAL accidents by phase of flight is shown in Figure A4. The shaded portions represent fatal accidents. For the fatal accidents, the most common flight phase is "in-flight" (which means essentially other than takeoff or landing) except for the mush type of accident which is most often associated with takeoff.

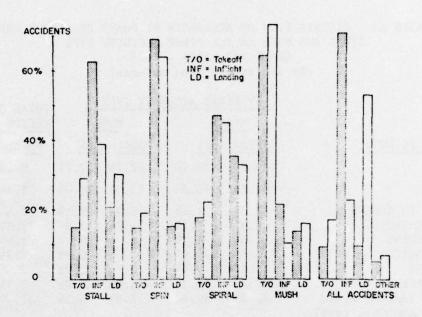


Figure A4. Accident Distribution According to Phase of Flight.

A detailed breakdown is given in Table A4 for stall and mush accidents. Here the major phases are subdivided into several categories. While most (62.6%) of the fatal stall accidents happen in the "in-flight" phase, relatively few (9%) occur in the in-flight operations "climb to cruise," "normal cruise," and "descending." Most of the fatal in-flight stall accidents are associated with "low-pass," "buzzing," "acrobatics," and "other." The "other" category here includes a variety of phases on which NTSB does not give further breakdown, such as uncontrolled descent, hunting, cattle roundup, and unknown - in-flight.

Of the accidents with clearly defined phase it is apparent that low-altitude operations are the most hazardous. For the stall, Table A4 indicates that the in-flight phase accounts for most of the fatal accidents, followed by landing and then takeoff. For the landing phase the largest subcategory is "final approach," but the "go-around" is rather high considering the infrequency of the maneuver compared to the number of operations in the traffic pattern and on final approach.

Takeoff is the flight phase in 28.5% of all stall accidents, but only 14.9% of fatal stall accidents. Takeoff is defined by the NTSB as the period from takeoff run to the point of reduction to climb power.

The takeoff is by far the most important phase for the mush accident. In fact, this phase (and the landing "go-around" which is similar in several respects) almost serve to define the mush accident as opposed to the stall. The distinction between the two is not always clear, although

TABLE A4. DISTRIBUTION OF ACCIDENTS BY PHASE OF FLIGHT FOR STALL AND MUSH AS THE FIRST ACCIDENT TYPE

GROUP #32 1965 - 1973

(%s are formed down columns)

	BY FI	RST ACCI	TOTAL OF EVERY			
	STA	STALL		MUSH		TYPE:
PHASE OF FLIGHT:	FATAL	ALL	FATAL	ALL	FATAL	ALL
TAKEOFF	14.9%	28.5%	62.7%	72.7%	9.2%	17.0%
INFLIGHT	62.6%	40.3%	21.6%	10.6%	71.1%	22.8%
CLIMB TO CRUISE NORMAL CRUISE DESCENDING ACROBATICS BUZZING LOW PASS OTHER (uncontrolled descent, hunting, cattle roundup, etc.; also unknown- inflight)	2.3% 6.4% 0.3% 3.6% 5.2% 12.4% 32.5%	1.5% 3.7% 0.3% 1.6% 2.6% 11.2% 19.4%	5.9% 3.9% 0 0 0 3.9% 7.8%	0 0.2% 0.2% 3.9%	1.6% 2.9% 2.7% 5.1%	0.5%
LANDING	20.6%	30.2%	13.7%	15.3%	14.5%	53.1%
TRAFFIC PATTERN FINAL APPROACH GO-AROUND OTHER (leveloff, touchdown, roll, etc.)	5.7% 9.0% 5.4% 0.5%	5.0% 12.6% 11.3% 1.3%	2.0% 2.0% 9.8% 0	0.5% 6.2% 8.6% 0.7%	6.2%	7.6% 2.3%
OTHER (static, taxi, unknown phase)	1.8%	0.7%	0	0	5.2%	7.0%
TOTAL (DOWN COLUMNS):	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
(TOTAL NUMBER)	(388)	(1057)	(51)	(1073)	(3639)	(30606)

by inference from the data, there are differences in phase distribution and accident severity.

The in-flight phase may be seen to account for a disproportionally high percentage (62.6%) of the <u>fatal</u> stall accidents considering that only 40.3% of this type of accident occurs there. The in-flight subcategories suggest that perhaps there is a high incidence of low altitude accelerated stalls in this phase, associated with pull-ups or turning maneuvers.

The question of whether the airplane was turning or not just prior to the stall cannot be answered by reference to the NTSB coded tapes. It is an important consideration, however, and the information can in some cases be determined from the original accident reports. Examination of the files of 48 fatal stall accidents for 1973 yielded the results shown in Table A5.

TABLE AS. BREAKDOWN OF FATAL STALL ACCIDENTS BY TURNING AND CLIMBING MANEUVERS (based on a Survey of 48 Accidents from 1973)

Phase and Maneuver	Number of Accidents
In-Flight	
Turning Climbing Turning and Climbing Not Turning or Climbing Unknown	13 6 2 2 2 6
Subtotal	29
Takeoff or Landing	
Initial Climb (Turn) Initial Climb (No Turn) Departing Pattern (Turn) Departing Pattern (Climb)	6 3 2 1
Turn, Downwind to Base Base Leg (No Turn) Turn, Base to Final Final Approach (In Turn) Unknown	1 1 2 1 2
Subtotal	19

Thus the table indicates that the 40 accidents in which the prestall maneuver is known, 24 (or 60%) involved turning and 34 (or 85%) involved turning and/or climbing.

Conditions of Light. The record indicates that most general aviation accidents occur in daylight, corresponding to the fact that most flying takes place in daylight. Table A6 presents the distribution of stall, mush and TOTAL (of all accident types) by condition of light. This shows that the stall accident is even more a daylight phenomenon than other types. Note the relatively high percentage of fatal night accidents in the TOTAL column.

TABLE A6. DISTRIBUTION OF ACCIDENTS BY CONDITION OF LIGHT FOR STALL AND MUSH AS THE FIRST ACCIDENT TYPE GROUP #32 1965 - 1973 (%s are formed down columns)

	BY F	IRST ACC	TOTAL OF EVERY				
	STA	LL	MUS	H	ACCIDENT TYPE:		
CONDITION OF LIGHT:	FATAL	ALL	FATAL	ALL	FATAL	ALL	
DAYLIGHT	91%	93%	92%	93%	69%	86%	
DAWN OR DUSK	3%	3%	6%	3%	5%	4%	
NIGHT	6%	5%	2%	3%	26%	10%	

Weather Conditions. Not only do more than 90% of stall accidents occur in daylight, but they also happen essentially in fair weather. This information is presented in Table A7 for stall, mush, and TOTAL accidents. For the accidents reported as stalls, 96% were in VFR conditions; for mush accidents the incidence is 99%. Also noteworthy is the relatively high incidence of IFR weather accidents in the TOTAL column.

Almost 90% of the accidents happended with no flight plan filed; the remainder were under a VFR flight plan.

TABLE A7. DISTRIBUTION OF ACCIDENTS BY WEATHER CONDITION FOR STALL AND MUSH AS THE FIRST ACCIDENT TYPE

GROUP # 32 1965 - 1973

(%s are formed down columns)

	BY FIRST ACCIDENT TYPE:				TOTAL OF	EVERY
	STAL	L	MUSI	H	ACCIDENT	
WEATHER:	FATAL	ALL	FATAL	ALL	FATAL	ALL
VISUAL FLIGHT RULES (VFR)	93%	96%	98%	99%	73%	95%
INSTRUMENT FLT. RULES (IFR)	7%	4%	2%	1%	27%	5%

Airport Proximity. The proximity of the nearest airport to the accident site is coded on the NTSB tapes. For stall accidents, the occurrence tends to be either within the traffic pattern or at a distance greater than 5 miles. The mush accident happens predominantly near airports, which correlates with the earlier-cited association with the takeoff phase. For both stall and mush accidents, those which occur away from an airport tend to be more severe.

Airport Characteristics. The distribution of all accidents happening at airports indicates that most of those for Group 32 occur at "local" airports, followed by "municipal" and "private" fields. However, for stall and mush accidents there is a relatively larger frequency at "private" airports and a relatively smaller frequency at those termed "municipal."

Mush accidents are more frequently associated with unpaved than paved runways, the reverse of the situation found for TOTAL accidents. The stall accident falls in between, with roughly equal numbers for paved and unpaved runways.

The distribution relative to runway length shows that the mush is relatively more likely at short fields (1500 to 2500 ft), although the stall distribution is very nearly the same as that for TOTAL accidents (most accidents occurring where runway length is between 1500 and 5000 ft - which probably encompasses the largest percentage of general aviation airports).

The percentage of stall and mush accidents at high altitude (greater than 2500 ft elevation) fields is somewhat greater than the percentage of TOTAL accidents.

<u>Pilot Experience</u>. The following five items related to pilot experience are covered in this section; each is recorded by the NTSB for almost every accident:

Total time
Time in type
Age
Instrument Rating (yes or No)
Pilot Certificate held (student, private, etc.)

The distribution of accidents as a function of total time is shown in Figure A5 (note that the absicissa is nonlinear). In considering this plot the matter of exposure must be considered. It would be very desirable to compare this accident distribution with a distribution of pilot experience for all aircraft in the group, but this is not available. The next best thing is to compare the stall and mush accident distributions with that for some other type of accident, preferably one which is a random event, unrelated to pilot experience. The one picked here is "true engine failure." defined as an actual powerplant breakdown not due to piloting

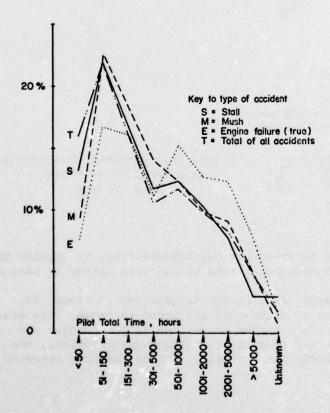


Figure A5. Accident Distribution as a Function of Pilot Total Flight Time.

factors such as fuel mismanagement (although it might be argued that higher time pilots might be better able to detect an impending failure and take

precautionary measures to avoid an accident).

If the true engine failure accidents are accepted as a somewhat random event, Figure A5 indicates that stall, mush, and TOTAL accidents occur more frequently to low time pilots less frequently to high time individuals, thus bearing out one's intuition that experience decreases the likelihood of an accident. The crossover point on total time appears to be about 500 hours; stall and mush accidents are relatively more likely below that figure, and less likely above.

Figure A6 presents a similar picture for time in type. Again, stall, mush, and TOTAL accident distributions are above that for true engine failure for low time pilots and vice versa; the curves cross over in the

neighborhood of 100 hours in type.

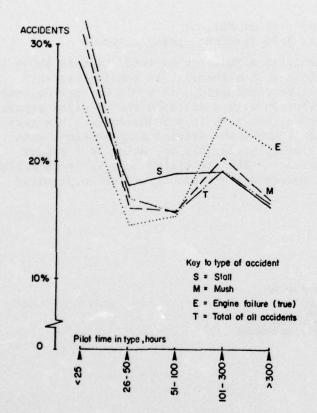


Figure A6. Accident Distribution as a Function of Pilot
Time in Type.

Although the differences observed are not overwhelming, it appears that after 500 hours and 100 hours in type, pilots become less likely to have a stall or mush accident.

Age, rather than experience, as a factor is examined in Figure A7, where accident distribution as a function of age group is shown. The stall and mush accidents show a markedly higher proportion in the younger age groups relative to both TOTAL and true engine failure distributions, the crossover point being about forty years of age. The differences observed

according to pilot age are more striking than those seen above for experience, a possible implication being that the element of caution enters the picture in a significant way.

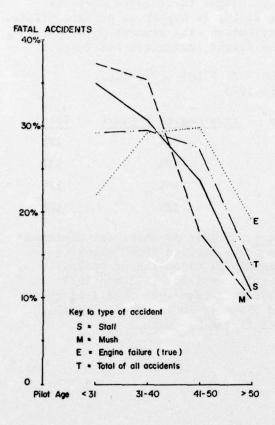


Figure A7. Accident Distribution as a Function of Pilot Age.

Although stall and mush accidents have been shown to be overwhelmingly fair-weather, daytime occurrences, the instrument rating should be indicative of a higher level of pilot proficiency. Table A8 shows that the distribution of stall, mush and TOTAL accidents is nearly the same relative to instrument rating, but the true engine failure is notably different. If the true engine failure is accepted as a nearly random event, then it appears that the instrument rated pilots are more successful in avoiding accidents.

TABLE A8. DISTRIBUTION OF ACCIDENTS BY PILOT INSTRUMENT RATING GROUP 32 1965-1973

Instrument Rating	Stall	Mush	True Engine Failure	Total of Every Accident Type
YES:	16%	15%	24%	16%
NO:	84%	85%	76%	84%

The final pilot factor to be considered here is the category of pilot certificate - student, private, commercial (or ATR without flight instructor rating) or flight instructor (including ATR with flight instructor rating). Table A9 summarizes the results, with percentages to be added down the columns. Slightly more than half of the accidents happen to private pilots. Compared to the true engine failure distribution, the student pilot has relatively more stall accidents while the flight instructor has fewer.

TABLE A9. DISTRIBUTION OF ACCIDENTS BY PILOT CERTIFICATE GROUP 32 1965-1973

Certificate:	Stall	Mush	True Engine Failure	Tota1
Student	20%	14%	12%	22%
Private	54%	57%	53%	53%
Commercial	13%	15%	16%	13%
Flight Instructor	13%	13%	18%	12%

Month of the Year and Air Temperature. Figure A8 shows the distribution of accidents by month, along with a curve labeled "REF" which is based on a numerical smoothing of the monthly distribution of general aviation operations reported by FAA control towers for 1973 and 1974 (Reference A3). This curve tracks the TOTAL accidents line well in the spring but is below it in the summer and above it in the fall; overall, it appears to be a reasonable estimate of flying by month.

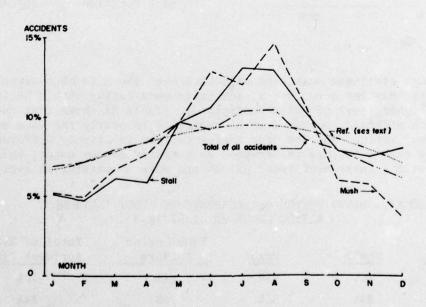


Figure A8. Accident Distribution by Month of Year

Relative to both REF and TOTAL, the stall and mush traces show a definite seasonal variation, being higher in summer and lower in winter, a finding probably related to the following factor temperature.

The distribution relative to temperature is given in Figure A9, when compared to TOTAL accidents, stall and mush are more frequent at high temperatures and less frequent at low ones.

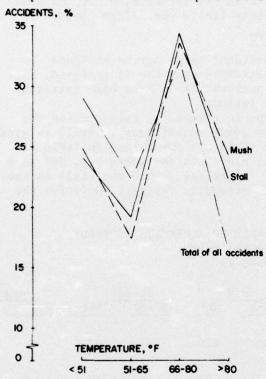


Figure A9. Accident Distribution According to Temperature.

Stall Warning Indicator. A stall warning indicator is required by FAR Part 23, § 23,207 for modern production airplanes which do not demonstrate clear and distinctive natural warning, such as aerodynamic buffeting. However, some older designs do have such a device.

The NTSB does not record whether a stall warning indicator was installed for every accident; the information is probably recorded more often in the now-unusual case of such a device not being present. Table A10 summarizes the available data for Group 32 by accident type.

TABLE A10. STALL WARNING INDICATOR INSTALLED?

ACCIDENT TYPE: (first type)	YES:	<u>NO:</u>
STALL	68%	32%
SPIN	50%	50%
SPIRAL	79%	21%
MUSH	82%	18%
TRUE ENGINE FAILURE	84%	16%
TOTAL OF EVERY ACCIDENT TYPE:	81%	19%

According to the table, one-third of the stall accidents and onehalf of the spin accidents involved airplanes without stall warning indi-

cators (88 stall and 115 spin accidents are represented).

Weight and Balance. The NTSB data on weight and balance for airplanes involved in accidents is very sparse, it not being a required entry in the coding system. The most prevalent indication - still sparse - is that a mush type accident is more likely with an overloaded airplane, an expected finding. A violation of center of gravity limits was seldom noted.

GROUP 32 RESULTS BY SECOND ACCIDENT TYPE

As discussed in Appendix B, two accident types may be assigned (sequentially) by the NTSB. In most accidents only one is assigned, but it is easily appreciated that a stall accident could have been initiated

by an earlier event, such as an engine failure.

The stall as a second accident type is covered in this section for Group 32 (see page A2 or Appendix C for group definitions). Stall-related accidents as first and second accident types are summarized in Table A11. For example, there were 500 fatal stall accidents for the group, 388 as a first accident type, 112 as a second. In general, where the stall is the second accident type, the first type is an engine failure. Only for the mush accident is this not so.

TABLE A11. SUMMARY OF STALL RELATED ACCIDENTS AS FIRST AND SECOND ACCIDENT TYPES GROUP 32 1965-1973

	STALL		SPI	N	SPIRAL		MUS	Н
	FATAL	ALL	FATAL	ALL	FATAL	ALL	FATAL	ALL
AS FIRST ACCIDENT TYPE:	388	1057	381	529	34	91	51	1073
AS SECOND ACCIDENT TYPE:	112	396	47	68	8	20	8	233
EITHER FIRST OR SECOND:	500	1453	428	597	42	111	59	1306
SECOND ACCIDENT TYPE PRECEDED BY ENGINE FAIL- URE AS FIRST	88%	748	81%	79%	75%	80%	50%	40%
TYPE:	88%	74%	81%	/9%	/5%	80%	50%	40%

When engine failure is cited as the first accident type, the most li ly flight phases to be involved are takeoff and in-flight (about 40% each), both for stall and mush second accident type; the landing phase is less common (about 20%). Non-engine-failures, as first-types, are more likely (85%) to be initiated in the landing phase in the form of overshoots, undershoots, hard landings or ground loops; the subsequent stall or mush then occurs in a go-around or on final approach.

Table A12 presents a comparison of stall and mush as first and second accident types according to the kind of flying. Note that the percentage of accidents which occurs in instructional flying is higher for stall and mush as second accident types than as first types. For those stall or mush

accidents preceded by an engine failure, 63% were "complete" failures, 28% were "partial" power losses, and 9% were "simulated" engine failures.

TABLE A12. DISTRIBUTION OF ACCIDENTS BY KIND OF FLYING FOR FIRST AND SECOND ACCIDENT TYPES GROUP 32 1965-1973

(Percentages formed down columns)

	S	TALL	MUSH		
KIND OF FLYING	FIRST TYPE	SECOND TYPE	FIRST TYPE	SECOND TYPE	
INSTRUCTIONAL	17.6%	26.8%	13.7%	24.0%	
PERSONAL	65.1%	58.3%	68.8%	61.8%	
EXECUTIVE-BUSINESS	6.9%	6.6%	9.7%	9.4%	
OTHER	10.4%	8.3%	7.8%	4.7%	
ALL KINDS OF FLYING:	100.0%	100.0%	100.0%	100.0%	

GROUP 32 RESULTS - CAUSES AND FACTORS

While the type of accident is intended to tell what happened, the cause is intended to indicate why it happened. The NTSB has the responsibility for determining this "probable cause," and has established some 860 codes which may be used for the purpose. Often more than one cause is assigned to a single accident; when this is done, all are considered to have equal weight.

The same codes are available for selection as "factors," which are not considered to have as much causal significance as the "causes." The formal definitions of the two terms are:

- CAUSE: Had the condition or event been prevented, the accident would not have occurred.
- FACTOR: A related condition or event, the omission of which would not necessarily have prevented the accident.

Table A13 presents the ten most frequently cited pilot in command cause factors, ordered according to a formula which counts fatal accidents ten times heavier than non-fatal ones, and "causes" twice as heavy as "factors."

The most common cause cited for stall accidents is the following:
"Pilot in command failed to obtain or maintain flying speed." It must be
taken on faith that the NTSB means by this statement that the stall angle
of attack was reached or exceeded, and control over the flight path was
adversely affected. (A severe deceleration from an already-low speed
would cause a downward change in flight path, but it is hard to imagine
this happening unless very effective flaps, spoilers, dive brakes, thrust
reversers, or Beta propellers were deployed, or severe wind shear encountered;
and none of these would necessarily produce the high angle of attack flow
separation which ordinarily defines a stall.) At any rate, the citation
clearly indicates that the pilot is at fault, and this cause is listed in
91% of stall accidents and 76% of mush accidents for the Group 32 airplanes.

TOR 5% TABLE A13. PERCENT OF ACCIDENTS IN WHICH PILOT IN COMMAND IS CITED AS A CAUSE/FACTOR GROUP #32 1965 - 1973 FIRST ACCIDENT TYPE:

	STALL		MUSH	
CAUSE/FACTOR DESCRIPTION:	CAUSE	FACTOR	CAUSE	FACTO
ALL PILOT IN COMMAND:	98.8%	14.3%	98.5%	11.5%
Failed to obtain or maintain flying speed:	91.0%	0	76.0%	0
Inadequate preflight preparation and/or planning:	6.5%	2.6%	14.6%	2.3%
Exercised poor judgement:	4.0%	0.5%	2.8%	0
Improper inflight decisions or planning:	3.2%	0.7%	1.7%	0.1%
Premature liftoff:	3.9%	0	24.2%	0.3%
Diverted attention from operation of aircraft:	5.0%	2.7%	1.3%	0.4%
Physical impairment (includes drinking)	2.6%	0.8%	0.2%	0
Continued VFR flight into adverse weather conditions: 2.9%	s: 2.9%	0.2%	0.5%	0
Improper operation of flight controls:	3.8%	0	2.0%	0.1%
Misused or failed to use flaps:	2.1%	2.6%	4.9%	3.0%

It is noteworthy that over 20% of the mush accidents are associated with premature liftoff.

Causes and factors not assigned to the pilot in command are shown in Table A14, ordered according to the same rules used in constructing the previous table. The first block summarizes weather cause/factors. In a previous section it was pointed out that stall and mush accidents are typically fair weather events, and in fact Table A14 indicates that weather is a cause in less than 5% of the cases and a factor in less than 25%. Most often cited is high density altitude, which is listed under weather in the NTSB coding system: low ceiling, icing, and fog are cited in fewer than 3% of the accidents.

The second block of Table A14 lists miscellaneous factors, some of them clearly associated with some other citation directed to the pilot in command (such as "exercised poor judgment"). The list is headed by "unwarranted low flying," which is consistent with the "buzzing" and "low pass" items discussed earlier in connection with accident distributions. High obstructions are considered a cause or factor in about 5% of the cases; this is coded only when obstruction is considered to be of more than normal height, and the airplane stalled or mushed during an attempt to avoid the obstacle.

The cause/factor labeled "airframe came to rest in water" implies that the machine ended up in the water after the accident and that this was significant to the damage or injuries sustained.

RESULTS FOR INDIVIDUAL AIRCRAFT

Background. In this section the stall-related accident rates for the 31 individual aircraft compromising Group 32 are presented and discussed. Appendix C gives a full description of the makes and models included; for brevity, the "short names" of Appendix C will be used to refer to individual aircraft (for example, "ERCOUPE" will mean Group 2: Ercoupe 415, Forney F-1, Alon A2, and Mooney M10).

The objective here is to determine how the accident patterns for individual makes and models compare with the patterns for the 31 aircraft as a group. Statistical tests are applied to determine whether the observed differences and the sample size are sufficiently large to justify a statement that the pattern is significant. The statistical test most often used is the "Chi-square" test. This permits one to state that the observed differences in accidents (rates or percentages) could have occurred by chance with a probability which is lower than a selected value. Two measures are used here, one based on a probability of 5% or less, and another more stringent test based on 0.1%. The tested accident patterns are "flagged" as follows:

Flag	Accident Rate Compared to Group	Probability of Chance Result
H L	HIGH LOW	5% or less
VH VL	VERY HIGH VERY LOW	0.1% or less

TABLE A14. CAUSE/FACTOR (OTHER THAN PILOT IN COMMAND) CITATIONS GROUP #32 1965 - 1973

		FIRST ACCIDENT TYPE	ENT TYPE	
CAUSE/FACTOR DESCRIPTION:	CAUSE	STALL FACTOR	CAUSE	MUSH FACTOR
WEATHER:	2.8%	19.2%	4.1%	24.3%
High density altitude:	0.2%	7.5%	1.6%	12.4%
Downdrafts, updrafts:	0.7%	2.9%	0.7%	4.4%
Unfavorable wind conditions:	1.0%	4.1%	1.3%	4.7%
Low ceiling:	0	2.9%	0.1%	0.3%
Icing conditions:	0.8%	1.0%	0.2%	0.5%
Fog:	0.1%	2.1%	0.1%	0.4%
MISCELLANEOUS CAUSE/FACTORS:				
Unwarranted low flying:	7.9%	6.1%	0.7%	0.5%
Alcoholic impairment of efficiency and judgment:	2.6%	0.4%	0.2%	0
Improperly loaded aircraft (weight and balance):	0.9%	2.2%	2.3%	2.9%
Flew into a blind canyon:	1.9%	1.3%	0.7%	0.3%
High obstructions (towers, hills, trees, etc.)	0.5%	5.1%	1.3%	5.6%
Airframe came to rest in water:	0	5.7%	0	2.7%
Airframe ice:	1.5%	%6.0	2.5%	1.0%
Poorly planned approach:	0.5%	2.8%	0.1%	0.4%
Evasive maneuver (such as collision avoidance)	2.4%	1.3%	96.0	0.5%

Accident Statistics for 31 Aircraft. Accident count and rate data for the 31 individual aircraft groups are presented in Table A15, with crop control hours and accidents excluded. The accident rates shown are per 100,000 flight hours. A comparison is made relative to the 31 aircraft

TABLE A15. TOTAL ACCIDENT STATISTICS FOR 31 SINGLE-ENGINE AIRCRAFT (1965 - 1973)

CD	CHOPE	TOTAL		HOURS	TOTAL			ATIV		
GR.	SHORT	ACCIDENT		5	ACCID.		GR.#3		CHI-SQUA	RE
#	NAME:	FATAL	ALL	X 10 ³	FATAL	ALL	FAT	AL	ALL	
1	AERON.11		162	3.595	5.01	45.06	+98%	Н	+112%	
2	ERCOUPE	49 5	505	13.727	3.57	36.79	+41%	Н	+73%	
3	YANKEE	35	194	6.060	5.78	32.02	+128%	VH	+50%	VH
4	B-23		789	25.505	2.47	30.94	-2%		+45%	VH
5	BONANZA		840	105.359	3.25	17.46	+28%	VH	-18%	
6	BELLANCA	27	216	6.517	4.14	33.14	+64%	Н	+56%	VH
7	CITABRIA	162 13	293	35.386	4.58	36.54	+81%	VH	+72%	VH
8	C-140	61 9	991	24.944	2.45	39.73	-3%		+87%	VH
9	C-150	387 42	290	284.885	1.36	15.06	-46%	VL	-29%	VL
10	C-170	64	712	21.541	2.97	33.05	+17%		+55%	
11	C-172	343 2	723	192.896	1.78	14.12	- 30%	VL	-34%	VL
12	C-175	36	261	12.884	2.79	20.26	+10%		-5%	
13	C-180	68	853	31.933	2.13	26.71	-16%		+25%	VH
14	C-182	214 18	872	104.616	2.05	17.89	-19%	L	-16%	VL
15	C-185	20	196	9.359	2.14	20.94	-15%		-2%	
16	C-206	33	319	21.948	1.50	14.53	-41%	L	-32%	VL
17	C-210	102	755	32.960	3.09	22.91	+22%	Н	*8%	
18	C-177	48	478	14.852	3.23	32.18	+28%		+51%	VH
19	MOONEY	193 1	185	56.566	3.41	20.95	+35%	VH	-2%	
20	NAVION	63	304	10.094	6.24	30.12	+147%	VH	+41%	VH
21	CUB	96 (535	19.051	5.04	33.33	+99%	VH	+56%	VH
22	PA-12	21 2	296	9.171	2.29	32.28	-9%		+52%	VH
23	PA-18	119	751	26.694	4.46	28.13	+76%	VH	+32%	VH
24	TRIPACER	160 16	587	55.552	2.88	30.37	+12%		+43%	VH
25	COMANCHE	200 13	398	49.117	4.07	28.46	+61%	VH	+34%	VH
26	CHEROKEE	459 36	674	204.634	2.24	17.95	-11%	L	-16%	
27	CHER-6	65	401	23.886	2.72	16.79	+8%		-21%	
28	LUSCOMBE	59	731	11.088	5.32	65.93	+110%	VH	+210%	VH
29	TAYLORCR	51	339	8.404	6.07	40.34	+140%	VH	+89%	VH
30	SWIFT	33 2	255	3.280	10.06	77.74	+298%	VH	+265%	VH
31	STINSON	48 9	501	10.069	4.77	49.76	+89%	VH	+134%	
32	GR.#32	3639 306	506 1	436.573	2.53	21.30	0		0	

taken as a group (Group 32, at the bottom of the table); this is shown as a percentage difference between the rate for a given aircraft make and that for Group 32. For example, the first airplane listed, "AERON 11," has a fatal accident rate of 5.01 and this is larger than that for Group 32 by 98%. The Chi-square test is applied to the difference, and in this example is found to satisfy the 5% test; hence the "H" flag is appended to the 98%.

shown in the second column from the right. To continue the example, the count of ALL (fatal plus non-fatal) accidents for the AERON. 11 is 162. The resulting rate is 45.06, more than double that of the comparison group, and explained by chance with a probability of 0.1% or less (VH flag).

In reviewing these results it is noteworthy that there are large observed differences in accident rates, and a high incidence of Chi-square test flags. The latter reflects the very large data base. There are more VERY HIGH flags than VERY LOW flags, which arises from the fact that several very popular airplanes have lower than average accident rates. The lowest fatal accident rate is attained by the Cessna 150, which also flew more hours than any other airplane in the nine years of the study. In Table A16, stall-related accidents for the 31 aircraft have been

TABLE A16. STALL, SPIN, SPIRAL, MUSH ACCIDENTS FOR 31 SINGLE-ENGINE AIRCRAFT (1965-1973) ACCIDENT COUNT (EITHER FIRST OR SECOND ACCIDENT TYPE):

		(2		or on or	COMP MGC	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	.,.		
GR.	SHORT	STA		SPI		SPII		MUS	
#	NAME	FATAL	ALL	FATAL	ALL	FATAL	ALL	FATAL	ALL
1	AERON.11	6	20	10	18	0	1	0	9
2	ERCOUPE	6	24	0	1	2	3	•0	19
3	YANKEE	11	23	14	18	0	0	0	13
4	B-23	14	33	4	5	0	0	1	50
5	BONANZA	39	64	33	36	7	9	3	71
6	BELLANCA	2	5	0	1	0	0	0	3
7	CITABRIA	40	131	61	85	0	6	4	65
8	C-140	13	45	14	21	1	4	0	41
9	C-150	73	263	83	101	7	20	2	164
10	C-170	9	35	12	15	3	3	0	45
11	C-172	37	120	10	16	2	4	7	120
12	C-175	1	8	5	5	0	0	0	16
13	C-180	5	21	1	2	1	2	1	26
14	C-182	13	31	5	10	1	2	0	32
15	C-185	2	4	0	0	0	0	0	5
16	C-206	5	5	1	2	0	0	1	10
17	C-210	4	7	4	5	1	2	1	7
18	C-177	8	35	4	4	0	1	6	53
19	MOONEY	26	46	15	17	4	4	4	45
20	NAVION	6	13	2	2	0	1	2	14
21	CUB	28	101	38	57	0	2	1	57
22	PA-12	2	16	4	6	0	2	0	15
23	PA-18	38	92	25	36	1	8	2	46
24	TRIPACER	19	43	8	15	2	6	3	54
25	COMANCHE	11	19	14	15	1	2	4	47
26	CHEROKEE	39	111	12	19	8	13	13	159
27	CHER-6	5	9	4	4	0	0	1	16
28	LUSCOMBE	16	44	15	30	1	11	0	28
29	TAYORCR	9	35	26	43	0	3	1	29
30	SWIFT	8	21	3	4	0	1	2	29
31	STINSON	5	29	1	4	0	1	0	18
32	GR.#32	500	1453	428	597	42	111	59	1306

extracted from the overall accident count. The AERON. 11, for example, had 20 stall accidents, 6 of them fatal. This may be compared with the total of 18 fatal accidents listed in Table A15. The airplane also had 10 fatal spin accidents, and thus 16 out of a total of 18 fatal accidents were due to stall or spin.

For purposes of comparison, two different measures were formed from the data in the tables above. One involved computing accident rates; the other percentages of TOTAL accidents accounted for by a particular accident type. (Rate data alone could be misleading if the airplane has an unusual usage pattern; percentage data alone might also mislead if, for example, an airplane had few accidents but they were all of one type.) Using the AERON. 11 as an example again, the tables show a total of 29 stall and mush accidents (as either first or second type) for a rate of 8.07; this may be compared with a similarly-obtained rate of 1.92 for comparison Group 32. Considering the second approach, the percentage of total AERON. 11 accidents (162) accounted for by stall or mush accidents (29) is 17.9%.

Using the two approaches above, measures for stall and mush accidents were formed for the 31 airplanes which were then ranked accordingly, as shown in Table A17. Two rankings are given, both of which weigh fatal accidents more heavily than non-fatal ones. RANK 1 is based on accident rates, according to the sum 10 x (Fatal Stall and Mush Accident Rate) + (Stall and Mush Accident Rate); RANK 2 is based on the percentage of TOTAL accidents represented by stall and mush, according to 10 x (Fatal Stall and Mush as a Percentage of TOTAL accidents) + (All Stall and Mush Accidents as a Percentage of TOTAL accidents). In both cases the individual rates and percentages are compared with Group 32 and tested with a Chi-square technique.

The airplane with the best stall/mush safety record, according to RANK 1 is the Cessna 182, and its accident rates are Chi-square VERY LOW with respect to the comparison group. The 182 is ranked number 3 according to the other system, which finds the Cessna 175 on top; however, this airplane had insufficient exposure to activate the Chi-square flags.

The two ranking systems in Table A17 show a rather high degree of correlation, the top three and bottom nine (with one exception, the Taylorcraft) airplanes being the same in each case, although in different order. Most of the airplanes near the bottom are older designs, dating in some cases back to the 1940's and before; exceptions are the Beech 23, Cessna 177, and Grumman American Yankee, all of them of relatively recent design.

Figure AlO is a graphical presentation of the accident data, showing fatal stall and mush accidents as a percentage of TOTAL accidents versus the fatal accident rate for each aircraft. The results for the summary group (Group 32) are shown by dashed lines; thus an airplane plotted in the upper right-hand quadrant has both a total fatal accident rate and a percentage of fatal stall/mush accidents higher than the group mean.

A third approach may be taken which considers the sample size in addition to the accident rate in ranking the aircraft. In this case, the Chi-square test itself is used, and the more populous airplanes will tend to migrate to the top or bottom of the list because their results have the benefit of a larger data sample.

TABLE A17. TWO STALL/MUSH RANKING SYSTEMS FOR 31 SINGLE-ENGINE AIRCRAFT (1965 - 1973)

(10 x FATAL Rate + ALL Rate) (10 x FATAL % + ALL %)

RANK 1: Ranked according to RANK 2: RUanked according to

EITHER STALL OR MUSH AS FIRST OR SECOND ACCIDENT TYPES: ACCIDENT RATES: % OF TOTAL: GR. SHORT RANK1 # NAME FATAL ALL FATAL RANK2 ALL 14 C-182 0.12 VL 0.60 VL 6.1% VL 1 3.4% VL 17 C-210 0.15 VL 0.43 VL 4.9% L 2 1.9% VL 2 12 C-175 0.08 VL 1.86 VL 2.8% 9.2% 3 1 15 C-185 0.21 L 0.96 VL 10.0% 4 4.6% L 1.47 VL 5 13 C-180 0.19 8.8% 5.5% 6 6 16 C-206 0.27 0.68 18.2% 4.7% 19 7 C-172 0.23 1.24 12.8% 11 0.23 8.8% 15 8 27 CHER-6 1.05 9.2% 6.2% 7 CHEROKEE 0.25 9 1.32 26 11.3% L 7.3% VL 11 19.4% 9 C-150 0.26 1.50 10 10.0% 20 H BELLANCA 0.31 1.23 VL 7.4% 11 3.7% L 4 1.34 COMANCHE 0.31 12 25 L 7.5% 4.7% VL 5 5 BONANZA 0.40 1.28 H 12.3% 7.3% 13 L 12 22 0.22 3.38 14 PA-12 9.5% 10.5% 9 15 24 TRIPACER 0.40 1.75 13.8% 5.7% VL 16 19 MOONEY 0.53 1.61 VL 15.5% 16 7.7% 18 3.13 VH 12.2% 17 2 ERCOUPE 0.44 8.5% 13 18 10 C-170 0.42 3.71 H 14.1% 11.2% H 17 3.45 VH 21.3% 0.52 19 8 C-140 8.7% 22 20 B-23 0.59 3.25 VH 23.8% 4 10.5% 23 21 31 STINSON 0.50 4.67 VH 10.4% 9.4% 10 NAVION 0.79 H 2.68 22 20 12.7% 8.9% 14 23 18 C-177 0.94 VH 5.93 VH 29.2% H 18.4% VH 24 7 CITABRIA 1.24 VH 5.54 VH 27.2% VH 15.2% VH TAYLORCR 1.19 VH 25 29 7.62 VH 19.6% 18.9% VH 21 26 23 PA-18 1.50 VH 5.17 VH 33.6% VH 18.4% VH 31 LUSCOBME 27 28 1.44 VH 6.49 VH 27.1% 9.8% 24 H 28 21 CUB 1.52 VH 8.29 VH 30.2% 24.9% VH VH 29 3 YANKEE 1.82 VH 5.94 VH 31.4% 18.6% VH 29 H 30 1 AERON.11 1.67 VH 8.07 VH 33.3% H 17.9% VH 30 31 30 SWIFT 3.05 VH 15.24 VH 30.3% H 19.6% VH GR.#32 0.389 32 1.92 15.36% 9.02%

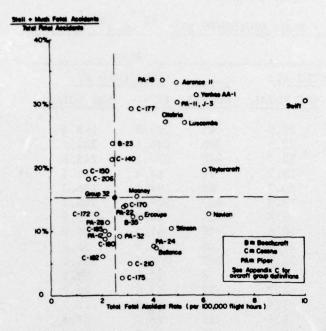


Figure A10. Fatal Stall and Mush Accident Percentage versus Total Fatal Accident Rate for Group 32 Airplanes.

A ranking based on the Chi-square test for both accident rate and percentage of TOTAL is presented in Table A18. The aircraft are ordered according to the sum of the (signed) Chi-square values calculated for both rate and percentage for fatal accidents only. If the examples are selected from near the top or bottom of the list, one may be confident that a relatively "good" case is not really a relatively "bad" one and vice-versa.

Also presented in Table A18 is the actual number of stall plus mush accidents for the period, to be compared in the next two columns with the number of accidents which would be predicted on the basis of the summary group (32) rate and percentage. For example, the Cessna 182 had 13 fatal accidents, whereas if it had the same rate or percentage of TOTAL accidents as the Group 32 mean, the number would have been 40.7 or 32.9, respectively. The Piper PA-18, on the other hand, had more than twice the number of fatal stall/mush accidents than would have been predicted according to the Group 32 mean.

In Figure All the Chi-square value calculated on the basis of the stall/much fatal accident rate, and the accident rate itself, are shown for each airplane. The dashed vertical line represents the mean rate for Group 32, while the horizontal lines labeled 0.1% and 0.5% mark the cut-off points for the two Chi-square tests (3.841 and 10.827). For several of the high accident rate airplanes the Chi-square value is so high that it is extremely unlikely that the observed differences occurred by chance.

TABLE A18. 31 SINGLE-ENGINE AIRCRAFT RANKED BY CHI-SQUARE TEST FOR STALL + MUSH ACCIDENTS

NUMBER OF STALL + MUSH ACCIDENTS (AS 1st OR 2nd TYPE)

			F	ATAL:			ALI	L:
	GR.	SHORT	ACTUAL	PREDI	CTED BY:	ACTUAL	PREDIC	CTED BY:
RANK3	#	NAME	NUMBER	RATE	%OF TOTAL	NUMBER	RATE	%OF TOTAL
1	14	C-182	13	40.7	32.9	63	201.0	168.8
2	26	CHEROKEE	52	79.6	70.5	270	393.1	331.2
3	11	C-172	44	75.1	52.7	240	370.6	245.5
4	17	C-210	5	12.8	15.7	14	63.3	68.1
5	25	COMANCHE	15	19.1	30.7	66	94.4	126.0
6	9	C-150	75	110.8	59.4	427	547.3	386.7
7	12	C-175	1	5.0	5.5	24	24.8	23.5
8	13	C-180	6	12.4		47	61.3	76.9
9	27	CHER-6	6	9.3		25	45.9	36.2
10	5	BONANZA	42	41.0	52.5	135	202.4	165.9
11	6	BELLANCA	2	2.5	4.1	8	12.5	19.5
12	22	PA-12	2	3.6	3.2	31	17.6	26.7
13	15	C-185	2	3.6	3.1	9	18.0	17.7
14	16	C-206	6	8.5	5.1	15	42.2	28.8
15	31	STINSON	5	3.9	7.4	47	19.3	45.2
16	24	TRIPACER	22	21.6	24.6	97	106.7	152.1
17	2	ERCOUPE	6	5.3	7.5	43	26.4	45.5
18	10	C-170	9	8.4	9.8	80	41.4	64.2
19	8	C-140	13	9.7	9.4	86	47.9	89.3
20	19	MOONEY	30	22.0	29.6	91	108.7	106.8
21	20	NAVION	8	3.9	9.7	27	19.4	27.4
22	4	B-23	15	9.9	9.7	83	49.0	71.1
23	29	TAYLORCR	10	3.3	7.8	64	16.1	30.6
24	18	C-177	14	5.8	7.4	88	28.5	43.1
25	1	AERON.11	6	1.4	2.8	29	6.9	14.6
26	28	LUSCOMBE	16	4.3	9.1	72	21.3	65.9
27	3	YANKEE	11	2.4	5.4	36	11.6	17.5
28	30	SWIFT	10	1.3	5.1	50	6.3	23.0
29	21	CUB	29	7.4	14.7	158	36.6	57.3
30	7	CITABRIA	44	13.8	24.9	196	68.0	116.6
31	23	PA-18	40	10.4	18.3	138	51.3	67.7
3	2	GR.#32	559	559	559	2759	2759	2759

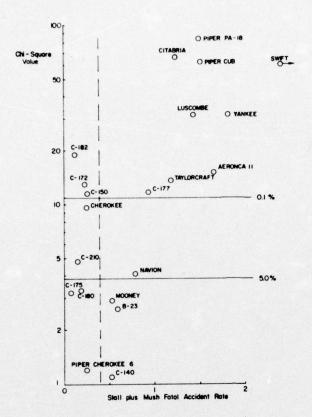


Figure All. Chi-square Test Value versus Stall plus Mush Fatal Accident Rate for Group 32 Airplanes.

REFERENCES - APPENDIX A

- A1. Silver, B. W., Statistical Analysis of General Aviation Stall Spin Accidents, SAE Paper 760480, April 1976.
- A2. Special Study General Aviation Stall/Spin Accidents 1967-1969, NTSB Report AAS-72-8, September 1972.
- A3. "General Aviation Activity Survey, 1972," Federal Aviation Administration, July 1974.

APPENDIX B

TYPES OF ACCIDENTS

The purpose of the appendix is to give a short description of the

NTSB method of defining accident types.

The phrase "accident type" refers to what happened. Examples are "groundloop," "stall," and "undershoot." There may be up to two accident types assigned for each accident. The two accident types, when used, are sequential in time. For example, the first type might be "engine failure or malfunction," followed by a second type, "stall." This would mean that the pilot had trouble with his engine and subsequently stalled the aircraft (perhaps in a forced landing attempt).

There are 59 different codes which the NTSB has defined for accident types. Only the stall-related are of primary interest in this report. The following accident type descriptions are abstracted in part from NTSB

coding manuals.

STALL: Stall occurs when the wing angle of attack is too great to maintain smooth air flow. An accident occurs if the pilot does not "recover" before striking the ground. That event is counted in this accident type. A second accident type is not required; the collision with the ground is implicit. During the landing phase, a stall which results in a hard landing is coded as a "hard landing" rather than a "stall." Examples of occurrence: stalled while attempting to clear an obstruction; pull-up from a low pass; stalled from steep turn after buzzing friend's house; stalled during turn to final approach.

MUSH: The mush is a form of near-stall in which the airplane staggers along at a high angle of attack, generally on the back side of the power required curve. For most lightplanes with their modest or high power loadings, only a reduction in the angle of attack will allow acceleration out of this condition. Low altitude or obstacles may discourage this choice. This accident is generally (70%) a takeoff accident. Since it occurs at low speed and low altitude, it is seldom fatal, but it does cause substantial damage to the aircraft. Most mush accidents (99%) are blamed on the pilot. The accident is more likely with short fields and high density altitude. Examples of occurrence: takeoff in overloaded aircraft, especially uphill or downwind; pilot unable to climb with full flaps after an aborted landing; pilot attempted to climb in the lee of a mountain ridge.

SPIN: A spin is a self-propelling rotary motion ("autorotation") superimposed on a stall. In light aircraft, each turn of a spin typically takes only a few seconds and results in the loss of many hundred feet of altitude. The large sink rate of the spin makes this accident fatal in approximately 70% of the cases. Most spins (about two-thirds) occur in the in-flight phase of flight and are often associated with aerobatics, buzzing, or low flight. Fewer than 20% occur in each of takeoff and landing phases.

SPIRAL: The spiral is a tight turn superimposed on a dive. It is often associated with loss of horizontal reference. In appearance similar to the spin, the two differ in that the spiral does not involve significant

aerodynamic stall. Nevertheless, it is often included in stall-related accidents because it may be difficult to differentiate between the spin and the spiral after an accident has occurred. The distinction will generally be that the spin has almost no net forward motion at impact, while the spiral does have forward motion. The spiral is fatal in approximately 37% of such accidents. This number of fatal spirals is less than one-tenth of the number of fatal spins, thus no great statistical error is made in combining these two accident types.

When a stall-related accident is listed as a second type, it is often preceded by an "engine failure or malfunction" as a first type. This

accident type is described here:

ENGINE FAILURE OR MALFUNCTION: An engine failure of itself is not considered an accident; it must be followed by a second accident type. Undoubtably many engine failures occur which never show up as accidents. Those which do add up to about 17% of general aviation accidents. Most engine failures are also blamed on the pilot. Among the most common errors: fuel starvation (selected the wrong tank), fuel exhaustion (ran out of gas), and improper use of carburator heat. Actual mechanical failure occurs only in about 40% of engine failures reported by the NTSB. The phrase "TRUE ENGINE FAILURE" is used to denote engine failures which were caused by actual failure of some part of the powerplant (rather than pilot error).

In this report the use of the word TOTAL in capital letters always refers to the total of all accident types, whether stall-related or not. There are two categories under TOTAL and these are FATAL (fatal accidents

only) and ALL (fatal plus nonfatal accidents).

APPENDIX C

		AIRCRAFT GROUPS			(1973) NUMBER
GR.	SHORT NAME	MANUFACTURER NAME AND MODEL	FAA CODE:	NTSB CODE:	OF ACTIVE AIRCRAFT
1	AERON.11	Aeronca 11	19-11	3-8,3-10	665
2	ERCOUPE	Ercoupe 415, Forney F-1, Alon A2, Mooney M10	42-1,-2,-3,-4, -5,-7;54-1; 587-20	63-1,-2	1968
3	YANKEE	Grumman American AA-1 (Excludes AA-5)	63-6,-7,-8, -12,-20	56-3	887
4	B-23	Beech 23, 19, 24 ("Musketeer", etc.)	115-12	22-25	1739
5	BONANZA	Beech 33, 35, 36 ("Bonanza", Debonair")	115-14,-15,-16	22-19,-20	8071
6	BELLANCA	Bellanca 14-19, 17-30, 17-31	*122-4; 308-1; 458-8	56-1,-4	1015
7	CITABRIA	Champion, Aeronca, Bellanca Model 7	*122-4,-5,-6 -7; 211-1	3-12	3974
8	C-140	Cessna 120, 140, 140A	207-14,-16	39-10,-11	3017
9	C-150	Cessna 150	207-18	39-12	12915
10	C-170	Cessna 170	207-23	39-13	2541
11	C-172	Cessna 172	207-24	39-14	13927
12	C-175	Cessna 175, P172D	207-25,-22	39-15	1544
13	C-180	Cessna 180	207-26	39-16	2315
14	C-182	Cessna 182	207-27,-58	39-17	8342
15	C-185	Cessna 185	207-28	39-26	621
16	C-206	Cessna 206	207-33	39-29	1431
17	C-210	Cessna 210, 205	207-34,-32	39-19	2775
18	C-177	Cessna 177 "Cardinal" (Exclude 177RG)	**207-37	39-33	1431
19	MOONEY	Mooney M20 ("Mark 21",etc.)	587-2,-3	101-2,-3	4181
20	NAVION	Navion	615-1	107-1	1204
21	CUB	Piper J-3, L-4, PA-11	710-5,-11	124-4,-5,-6, -7,-8	2766
22	PA-12	Piper PA-12 ("Super Cruiser")	710-12	124-15	1077
23	PA-18	Piper PA-18, L-21, PA-19, ("Super Cub")	710-18,-19	124-20,-21	2417

^{*}FAA Code 122-4 must be further subdivided between BELLANCA and CITABRIA by name of model.
**Exclude Cessna 177RG (retractable gear) from FAA Code 207-37.

APPENDIX C (Continued)

GR.	SHORT NAME	MANUFACTURER NAME AND MODEL	FAA CODE:	NTSB CODE:	(1973) NUMBER OF ACTIVE AIRCRAFT
24	TRIPACER	Piper PA-22 ("Tripacer", "Colt")	710-22	124-23	4733
25	COMANCHE	Piper PA-24 ("Comanche")	710-24	124-25	3449
26	CHEROKEE	Piper PA-28 ("Cherokee")	710-28	124-28	14180
27	CHER-6	Piper PA-32 ("Cherokee Six")	710-32	124-30	1769
28	LUSCOMBE	Luscombe 8 ("Silvaire")	819-1	89-3	1763
29	TAYLORCR	Taylorcraft B, L-2	885-3; 923-9	157-5,-6,-7	1355
30	SWIFT	Globe GC-1 ("Swift")	923-1	162-1	538
31	STINSON	Stinson 108	923-4	162-2	1746
32	GR.#32	All aircraft GR.#1 through GR.#31 (NO crop control)	all above	all above	110366
33	GR.#33	Crop control accidents only for Group 32 aircraft	all above	all above	(110366)
34	GR.#34	All general aviation, fixed- wing, single- or twin-engine aircraft			
35	GR.#35	All general aviation, fixed- wing, signle-engine aircraft			
36	GR.#36	All general aviation, fixed- wing, twin-engine aircraft			

APPENDIX D

SUMMARY OF STALL BEHAVIOR

I. CESSNA 150L N19020

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C.G. - nose bob, nose slice back and forth, repeated pitch breaks if wheel held back; roll control good with ailerons, left roll off if deceleration fast Forward C. G. - no break; roll control with ailerons good but with rudder poor

2. POWER OFF, FLAPS DOWN

Aft C. G. - no roll off, oscillates if wheel held full back; can hold wings level with vigorous aileron movement Forward C. G. - no break

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - roll off either direction, nose slice, not confident about picking up wing
Forward C. G. - left roll off first time, right roll off second time

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off; if wheel immediately put forward can control roll
Forward C. G. - left roll off, nose oscillation

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - no roll off
Forward C. G. - no roll off, pitch oscillation in left turn,
slight break at top; more pronounced in right turn but no
full stall, roll control positive; left roll off in right
turn when deceleration fast

2. POWER OFF, FLAPS DOWN

Aft C. G. - no roll off Forward C. G. - no roll off, pitch oscillation (nose drops 10° back up to 0°); roll control positive

3. POWER MAXIMUM, FLAPS 00

Aft C. G. - right roll off in both left and right turn Forward C. G. - tendency for right roll off in left turn, left roll off in right turn; roll control OK

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - right roll off in left turn, left roll of in right turn

Forward C. G. - right roll off in left turn, left roll off in right turn; roll control good, can hold in stall

I. CESSNA 150L (continued)

C. WINGS LEVEL, NO RUDDER USED

1. POWER OFF, FLAPS 00

Aft C. G. - no roll off, lots of yaw, can hold wings level Forward C. G. - no roll, ball centered, good control

2. POWER OFF, FLAPS DOWN

Aft C. G. - no roll off initially but if trying to stop yaw with aileron can cause left roll off
Forward C. G. - no roll off, can't completely stall

3. POWER MAXIMUM, FLAPS 00

Aft C. G. - left roll off; can prevent roll off only if wheel back pressure released or not increased Forward C. G. - left roll off, ball 3/4 right

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off; cannot hold even when back pressure released immediately and wheel pushed forward Forward C. G. - left roll, spin entry to left; can hold with aileron only to beginning of warning horn.

II. CESSNA 182 N7374Q

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 00

Aft C. G. - roll control good, no pitch break from slow decel. Forward C. G. - no break, nose bob, roll control good

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob, roll control adequate Forward C. G. - nose bob, roll control OK

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - roll control good, no pitch break from slow decel. Forward C. G. - roll control good, no pitch break from slow decel.

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - roll control acceptable
Forward C. G. - roll control good, no pitch break from slow decel.

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - rolls right in left turn, rolls right and nose bob in right turn; no uncontrollable tendencies Forward C. G. - no break, tends to roll right; but controllable

II. CESSNA 182 (continued)

B. TWENTY DEGREE BANK, BALL CENTERED (continued)

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob and no roll off in left turn, right roll off in right turn; rocking chair motion
Forward C. G. - nose bob, tends to roll right, controllable

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - tends to roll right, roll control good, attitude very high
Forward C. G. - rolls right from left and right turns; controllable

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - not much roll tendency, lots of buffet but no pitch problem

Forward C. G. - no pitch break, roll controllable with aileron

C. WINGS LEVEL, NO RUDDER USED

1. POWER OFF, FLAPS 0°

Aft C. G. - slight right roll, rocking chair motion; can hold wings level (±5°); can track heading (±15°)
Forward C. G. - no break, slight nose bob; can hold wings level, can track heading

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob, rocking chair motion; bank angle controllable, can track heading (±15°)
Forward C. G. - nose bob, then breaks down 10°; some nose slice, can hold wings level, can track heading (±10°)

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - ball moves 1 right but airplane rolls right; can hold wings level with full left aileron but yaws right Forward C. G. - no bad roll off, can hold wings level (±15°), heading control poor; controls too heavy to hold long with one hand; ball moves 1/2 to 3/4 right

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - rolls right, can hold with aileron Forward C. G. - no bad roll off, cannot hold heading to ±30°; elevator very heavy, ball moves 1/2 right

III. CESSNA 177 N124KA

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - roll control good except right at break when cannot hold wings level (±10°); nose oscillates in pitch (∿10°) Forward C. G. - nose bob, wing drops either way, can hold with rudder

III. CESSNA 177 (continued)

A. WINGS LEVEL, BALL CENTERED (continued)

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob Forward C. G. - nose bob; roll control good

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - can catch right roll at break; further into stall right roll off, coordinated aileron and rudder needed to hold wings level
Forward C. G. - roll control good

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off, cannot stop with rudder or aileron Forward C. G. - roll off, roll control fair to good

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - wing rock, nose pitches down, can hold bank with coordinated rudder and aileron
Forward C. G. - tendency for right roll off in left turn, left roll off in right turn; roll control good with ailerons

2. POWER OFF, FLAPS DOWN

Aft C. G. - pitch oscillation, not controllable, can keep upright or in bank but sloppy
Forward C. G. - gentle nose oscillation (±150), no roll off, roll control good

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - right roll off in right turn, cannot hold with ailerons

Forward C. G. - right roll off, can hold with ailerons

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off, can hold with aileron if back pressure relaxed slightly

Forward C. G. - yaw and gentle left roll in left turn, left roll to level in right turn; right roll in left turn if accelerated

C. WINGS LEVEL, NO RUDDER USED

1. POWER OFF, FLAPS 00

Aft C. G. - pitch break; not much roll, can hold wings level but cannot track heading (±30°)

Forward C. G. - left roll off, controllable with ailerons; nose holds position; can hold wings level but sloppy (±5°), can track heading but sloppy (±10-15°)

III. CESSNA 177 (continued)

C. WINGS LEVEL, NO RUDDER USED (continued)

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose oscillation, can hold wings level with fairly vigorous aileron movement; lost it in left departure trying to hold heading

Forward C. G. - nose oscillation $(\pm 5^{\circ})$, slightly right roll, can catch with aileron, can hold wings level, tracking heading poor $(\pm 15^{\circ})$

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - tendency for left departure, can catch roll with full right aileron if no further back pressure used; ball moves 2 right

Forward C. G. - rolls left, can catch with ailerons but control over bank and heading gross; ball moves full right side

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left departure, cannot hold with ailerons Forward C. G. - left departure, ball moves 1-1/2 right

IV. CITABRIA 150 N87108

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF

Aft C. G. - roll control OK if coordinated, aileron alone not good

Forward C. G. - ailerons effective to just above stall; increasing back pressure hold nose in position; roll off either direction, aileron alone will not hold it, coordinated controls will

2. POWER MAXIMUM

Aft C. G. - roll control OK if coordinated
Forward C. G. - nose drop; right wing drop; cannot hold with
left aileron unless back pressure relaxed slightly

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF

Aft C. G. - at one trim speed rolls wings level, at another trim speed rolls off left in right turn; rolls off right in left turn, roll control poor, need rudder

Forward C. G. - no roll at break, then right roll in left turn; no roll at break then left roll and wing rock in right turn

2. POWER MAXIMUM

Aft C. G. - at one trim speed rolls back to wings level in left turn, rolls left unless back stick released in right turn; at another trim speed rolls right in left turn, rolls left in right turn, roll control poor

Forward C. G. - small bank excursions can be held with aileron; if coordinated controls used not much happens

IV. CITABRIA 150 (continued)

C. WINGS LEVEL, NO RUDDER NEEDED

1. POWER OFF

Aft C. G. - rolls right, nose pitches immediately after, can hold wings level for a bit but big aileron inputs cause yaw; can track heading but will eventually roll off right; ball moves 1/2 right

Forward C. G. - right roll off, if held just at break then can control roll with aileron for a while; ball moves 3/4 left, left bank needed to track heading

2. POWER MAXIMUM

Aft C. G. - left roll off, nose drop, plenty of stick left at break; hangs on surprisingly well but could get violent departure easily

Forward C. G. - rolls left, cannot hold with rudder, ball moves 1/2 right; 5° right bank to track heading

V. GRUMMAN AMERICAN AA-1 YANKEE N5738L

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - nose bob, adequate roll control Forward C. G. - gentle nose bobs, good roll control

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob, adequate roll control Forward C. G. - nose bob, adequate roll control

3. POWER MAXIMUM, FLAPS 00

Aft C. G. - wing rock; roll control good if coordinated Forward C. G. - some nose bob, good roll control

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - nose bob, wing rock, control good Forward C. G. - nose bob, good roll control

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - sharp left roll and pitch down in left turn, caught with rudder

Forward C. G. - wing rock, rapid break left, and pitch down in left turn; little wing rock and left roll in right turn

2. POWER OFF, FLAPS DOWN

Aft C. G. - rolls back level
Forward C. G. - rolls left and then pitches; can aggravate with
aileron and get right roll

V. GRUMMAN AMERICAN AA-1 YANKEE (continued)

B. TWENTY DEGREE BANK, BALL CENTERED (continued)

3. Aft.C. G. - rolls back level; rapid left roll off with fixed controls in right turn; vigorous rudder helpful but cannot hold full back stick
Forward C. G. - rolls left followed by pitch

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - rolls left with fixed controls; can stop roll with rudder but not with aileron alone
Forward C. G. - rolls left, can hold with vigorous right rudder; nose pitches down, can aggravate into right roll

C. WINGS LEVEL, NO RUDDER USED

1. POWER OFF, FLAPS 0°

Aft C. G. - lot of buffet; held wings level and heading with small aileron inputs for a while, then sharp left wing down followed immediately by pitch - very quick
Forward C. G. - yaws and rolls right, pitches down, left roll second time; nose and roll oscillation build in amplitude

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob, hold for a while with small control inputs, then lost it to the left

Forward C. G. - yaws and then rolls right, nose drop (100), cannot hold

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - left nose slice; cannot hold with aileron, ball moves 1/2 right
Forward C. G. - yaws and rolls left; cannot hold with full aileron, will roll violently left; ball moves 1/2 right

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off, cannot hold wings level or heading with aileron

Forward C. G. - rolls and yaws left, cannot hold with aileron; pall moves 1/4 right

VI. GRUMMAN AMERICAN AA-1B TRAINER N8982L

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - right roll off, can hold with rudder

2. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - roll control good, especially if aileron and rudder coordinated

3. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - roll control fair, can control bank with combined aileron and rudder with stick full back

NOTE: Complete series was not carried out with this airplane.

VII. PIPER CHEROKEE 140 N422FL

A. WINGS LEVEL, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - pitch oscillation, roll control poor, need conscious rulder coordination
Forward C. G. - nose oscillation

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose drop, oscillation; wallows - small roll oscillation, roll control adequate
Forward C. G. - gentle nose bob

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - pitch oscillation; roll control adequate Forward C. G. - no break, roll control adequate

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - nose bob starts pronounced pitch oscillations; roll control adequate
Forward C. G. - left wing drop, can hold with aileron

B. TWENTY DEGREE BANK, BALL CENTERED

1. POWER OFF, FLAPS 0°

Aft C. G. - pitch oscillation; no roll, roll control good Forward C. G. - no break, nose bob; little roll oscillation controllable with aileron

2. POWER OFF, FLAPS DOWN

Aft C. G. - nose bob; no roll off in left turn, right roll off in right turn, roll control good

Forward C. G. - nose bob, builds up to sharp break (.3 g). roll control adequate

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - pitch oscillation; no roll off, roll control good Forward C. G. - no break, nose bob; roll control good

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - rolls left in both left and right turn, can level wings with aileron (sometimes difficult); nose bob violent (>50)

Forward C. G. - no break, pitch oscillation; rolls off left in both left and right turn, can hold with aileron

C. WINGS LEVEL, NO RUDDER USED

1. POWER OFF, FLAPS 0°

Aft C. G. - nose bob; wallows in roll, tends to roll right, ball moves 1/4 left; can hold with a lot of left aileron; some nose slice and sloppy performance in tracking heading

VII. PIPER CHEROKEE 140 (continued)

C. WINGS LEVEL, NO RUDDER USED (continued)

1. POWER OFF, FLAPS 0° (continued)

Aft C. G. - requires full left aileron to hold wings level, roll control poor; right roll and nose drop while trying to track heading

Forward C. G. - pitch oscillation; no roll problems, ball stays centered; rolls better right than left and some adverse yaw in tracking heading

2. POWER OFF, FLAPS DOWN

Aft C. G. - small pitch oscillation, can hold heading with aileron

Forward C. G. = pitch oscillation; no roll problems except reluctance to bank left

3. POWER MAXIMUM, FLAPS 0°

Aft C. G. - nose bob; no roll off, can hold heading with aileron, ball moves 1/4 right

Forward C. G. - nose bob; roll control adequate, ball less than 1/4 right, can hold heading with aileron

4. POWER MAXIMUM, FLAPS DOWN

Aft C. G. - left roll off, cannot hold wings level with aileron if back pressure continued; ball 1/3 right Forward C. G. - incipient yaw, left roll, can hold with

aileron, ball 1/3 right

APPENDIX E

STALL-RELATED PORTIONS OF FAR PART 23

23.3 Airplane categories

- (a) The normal category is limited to airplanes intended for nonacrobatic operation. Nonacrobatic operation includes
 - (1) Any manuever incident to normal flying;

(2) Stalls (except whip stalls); and

- (3) Lazy eights, chandelles, and steep turns, in which the angle of bank is not more than 60°.
- (b) The utility category is limited to airplanes intended for limited acrobatic operation. Airplanes certificated in the utility category may be used in any of the operation covered under paragraph (a) of this section and in limited acrobatic operations. Limited acrobatic operation includes
 - (1) Spins (if approved for the particular type of airplane); and
 - (2) Lazy eights, chandelles, and steep turns, in which the angle of bank is more than 60°.
- (c) The acrobatic category is limited to airplanes intended for use without restrictions other than those shown to be necessary as a result of required flight tests.
- (d) Small airplanes may be certificated in more than one category if the requirements of each requested category are met.

23.49 Stalling speed.

- (a) V_S is the stalling speed, if obtainable, or the minimum steady speed, in knots (CAS), at which the airplane is controllable with the -
 - Engines idling, throttles closed (or at not more than the power necessary for zero thrust at a speed not more than 110 percent of the stalling speed);
 - (2) Propellers in the takeoff position;

(3) Landing gear extended;

(4) Wing flaps in the landing position;

(5) Cowl flaps closed;

- (6) Center of gravity in the most unfavorable position within the allowable landing range; and
- (7) Weight used when V_s is being used as a factor to determine compliance with a required performance standard.
- (b) V_{s_0} at maximum weight may not exceed 61 knots for -

(1) Single-engine airplanes; and

(2) Multiengine airplanes of 6,000 pounds or less maximum weight that cannot meet the minimum rate of climb specified in § 23.67(b) with the critical engine inoperative.

- (c) V_s is the calibrated stalling speed, if obtainable, or the minimum steady speed, in knots, at which the airplane is controllable, with the -
 - (1) Engines idling, throttles closed (or at not more than the power necessary for zero thrust at a speed not more than 110 percent of the stalling speed);

(2) Propellers in the takeoff position;

- (3) Airplane in the condition existing in the test in which V is being used; and
- (4) Weight used when V_s is being used as a factor to determine compliance with a required performance standard.
- (d) V_s and V_s must be determined by flight tests, using the procedure specified in § 23.201.

23.143 General.

- (a) The airplane must be safely controllable and maneuverable during -
 - (1) Takeoff;
 - (2) Climb;
 - (3) Level flight;
 - (4) Dive; and
 - (5) Landing (power on and power off) with the wing flaps extended and retracted.
- (b) It must be possible to make a smooth transition from one flight condition to another (including turns and slips) without exceptional piloting skill, alertness, or strength, and without danger of exceeding the limit load factor, under any probable operating condition (including, for multiengine airplanes, those conditions normally encountered in the sudden failure of any engine).
- (c) If marginal conditions exist with regard to required pilot strength, the "strength of pilots" limits must be shown by quantitative tests. In no case may the limits exceed those prescribed in the following table:

Values in pounds of force as applied to the control wheel or rudder pedals	Pitch	Roll	Yaw
(a) For temporary application:	60	30	
Wheel (applied to rim) Rudder pedal	75	60	150
(b) For prolonged application	10	5	20

23.201 Wings level stall.

(a) For an airplane with independently controlled roll and directional controls, it must be possible to produce and to correct roll by unreversed use of the rolling control and to produce and to correct yaw by unreversed use of the directional control, up to the time the airplane pitches.

- (b) For an airplane with interconnected lateral and directional controls (2 controls) and for an airplane with only one of these controls, it must be possible to produce and correct roll by unreversed use of the rolling control without producing excessive yaw, up to the time the airplane pitches.
- (c) The wing level stall characteristics of the airplane must be demonstrated in flight as follows: The airplane speed must be reduced with the elevator control until the speed is slightly above the stalling speed, then the elevator control must be pulled back so that the rate of speed reduction will not exceed one knot per second until a stall is produced, as shown by an uncontrollable downward pitching motion of the airplane, or until the control reaches the stop. Normal use of the elevator control for recovery is allowed after the pitching motion has unmistakably developed.
- (d) Except where made inapplicable by the special features of a particular type of airplane, the following apply to the measurement of loss of altitude during a stall:
 - (1) The loss of altitude encountered in the stall (power on or power off) is the change in altitude (as observed on the sensitive altimeter testing installation) between the altitude at which the airplane pitches and the altitude at which horizontal flight is regained.
 - (2) If power or thrust is required during stall recovery the power or thrust used must be that which would be used under the normal operating procedures selected by the applicant for this maneuver. However, the power used to regain level flight may not be applied until flying control is regained.
- (e) During the recovery part of the maneuver, it must be possible to prevent more than 15 degrees of roll or yaw by the normal use of controls.
- (f) Compliance with the requirements of this section must be shown under the following conditions:
 - (1) Wing Flaps: Full up, full down, and intermediate, if appropriate.
 - (2) Landing Gear: Retracted and extended.
 - (3) Cowl flaps: Appropriate to configuration.
 - (4) Power: Power or thrust off, and 75 percent maximum continuous power or thrust.
 - (5) Trim: 1.5 V_{s_1} or at the minimum trim speed, whichever is higher.
 - (6) Propeller: Full increase rpm position for the power off condition.

23.203 Turning flight and accelerated stalls.

Turning flight and accelerated stalls must be demonstrated in tests as follows:

(a) Establish and maintain a coordinated turn in a 30 degree bank. Reduce speed by steadily and progressively tightening the turn with the elevator until the airplane is stalled or until the elevator has reached its stop. The rate of speed reduction must be constant, and -

- (1) For a turning flight stall, may not exceed one knot per second; and
- (2) For an accelerated stall, be 3 to 5 knots per second with steadily increasing normal acceleration.
- (b) When the stall has fully developed or the elevator has reached its stop, it must be possible to regain level flight without -
 - (1) Excessive loss of altitude;

(2) Undue pitchup;

(3) Uncontrollable tendency to spin;

- (4) Exceeding 60 degree of roll in either direction from the established 30 degree bank; and
- (5) For accelerated entry stalls, without exceeding the maximum permissible speed or the allowable limit load factor.
- (c) Compliance with the requirements of this section must be shown with -
 - (1) Wing Flaps: Retracted and fully extended for turning flight and accelerated entry stalls, and intermediate, if appropriate, for accelerated entry stalls;

(2) Landing Gear: Retracted and extended;

(3) Cowl Flaps: Appropriate to configuration;

(4) Power: 75 percent maximum continuous power; and

(5) Trim: 1.5 V_s or minimum trim speed, whichever is higher.

23.207 Stall warning.

- (a) There must be a clear and distinctive stall warning, with the flaps and landing gear in any normal position, in straight and turning flight.
- (b) The stall warning may be furnished either through the inherent aerodynamic qualities of the airplane or by a device that will give clearly distinguishable indications under expected conditions of flight. However, a visual stall warning device that requires the attention of the crew within the cockpit is not acceptable by itself.
- (c) The stall warning must begin at a speed exceeding the stalling speed by a margin of not less than 5 knots, but not more than the greater of 10 knots or 15 percent of the stalling speed, and must continue until the stall occurs.

23.251 Vibration and buffeting.

Each part of the airplane must be free from excessive vibration under any appropriate speed and power conditions up to at least the minimum value of $V_{\rm D}$ allowed in § 23.335. In addition, there may be no buffeting, in any normal flight condition, severe enough to interfere with the satisfactory control of the airplane, cause excessive fatigue to the crew, or result in structural damage. Stall warning buffeting within these limits is allowable.

23.1587 Performance information.

- (a) General. For each airplane, the following information must be furnished:
 - (1) Any loss of altitude more than 100 feet, or any pitch more than 30° below flight level, occurring during the recovery part of the maneuver prescribed in § 23.201(b).

- (2) The conditions under which the full amount of usable fuel in each tank can safely be used. This information must be in the Airplane Flight Manual (if provided) or on a placard.
- (b) Airplanes of more than 6,000 pounds maximum weight. For each airplane of more than 6,000 pounds maximum weight, the following information must be furnished:

 - (1) The stalling speed, V_{s} at maximum weight (2) The stalling speed, V_{s_1} at maximum weight and with landing gear and wing flaps retracted, and the effect upon this stalling speed of angles of bank up to 60°.
 - (3) The takeoff distance determined under § 23.51(a), the airspeed at the 50-foot height, the airplane configuration (if pertinent), the kind of surface used in the tests, and the pertinent information with respect to cowl flap position, use of flight-path control devices, and use of the landing gear retraction system.
 - (4) The landing distance determined under § 23.75(a), the airplane configuration (if pertinent), the kind of surface used in the tests, and the pertinent information with respect to flap position and the use of flight-path control devices.
 - (5) The steady rate of climb, determined under §§ 23.65(a), 23.67(a) (if appropriate) and 23.77(a), the airspeed, power, and, if pertinent, the airplane configuration.
 - The calculated approximate effect on takeoff distance (subparagraph (3) of this paragraph), landing distance (subparagraph (4) of this paragraph), and steady rate of climb (subparagraph (5) of this paragraph), of variations in -
 - (i) Altitude from sea level to 8,000 feet; and
 - (ii) Temperature at these altitudes from minus 60° F, below standard to plus 40° F. above standard.

For skiplanes, a statement in the Airplane Flight Manual of the approximate reduction in climb performance may be used instead of complete new data for the skiplane configuration if -

- The landing gear is fixed in both landplane and skiplane configurations;
- (2)The climb requirements are not critical; and
- The climb reduction in the skiplane configurations is small (30 to 50 feet per minute).
- (c) Multiengine airplanes. For multiengine airplanes, the following information must be furnished:
 - The loss of altitude during the one engine inoperative stall shown under § 23.205 (as measured from the altitude at which the airplane starts to pitch uncontrollably to the altitude at which level flight is regained) and the pitch angle during that maneuver. This information must be furnished -
 - In the Airplane Flight Manual, for airplanes of more than 6,000 pounds maximum weight; and
 - (ii) On a placard, for airplanes of 6,000 pounds or less maximum weight.

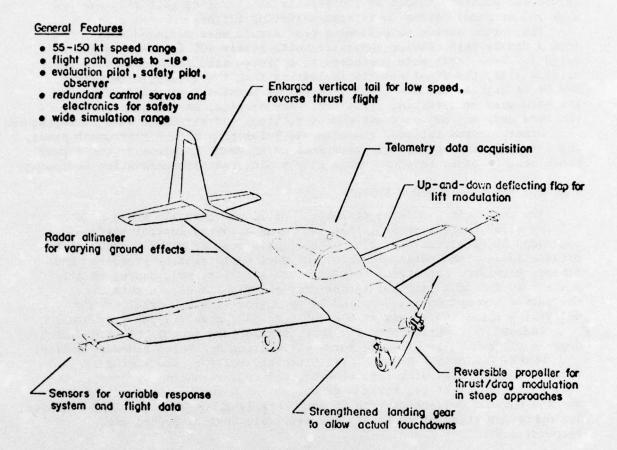
(2) The best climb speed, or the minimum descent speed, with one engine inoperative.

(3) The calculated approximate effect, on the steady rate of climb determined under § 23.67(b), of variation in -

- (i) Altitude at sea level and at 8,000 feet in a standard atmosphere and cruise configuration; and
- (ii) Temperature, at those altitudes from 60° F. below standard to 40° F. above standard.

APPENDIX F

THE IN-FLIGHT SIMULATOR



GENERAL DESCRIPTION

The In-Flight Simulator is based upon a modified Ryan Navion airframe; the power plant is a Teledyne-Continental IO-520B engine of 212.6 kilowatts (285 hp) driving a Hartzell reversing propeller. Gross weight has been increased from the original 12230 to 14010 N(2570 to 3150 lb).

Two externally noticeable airframe modifications were made to improve the research capability of the machine:

The flap hinging and actuation were changed to allow up, as well as down, deflection over a ±30 deg range, resulting in increased lift modulation authority and smaller drag changes compared to the previous 0-40 deg down-only flap. Aerodynamics of the basic airframe and of this flap arrangement were explored in the full-scale wind tunnel tests reported in References F1 and F2.

The second change was an increase in vertical tail area made necessary by serious losses in directional stability when operating in the reverse

thrust range. This was predicted by the wind tunnel tests and confirmed in flight. A 35.6 cm (14") extension, added to the base of the fin and bottom of the rudder, increased vertical tail area by nearly 50% and solved the problem, though at the expense of increased gust response and high rudder pedal forces in forward-thrusting flight.

The normal Navion main landing gear struts were replaced with those from a Camair twin (Navion conversion with nearly 40% increase in gross weight). Drop tests were conducted to optimize oleo strut inflation and orifice size, the final results indicating that the landing sink rate may be as high as 3.8 m/s (12.5 ft/s before permanent set will occur in the main gear or attaching structure. The original Navion nose gear strut was retained, but adjacent attachment fittings and structure were strengthened.

Other changes included redesign and reloaction of the instrument panel, and incorporation of a single rear seat arrangement in place of the former bench seat in order to accommodate electronics and instrumentation equipment.

VARIABLE RESPONSE CONTROL SYSTEM

The in-flight simulator utilizes what is now commonly known as a "fly-by-wire" control system, that is, power-actuated control surfaces commanded by electrical signals. The signals come from the various cockpit controllers and motion sensors, and when appropriately processed and summed, provide a net signal to each servo-actuator, and, hence, an air-plane response of a particular character and magnitude. In this case, the servos are hydraulic, supplied by an engine-driven hydraulic pump delivering about .03 m 3 /min at 5 x 10^6 N/m 2 (9 gpm at 725 psi pressure).

Independent control over the three angular and two of the three linear degrees of freedom is provided for - the missing one being sideways motion.

MOMENT CONTROLS - Control over pitching, rolling, and yawing are through conventional elevator, aileron, and rudder control surfaces. The full authority (that is, maximum travel) of each surface is available, and the maximum deflection rate in each case is about 70 deg/s. At a typical low operating speed of 70 knots, the available control powers are, respectively

Pitch: ±4.4 rad/s² (from trim)

Roll: ±4.1 rad/s² Yaw: ±1.3 rad/s²

The presently available inputs to each of these controls are shown in Table F1.

NORMAL FORCE CONTROL - Independent control over normal acceleration is exercised through the Navion flap, modified to deflect up, as well as down, through a ±30 deg range. The upward motion provides increased lift modulation authority and tends to minimize the problems of drag and angle of zero lift changes. Actuation is hydraulic, with a maximum available surface rate of 110 deg/s. At 70 knots, the available authority is slightly more than ±5 g. Inputs presently available are shown in Table F2.

THRUST CONTROL - Thrust and drag modulation is by direct control of the blade pitch on the Hartzell reversing propeller, with the engine governed at 2300 ± 30 rpm by means of a tachometer feedback and throttle servoactuator. This system allows precise control over thrust and drag at flight path angles and/or deceleration rates well beyond the capability of the basic airplane with normal powerplant and closed throttle.

TABLE F1. INPUTS TO MOMENT CONTROLS

Channel	Input	Function Varied
Pitch	Control column displacement	Control sensitivity
	Thrust lever	Simulated moment due to thrust
	Column thumbwheel	Simulated DLC moment
	Radar altitude	Ground effect moment
	Airspeed	Speed stability
	Angle of attack	Static stability, pitching at stall
	Pitch attitude	Attitude hold sensitivity
	Pitch rate	Pitch damping
	Flap angle	Trim change from flap
	Flap rate	Moment from flap rate (Approximately M.)
	Propeller pitch	Moment due to thrust
	Integral of column displace- ment	Rate command gain
	Simulated turbulence	Turbulence response
Ro11	Wheel displacement	Control sensitivity
	Sideslip	Dihedral effect
	Roll rate	Roll damping
	Yaw rate	Roll due to yaw rate
	Rudder pedal displacement	Roll due to rudder
	Simulated turbulence	Turbulence
YAW	Rudder pedal displacement	Control sensitivity
	Sideslip	Directional stability
	Yaw rate	Yaw damping
	Roll rate	Yaw due to roll rate
	Wheel displacement	Yaw due to aileron
	Simulated turbulence	Turbulence response

TABLE F2. INPUTS TO NORMAL FORCE CONTROL

Input

Function Varied

Control column displacement

Lift due to control (simulates elevator lift, or direct lift control integrated with column)

Thrust lever displacement

Lift due to thrust, direct lift control integrated with throttle

Column thumbwheel

Separate direct lift control

Radar altitude

Ground effect lift; wind gradients

Airspeed

Lift change with speed

Angle of attack

Lift response to angle of attack, lift change at stall

Drag change with angle of attack

Propeller pitch

Angle of attack

Lift due to thrust

Simulated turbulence

Turbulence response

Propeller blade pitch is commanded through an electrohydraulic actuator connected to the mechanical-feedback servo which normally drives the reversing propeller when it is operating in its "Beta" mode. The blade pitch range presently used is +25 to -8 deg. With the engine governed at 2300 rpm, this provides performance ranging from modest climb (about 152 m/min or 500 ft/min) to steep descent ($\gamma = -18$ deg with V = 70 knots). Maximum blade actuation rate is about 20 deg/s. Inputs to the thrust/drag modulation system are shown in Table F3.

TABLE F3., INPUTS TO THRUST/DRAG MODULATION SYSTEM

Input Function Varied Control column displacement Drag due to control (simulated control surface drag; drag due to direct lift controls integrated with column) Thrust lever displacement Thrust command/throttle sensitivity Column thumbwheel Drag change due to direct lift control (separate controller) Radar altitude Ground effect drag change; wind gradients Airspeed Drag change with speed

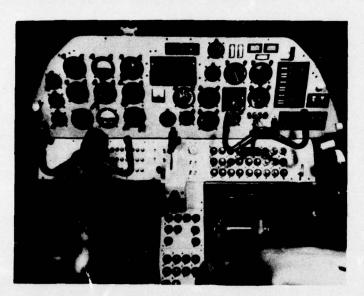
INTERCONNECTS - It may be noted in the lists of inputs for the system (Tables F1-F3) that several coupling functions are provided. For some experiments, it is desirable to remove interacting effects in the basic airframe: lift and moment changes from thrust may be eliminated with interconnects between the propeller pitch sensor and the flap and elevator; and pitching moments due to flap angle and flap rate are countered with inputs to the elevator.

Simulated interacting effects are handled by using inputs from the various cockpit controllers: pitching moments and lift changes due to power are provided by interconnecting the elevator and the flap with the thrust lever (M_{δ_T} , L_{δ_T}); and lift and drag changes due to pitch controller displacement are represented in L_{δ_T} and D_{δ_T} . Other controllers may be

similarly interconnected.

COCKPIT AND EVALUATION PILOT CONTROLS

The instrument panel and controls are shown at left. The right



seat is occupied by the safety pilot who operates the normal Navion wheel and rudder and the power plant controls which have been relocated on the right side of the cockpit. Simulation system controls occupy the right side of the panel and the lower and middle consoles.

The evaluation pilot is seated on the left and provided with a standard flight instrument layout and conventional column, rudder, and throttle controls. Linear force gradients with no perceptable nonlinearities are incorporated. The gradients

are ground adjustable by replacing springs. The values shown in Table F4 are currently being used.

TABLE F4. CURRENT VALUES FOR LINEAR FORCE GRADIENTS

Control	Force Gradient	Travel
Pitch column	7.9N/cm (4.5 lb/in.)	7.6 cm forward (3 in.) 15.2 cm aft (6 in.)
Wheel	2.6N/cm (1.5 lb/in.)	±19.5 cm (±7.7 in.) ±80 deg
Pedal Throttle.	44N/cm (25 lb/in.) Adjustable friction	± 6.3 cm (±2.5 in.) 13.3 cm (5.25 in.)

Note: Three-axis trimming is provided

Special controls presently installed include the following:

- 1. Direct Lift: Thumbwheel separate controller; integrated with pitch column; integrated with throttle. Adjustable moment and drag interconnects are available.
- Pitch attitude command proportional to column displacement, with trimmable attitude hold.
- 3. Pitch rate proportional to column displacement with attitude hold.

Attitude hold may also be selected with any of the direct lift system engaged.

DATA ACQUISITION

Data acquisition is through telemetry, with 43 channels available. Airframe motion parameters (linear accelerations, angular rates, attitude, and heading), control inputs, and performance measures, such as localizer and glide-slope deviation, are normally recorded. Altitude and altitude rate are available from the radar altimeter.

Correlation of touchdown time with the other parameters is obtained through a recording of fore-and-aft acceleration of the main landing gear strut; wheel spinup loads produce enough strut motion to record even very smooth landings.

SAFETY CONSIDERATIONS

By its very nature, landing research involves repeated exposure to minimum-speed, low-controllability situations, so special consideration was given to providing sufficient airframe strength and simulation system reliability to make the risk of damage from occasional hard touchdowns or control system failures acceptably low. The matter of strengthened landing gear was mentioned in an earlier section; the control system aspects will be discussed here.

SAFETY PILOT FUNCTION - Fundamental to the operation of an in-flight simulator is the concept that a safety pilot will continually follow the movements of the basic airplane controls, monitor the systems and the flight path, and be ready to disengage or override the evaluation pilot in case of a malfunction or unsafe condition. For disengaging, a disconnect switch on the control wheel is the primary cutout, with the main electrical and hydraulic controls providing secondary means of deactivating the system.

Manual override of the hydraulic servoactuators is possible for all controls except the flap. The force required is set through an adjustable poppet valve on each servo - 178 N(40 lb) being typical.

Warning of system failures is provided by a flashing master warning light on the upper edge of the instrument panel in front of the safety pilot, with individual channel disengage warning on a panel slightly lower and to the right.

REDUNDANT CONTROL CHANNELS - The elevator, aileron, and throttle systems incorporate redundant control channels. The philosophy here is that hard-over control inputs resulting from system failures are particularly dangerous in this low-speed, low-altitude situation, and should be guarded against if possible. With the redundant channels, any substantial error between the commanded and actual control position is detected, and a

switchover to a second servo is made. The evaluation pilot retains control during this process, but all inputs to the switched channel, except those from the control column, are eliminated, thus reducing the possibility that a defective transducer or signal path is causing the problem. Redundant sensors for the control input signal are incorporated; the other transducers are not duplicated. The fact that a channel has switched to the secondary servo is communicated to the safety pilot by the aforementioned warning lights, and he can then disengage the system and assume control.

The elevator is clearly critical with regard to failures which result in sudden full deflection, with the ailerons only slightly less so. Redundancy was incorporated in the throttle channel to reduce the possibility of a failure, which would apply power with the propeller blade pitch below the normal low-pitch stop, a condition which would overspeed the engine. Redundancy was not incorporated in the rudder or propeller pitch channels, because inadvertent disengages were felt to be less critical, and, since he follows pedal and Beta motions continuously, the safety pilot can very effectively override large-deflection failures. The flap channel was not duplicated because most failure modes are not hazardous the surface trails aerodynamically at a 10 deg down position, and upon disengage, its return to this position from up-deflections is rapid. Downflap deflections clearly pose no safety problem; up-flap hardovers could be hazardous due to the large lift loss, but this has proved to be a failure mode so instantly recognizable by the safety pilot that a disengage (with subsequent down-float of the flap) can be effected with very small altitude

WAVEOFF AUTOMATION - To aid the safety pilot in recovering from an excessive sink rate situation, and "abort mode" system disengage can be used. Activated by pressing the disengage thumb switch, the flap travels at maximum rate to a 20 deg down position and power is automatically advanced to a climb setting; primary control reverts to the safety pilot. Using this system, recovery from a 70 kt, 6 deg approach (sink rate of 3.8 m/s or 12.5 ft/s) with a simulated up-flap failure can be made with less than 3 m (10 ft) altitude loss.

MODIFICATIONS TO PROVIDE A STALL SIMULATION

The simulation of the stall requires two interconnects, an angle of attack to flap interconnect and a stick displacement to elevator interconnect. The lift loss, or "g" break, of the stall is simulated with upflap movement while the pitch break is obtained through the natural pitch response associated with flap motion combined with down elevator.

The angle of attack or stick position at which each surface began to deflect (stall onset) is variable along with the amount of surface movement per unit change of angle of attack or stick position (severity of the break). This permits the necessary nonlinear lift and pitching moment curves of the stall to be simulated at an angle of attack well below the real Navion stall angle of attack.

Two types of stall warning devices are available, a horn and light combination and a stick shaker. Either or both could be activated by the leading-edge tab-type sensor (Safe-Flight SC-150) or the angle of attack vanes on each wing tip.

The evaluation pilot may refer to any of three angle of attack indicators. These include a slow-fast meter (Safe-Flight-style horizontal scale), a Navy-style angle of attack indexer (chevrons and donut), and

a dial indicator with a scale of zero to one unit (Teledyne-type unit). The safety pilot's panel holds a dial angle of attack indicator with a scale of zero to thirty units.

LONGITUDINAL STABILITY DERIVATIVES

For a 70 kt approach condition the dimensional stability derivatives are the following:

$$\begin{array}{lll} (D_{V}^{-}T_{V}^{-}) & = & 0.16 \text{ 1/sec} \\ (D_{\alpha}^{-}g) & = & -12 \text{ ft/sec}^{2}/\text{rad} \\ L_{V} & = & 0.58 \text{ 1/sec} \\ L_{\alpha}^{-}V_{O} & = & 1.2 \text{ 1/sec} \\ M_{V} & = & 0 \\ M_{\alpha} & = & -6.1 \text{ rad/sec}^{2}/\text{rad (nominal stable value)} \\ M_{\alpha}^{\bullet} & = & -0.82 \text{ 1/sec} \\ M_{\theta}^{\bullet} & = & -1.7 \text{ 1/sec} \end{array}$$

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APPENDIX G

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FLIGHT EVALUATION OF ANGLE OF ATTACK AS A CONTROL PARAMETER IN GENERAL-AVIATION AIRCRAFT

by Shu W. Gee, Harold G. Gaidsick, and Einar K. Enevoldson Flight Research Center Edwards, Calif. 93523

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FLIGHT EVALUATION OF ANGLE OF ATTACK AS A CONTROL PARAMETER

IN GENERAL-AVIATION AIRCRAFT

Shu W. Gee, Harold G. Gaidsick, and Einar K. Enevoldson Flight Research Center

INTRODUCTION

Over the years, general-aviation airplanes have been improved so that they now achieve performance levels comparable to those of World War II fighter aircraft. The greater power, high wing loading, and vehicle complexity have resulted in increased demands on the pilot's ability. In consideration of this problem and the continued growth of general-aviation activity, the NASA Flight Research Center has undertaken a program to provide the technology upon which continued improvements in safety, utility, and economics of this class of aircraft may be based. As one part of this program, the use of a vane-type angle-of-attack system for a pilot's display was investigated. The results of this investigation are discussed in this report.

Numerous studies have been conducted and articles written on angle-of-attack displays for high-performance fighter, transport, and general-aviation aircraft (for example, refs. 1 to 6). The results of these studies show that angle-of-attack information is a usable parameter, but not necessarily a superior one. The expected advantages of angle-of-attack information as a primary flight parameter are generally based on two considerations: (1) angle of attack is a direct measure of stall margin independent of aircraft weight, and (2) angle of attack responds earlier than airspeed to the pilot's control stick and throttle inputs and to other variables which may change the equilibrium flight condition.

For use as a piloting aid, angle of attack was displayed on a horizontal indicator mounted above the instrument panel on the left side of the cockpit of a light, twin-engine, general-aviation airplane. Angle-of-attack information was obtained from a sensor mounted immediately in front of the leading edge of the left wing. Since the angle-of-attack indicator was not considered to be a replacement for other flight instruments, the primary question was whether this form of information, as displayed, enhanced pilot performance and safety to justify its presence in the cockpit. Appropriate piloting tasks, including takeoffs and climbs, low-speed maneuvering, approaches and landings, and instrument approaches, were performed at the NASA Flight Research Center by pilots with widely varied experience. Pilot opinion, onboard recorded data, and previously obtained full-scale wind-tunnel data for the airplane were used in the study.

DESCRIPTION OF APPARATUS

The commercially available angle-of-attack system consisted of a wing-mounted angle-of-attack vane, an electronic computer unit, and a display instrument, as shown in figure 1. The system components were installed in the test airplane, which was considered representative of a typical light, twin-engine, general-aviation airplane.

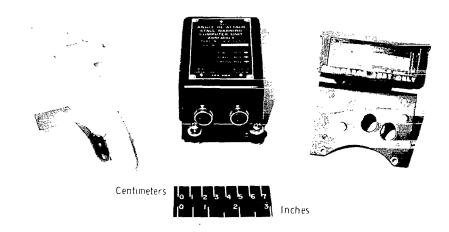


Figure 1. Components of angle-of-attack system.

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Wing-Mounted Vane

A photograph of the vane installation is shown in figure 2. A high-resolution potentiometer was mechanically connected to the wedge-shaped vane to provide an electrical

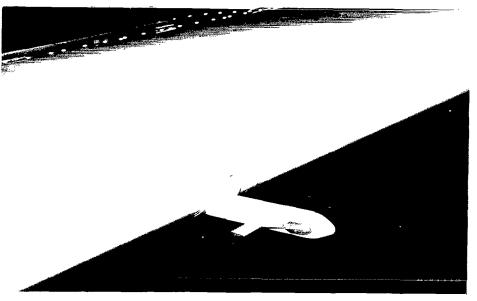


Figure 2. Wing-mounted-vane installation.

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signal as a function of vane position. Because of the proximity of the vane to the leading edge of the wing, the inflight vane deflection was not in true degrees of angle of attack but had a nonlinear magnification factor.

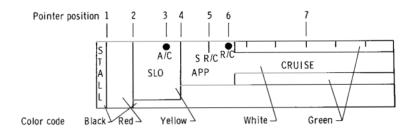
Electronic Computer Unit

The electronic computer unit was mounted in the nose section of the airplane. The unit contained the electronics for signal stabilization and conditioning for display and stall warning. A 6-volt dc regulated referenced voltage was used for the wing-mounted vane and the computer unit. Two adjustments were available for setting the stall point and scale factor for the display indicator. A balanced bridge circuit was used to insure stability and minimize drift near the stall point. Indicator damping was electronically provided in the circuitry.

Display Instrument

The display instrument used was basically a milliammeter with a milliampere range of 0 to 100. The horizontal movement minimized mechanical needle deflection caused by pitch or normal-acceleration forces. Figure 3 shows the indicator markings and briefly describes them. The regions were color-coded to facilitate interpretation of the displayed information.

The display instrument was mounted in the airplane above the instrument panel on the left side of the cockpit so that it would be in the pilot's field of view when he was looking through the windscreen and would not affect the arrangement of the instrument-panel display.



Pointer position	Flight condition	Indicated airspeed, knots (1)
1	Stal!	66
2	Stall warning	70
3	A/C (best angle of climb)	73 (half flaps)
4	Slow approach	73 (full flaps)
5	SR/C (single-engine climb) or	93
	normal approach	80 (full flaps)
6	R/C (best rate of climb)	97.5
7	IFR approach	100 (full flaps)

¹ Based on maximum gross weight.

Figure 3. Cockpit-indicator faceplate for display of angle-of-attack information.

SYSTEM CHARACTERISTICS

Single-Point Display for Approaches

The desired approach velocities for most aircraft are generally 1.3 times the stall velocity $V_{\rm stall}$. Because the $V_{\rm stall}$ differs with flap position and aircraft weight conditions, the desired approach velocity may vary as much as 25 knots for the test airplane. Two extreme conditions are shown in figure 4, which was derived from full-scale wind-tunnel data on the test airplane. It is also shown that the desired approach velocities occur at different angles of attack with different flap settings. Therefore,

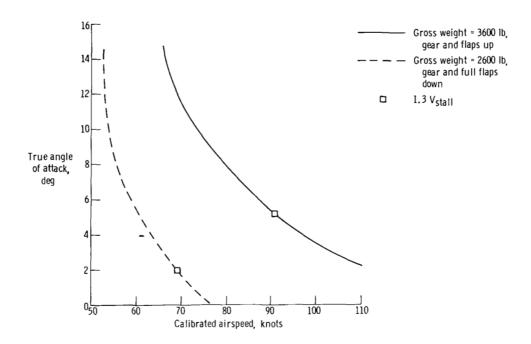


Figure 4. Variation of angle of attack with airspeed for the test airplane with power off, as determined from full-scale wind-tunnel test data.

to provide a single approach index for all configurations, the manufacturer, through flight tests. found a location within the upwash field near the wing leading edge where the vane deflection at 1.3 $\rm V_{stall}$ was nearly the same for all flap settings. Compensation for flap setting could have been achieved electrically if a suitable vane location had not been found. The correspondence of vane position to stall margin in the $\rm V_{stall}$ range of 1.0 to 1.5 was found to be satisfactorily insensitive to flap position.

Figure 5 shows the vane and display variations as a function of velocity for different flap settings on the test airplane. The single line on the display for approach resulted in an airspeed of 91 knots at flaps up, 81 knots at one-half flaps, and 76 knots at full flaps at an average gross weight of 3425 pounds.

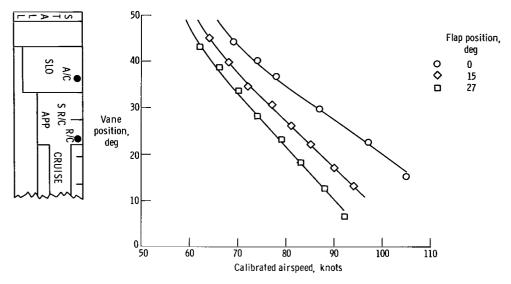


Figure 5. Position and display variations of wing-mounted vane as a function of velocity on the test airplane at an average gross weight of 3425 pounds.

Vane Friction and Balance

The torque required to overcome friction was measured at 0.140 inch-ounce for the combined vane and potentiometer assembly, and recordings of the vane output at takeoff indicated that friction was overcome at about 45 knots. The torque due to static mass unbalance of the vane-potentiometer assembly was less than that required to overcome friction.

Indicator Damping

After several trial flights, it became apparent that the display instrument needle was inadequately damped. By modifying the electronic circuitry to the indicator, the damping time constant was increased from 0.8 second to 2 seconds. This signal, used on all subsequent evaluation flights, can be compared with the undamped output from the vane potentiometer shown in figure 6. (The high-frequency noise on the display signal channel was not from the system output and did not appear on the display needle.) The 2-second time constant provided adequate stability for the needle under all flight conditions encountered in this study and did not result in an excessive response lag time to pilot inputs.

Indicator Calibration

To calibrate the display system the display had to be tailored to the vehicle. Recent wind-tunnel data from reference 7 and data from the aircraft owner's handbook were used to examine performance characteristics of the airplane. From preliminary flight tests, vane positions were determined for displaying stall, stall warning, best climb angle, slow and normal approach, and best climb rate. A short preliminary flight-test program was conducted to validate these data. A ground calibration

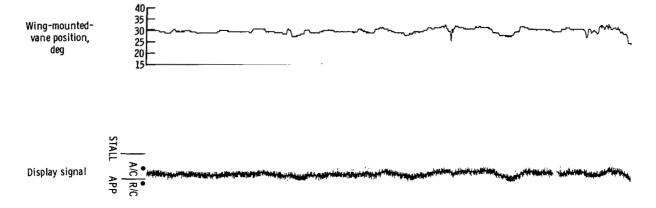


Figure 6. Time history of position and display signal of wing-mounted vane during a landing approach.

procedure was established in which the vane was manually positioned and the display indication recorded. For normal preflight operations a two-point display check of stall and maximum rate of climb was established, and the vane and display were operationally checked before each flight.

DATA ACQUISITION

A pulse code modulated (PCM) digital data-acquisition system was used during the flight-test program. Flight data were telemetered from the airplane and recorded on tape at the ground station. Angle-of-attack measurements were taken from two vanes installed on two 6-foot booms, one mounted on each wing tip, and were corrected to true angles. Airspeed and altitude measurements were taken from transducers connected to pressure sources located on the left wing-tip boom. The instrumentation parameters used were:

Parameter	Range	Frequency. Hz
Airspeed Altitude	0 to 250 knots 0 to 10,000 feet -2.5° to 17.5°	4 4 40
Angle of attack (right boom) Angle of attack	-2.5° to 17.5°	40
(left boom) Normal acceleration Wing-mounted-vane	0 to 4 g 0 to 50°	10 10
position Display signal Timer		4 1

Data from flight notes and pilot readings of cockpit instruments were also used.

EVALUATION PROCEDURE

The evaluation was designed to investigate the expected advantages and disadvantages of using angle-of-attack information. The expected advantages were:

- (1) Visual presentation of the stall margin under all flight conditions.
- (2) Approximate independence of performance points with respect to gross weight, load factor, velocity, and altitude of nonturning flight.
- (3) Better resolution than for an airspeed indicator when flight at specific points on the lift curve is required, such as for slow flight or maximum performance maneuvers.
- (4) Faster response to pilot control inputs than airspeed system when a departure from equilibrium flight is effected.

The expected disadvantages of using angle-of-attack information were:

- (1) Systems must be tailored for the particular aircraft.
- (2) Pilots must understand the characteristics, limitations, and operational techniques for using the display in order to interpret it.
- (3) An additional display in the cockpit because the system is not a replacement for airspeed.
 - (4) A mechanical-electrical system requires extra care and maintenance.
 - (5) The system's operation is dependent on the aircraft's electrical system.

The information analyzed was obtained from questionnaires (see appendix) and discussions with (1) the research project pilot who performed the critical maneuvers not included in the evaluation piloting tasks such as low-weight. short-field takeoffs and landings, and normal and accelerated stalls, and (2) a group of three additional research pilots and five general-aviation commercial instrument-rated pilots who performed the evaluation piloting tasks under high-gross-weight conditions. All pilots flew one or two familiarization flights in the test airplane before evaluating the angle-of-attack display system. The project pilot who obtained extensive individual experience with the system acted as safety pilot for all flights by other pilots.

The evaluation tasks were divided into the categories of takeoffs and climbs, low-speed maneuvers and speed changes in level flight, short-field and normal approaches and landings, and ILS approaches. No set procedure was followed in briefing the participating pilots on angle-of-attack properties before or during test flights. Each pilot used his own flight technique and ingenuity in adapting the angle-of-attack information to the tasks but was advised by the safety pilot in developing a satisfactory technique. Tasks were performed by using angle-of-attack and airspeed information

alternately for comparison purposes. The airspeed indicator was covered when the angle-of-attack display was used, and vice versa. Tasks and practice maneuvers were also performed using both instruments together. Pilots answered a questionnaire and discussed their results after completing their flights.

RESULTS AND DISCUSSION

Takeoff and Initial Climbout

Tests of the pilot's ability to take off and climb in a minimum distance from a standing start showed grossly inferior performance when the angle-of-attack system was used compared to that attained when airspeed was used. The reason for this surprising result was found in the slower pullup to the best climb angle that resulted from maintaining the best climb angle of attack after takeoff. It was observed on takeoffs in which airspeed was used that, for a short interval immediately after lift-off, angles of attack near the stall were used in order to rotate the flight-path vector to the best climb angle as the airspeed reached the best climb airspeed. When the angle-of-attack indicator was used, the airspeed increased above the best climb airspeed before the best climb angle was reached.

The climb path after lift-off was usually oscillatory, with the aircraft following a constant angle-of-attack phugoid when the angle-of-attack display was used. Typically, the airspeed varied ± 15 knots about its mean value, which for best angle climbs, periodically brought the speed below V_{mc} . The phugoid had a period of about 20 seconds and an amplitude dependent upon the initial displacement from the equilibrium flight path. The oscillation was lightly damped. Carefully holding constant angle of attack resulted in prolonging the oscillation. There was a strong tendency for pilots to fly the angle of attack carefully, thus inadvertently sustaining the oscillation. It puzzled the subject pilots that to apparently accomplish the required task—holding constant angle of attack—did not result in the desired steady, optimum flight path. In this characteristic, angle of attack flying was believed to be basically less satisfactory than airspeed flying, where constant airspeed directly implies a stabilized flight path.

Additionaly, it is noted that an angle-of-attack display provides no cue when the correct takeoff speed has been reached.

The characteristics described in the above paragraphs are not peculiar to the test aircraft and angle-of-attack system but would apply to almost any contemporary airplane and simple angle-of-attack indicator.

Figure 7 is a time history of airspeed and angle of attack for a typical short-field takeoff in which the pilot used airspeed for a rotation cue and maintained angle of attack for climb. As can be seen, the airspeed at lift-off (70 knots desired) was approximately correct, but flying constant angle of attack did not prevent further acceleration and the airspeed continued to increase beyond the best angle-of-climb speed of 73 knots. The induced phugoid oscillation in airspeed of over 10 knots variation eventually resulted in the airplane falling below the $V_{\rm mc}$ speed of 70 knots. From both pilot and ground observation, the flight path and pitch angles changed from being too shallow immediately after takeoff to too steep about 10 seconds later.

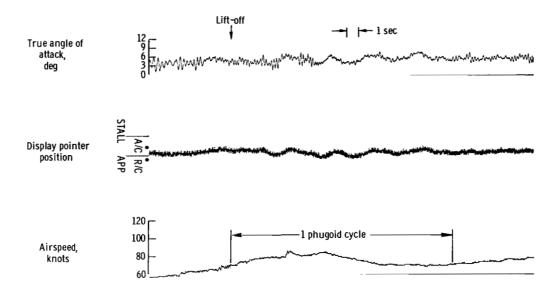


Figure 7. Time history of a short-field takeoff when pilot used angle-of-attack display instrument.

Although the best climb angle (A/C), best climb rate (R/C), and best single-engine climb rate (SR/C) are more closely determined by angle of attack than by airspeed, the curves for these quantities for the test airplane were so flat near the optimum values that the performance gained by defining the quantities in terms of angle of attack was insignificant. However, this may not be true for higher performance aircraft with greater weight variance or more sharply peaked performance curves than those of the test airplane. As seen from figure 8, the best climb rate was obtained at 92 knots or

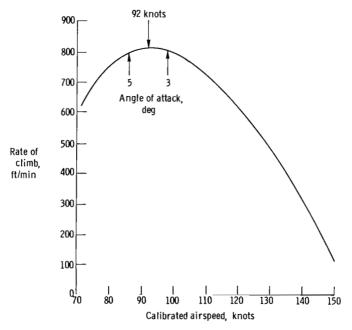


Figure 8. Rate-of-climb performance as a function of airspeed of the test airplane. Gross weight, 3450 pounds; gear and flaps up; 6000 feet altitude; 64° F.

3.8° angle of attack. For a variation of ± 5 knots in airspeed or ± 1 ° in angle of attack, the change in performance was only 20 feet per minute, which is about 2.5 percent.

Low-Speed Maneuvering

Performance in low-speed maneuvers was roughly equivalent whether angle-ofattack or airspeed information was used. Maneuvers are normally performed primarily by using attitude control, with reference to airspeed or angle of attack as a secondary control parameter. Although angle of attack responds faster to the pilot's pitch or throttle inputs, this expected advantage is more or less negated by the necessity of compensating for any induced phugoid, or, stated another way, angle of attack does not necessarily command the correct control inputs. At a given instant of time the correct input to maintain a desired stall margin may be in the opposite direction to the input required to achieve stabilized flight. Thus, the solution of the control problem is a compromise between objectives which cannot be directed by angle of attack alone. Because angle of attack represents the desired solution to the control problem only under stabilized conditions, it has no obvious advantage over airspeed as a control parameter for low-speed maneuvering. The main limitation on performance in this area is believed to be the pilot's ability to monitor attitude, altitude, heading, and either airspeed or angle of attack from different visual references. The substitution of angle of attack for airspeed did not materially reduce the workload; however, the pilots expressed no doubt that the visual indication of stall margin provided by the angle-ofattack indicator was desirable.

Approach and Landing

For approaches and landings, the angle-of-attack display was found to be of benefit when used properly in conjunction with other parameters, but it led to hazardous procedures and poor control techniques when used without the necessary understanding of how to use the display.

The major benefit derived from the angle-of-attack display was the convenience of having a single reference point for straight-in approaches which enabled the pilot to select an approach trim condition. This provided a constant stall margin before flare and therefore resulted in consistent flare and float characteristics regardless of weight and flap setting. Both normal and short-field approaches were evaluated, and the evaluation pilots found the flare and float characteristics to be consistent, predictable, and appropriate. However, during the full-flap, lightweight approaches, it was noted that the airspeed was slow enough to cause undesirable, low lateral-control response. In addition, the airspeed was below $V_{\mbox{mc}}$, and, although directional response was adequate for the landing task, the use of speeds below $V_{\mbox{mc}}$ was believed to be an unnecessary exposure to hazard. Therefore, it was concluded that the low-speed lateral- and directional-control capability of the test airplane limited the advantages of using angle-of attack information in that portion of the flight envelope.

A further benefit from the angle-of-attack display was the ability to establish the longitudinal trim setting for straight flight when not in that flight condition. Trim

settings for final approach were made before or during the turn to the final approach. Thereafter, stick force was a useful indication of stall margin. This was practical because of the close relationship between trim setting and angle of attack. On the test airplane the resulting trim was sufficiently accurate except when large power changes were made.

The use of angle of attack as a control parameter, independent of airspeed or attitude control, was found to be unsatisfactory. When a constant angle of attack was flown, the characteristic phugoid path was encountered following any displacement from equilibrium conditions. This was particularly noticeable on the entry to or rollout from the turn to final approach. An extreme example of this characteristic is shown in figure 9, a time history of a landing approach in which a 45° banked turn was used and the resulting airspeed variation was 40 knots. The airspeed for stabilized banked flight is higher than that for stabilized wings-level flight for the same angle of attack. When the transition was made from one condition to another, the stabilized airspeed difference was the amplitude of the phugoid which was excited by the maneuver.

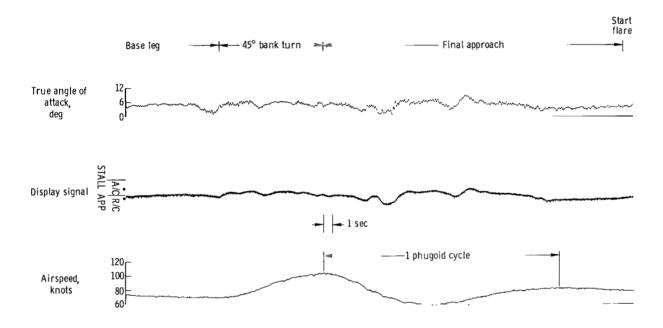


Figure 9. Time history of landing approach when pilot used angle-of-attack display instrument.

Three successful techniques for using angle-of-attack information on the final approach were observed. The first was to maintain a flight path by visual reference to the airport and its vicinity. Angle of attack was monitored occasionally, with pitch and power adjustments made to keep a large but decreasing margin from the target angle of attack in order to reach the target angle of attack at the flare point. This technique was used consistently and accurately by a pilot with only general-aviation experience. The second technique was to maneuver to a flare point using elevator control to stabilize the flight path while controlling angle of attack with power. This technique was used by several pilots with heavy aircraft experience. A third technique, successful when only small displacements from equilibrium were encountered, involved controlling

angle of attack with the elevator, and controlling the flight path with power. Combinations of these techniques were also used; however, to recover from any moderate displacement from equilibrium, it was always necessary to first resort to attitude stabilization using the elevator, then to establish control of flight path, and finally to adjust the angle of attack. To conscientiously maintain angle of attack following any departure from equilibrium only sustained the induced characteristic phugoid and delayed regaining stabilized flight; thus, the pilot was required to compensate for the nonstabilizing nature of angle of attack because it was not a reasonable control parameter except in combination with airspeed, attitude, or other information.

ILS Approach

In the ILS approach, use of the angle-of-attack system did not provide a significant advantage over the airspeed system. The pilot needed to spend nearly all the time monitoring attitude and course deviation. According to pilot opinion, the use of angle-of-attack in place of airspeed information did not significantly alter the workload or degree of accuracy with which the task could be performed. Because the ILS approach is a difficult task at best, excitation of the phugoid characteristics caused by using the angle-of-attack system was possibly more bothersome than it would be under VFR conditions. Again, the necessity for monitoring many instruments is thought to be the limiting performance factor.

CONCLUDING REMARKS

An investigation of the use of angle-of-attack information for the pilot's display in a light, twin-engine, general-aviation aircraft resulted in exposing certain fundamental complications which tended to negate some expected advantages of this parameter. As a result, the improvement in performance and flight safety was thought to be insignificant for the following reasons:

- (1) The pilot was required to compensate for the nonstabilizing nature of angle of attack because it was not a reasonable control parameter except in combination with airspeed, attitude, or other information.
- (2) The low-speed directional-control capability of the test airplane limited the advantages of using angle-of-attack information in that portion of the flight envelope, which led to undesirably low approach velocities (below minimum control speed) under low-weight conditions.
- (3) The maximum performance curves for the test airplane were so flat near optimum values that expected climb performance gains were insignificant.
- (4) Angle of attack was of no value as a cue when the correct speed for takeoff was reached.

Pilot acceptance of angle of attack was found to be highly dependent on a clear understanding of its meaning and limitations and the degree to which he combined it with other types of information. This understanding became important when angle of attack was used as a primary control parameter rather than as a stall margin displayed parameter.

Some of the characteristics of the angle-of-attack system were not adversely affected by vehicle aerodynamics and were considered to be desirable by the pilots. These were:

- (1) The visual indication of stall margin.
- (2) A single display point for straight-in approaches regardless of flap setting and gross weight, except for extremely lightweight conditions.
- (3) The ease of obtaining trim and power settings when using the angle-of-attack indicator as a reference.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., September 18, 1970.

ANGLE-OF-ATTACK EVALUATION - PILOT QUESTIONNAIRE

A. Display factors

1	Was	the	meter	face	readable	at	all	times?	
L.	was.	LIIC	HICKEL	Tacc	Teadable	a_{ι}	a_{11}	TITIES :	

T3+1 - 4		
Pilot		
(A)	Yes.	
(B)	Yes.	
(C)	Yes.	
(D)	Yes.	I would have preferred a vertical meter
(E)	Yes.	
(F)	Yes.	
(G)	Yes.	
(H)	Yes.	

2. Did the scale seem adequately expanded?

Pilot

- (A) Yes.
- (B) Yes.
- (C) Yes, although the cruise portion is greater than needed.
- (D) Yes.
- (E) No. Since angle of attack is useless near cruise (low angle of attack), eliminating the right half and doubling the left half would be desirable.
- (F) No, not in the cruise portion. Scale was adequate in high-angle-of-attack region.
 - (G) Yes.
 - (H) Yes.
 - 3. Were the markings readily understandable?

- (A) Only after explanation.
- (B) Yes.
- (C) Yes, after being prebriefed.
- (D) Yes. (E) Yes.
- (F) Yes.
- (G) Yes.
- (H) Yes, but some simplification may be needed.
- 4. Did the horizontal needle deflection cause any confusion?

- (A) No.
- (B) No.
- (C) No. It seemed natural.
- (D) Yes. Some ambiguity repeatedly throughout the flight.
- (E) No.

- (F) During the first several approaches, it seemed like there was too much horizontal movement of the needle with no apparent action by the pilot. At first, because of this, there was a tendency to chase the needle. After the first several approaches, the fluctuations were integrated and there was no further tendency to chase the needle.
- (G) Yes, due to unfamiliarity. Once trimmed the wrong way to bring the needle to a new position.
 - (H) No. but vertical needle deflection would be more appropriate.
 - 5. Would you have preferred a circular indicator?

- (A) No preference.
- (B) No.
- (C) No preference.
- (D) Yes, if the needle were nearly horizontal for approach speed range.
- (E) Can't say, since I haven't flown a circular one. Suspect I would not have any preference one way or the other.
- (F) Yes. I say this because I used the circular indicator in the Navy. Also. with the desired approach angle of attack at the 3 o'clock position, the instrument is easier to interpret.
 - (G) Not particularly.
 - (H) No.
 - 6. Was the location of the meter adequate?

Pilot

- (A) Yes.
- (B) Yes.
- (C) No. For IFR work I would like it below the attitude gyro or near the top center (like a head-up display) of the panel.
 - (D) Yes.
 - (E) Yes.(F) Yes.

 - (G) OK for temporary test installation but not for actual IFR.
 - (H) Yes.

B. Takeoffs, approaches, and landings

1. Is the takeoff procedure acceptable?

- (A) Procedure not acceptable when using angle of attack only.
- (B) No.
- (C) Yes, although I feel it's unsafe in high-density traffic; visibility over the nose is nonexistent. The task is acceptable.
 - (D) [No comment.]
 - (E) No. In fact it was ridiculous to try to take off on angle of attack alone.
- (F) No. I did not feel that the instrument could be interpreted quickly and accurately enough to use for a takeoff.
 - (G) No. Requires gentle touch and familiarity with aircraft.
 - (H) Yes.

2. Would you suggest a better procedure?

Pilot

- $\overline{(A)}$ 1. Use airspeed V_{mc} for rotation.
 - 2. Establish attitude using attitude indicator after rotation.
 - 3. Use airspeed or angle of attack thereafter.
- (B) No.
- (C) No. The results are as desired.
- (D) [No comment.]
- (E) Yes. Rotate on airspeed the way we always have.
- (F) No.
- (G) Prefer airspeed on takeoff. Did not try combination, but that might be best.
- (H) No.
- 3. Was there any tendency to overrotate?

Pilot

- (A) There was a tendency to underrotate because of the oscillatory nature of the angle-of-attack indication.
 - (B) No.
- (C) Not initially, but if the pilot initially underrotates, it leads to a tendency to overcorrect.
 - (D) [No comment.]
 - (E) No.
 - (F) Yes. However, it could easily be corrected.
- (G) Not initially, since I had been briefed, but reached an abnormal (I felt) nose-high attitude on climbout.
 - (H) No.
 - 4. After rotation, were airspeed and/or pitch oscillations induced?

Pilot

- (A) Some.
- (B) Yes.
- (C) Yes. This can happen at nearly constant angle of attack like a phugoid.
- (D) [No comment.]
- (E) No, since I fly primarily attitude and then just cross-check angle of attack or airspeed.
 - (F) No.
 - (G) Airspeed was covered. See preceding comment (B-3).
 - (H) No.
 - 5. Could you trim adequately on angle of attack?

- (A) Yes.
- (B) Yes.
- (C) Yes, quite well.
- (D) Yes.
- (E) Yes.
- (F) Yes, at least as well as when using airspeed.
- (G) Yes, because I normally do not trim at cruise for airspeed. However, for slow flight, angle of attack and airspeed were about the same.

- (H) Yes.
- 6. In trying to fly on set values, were pitch oscillations induced?

Pilot

- (A) Yes. Had tendency to chase needle at first.
- (B) Not in steady flight, but following any turn or change in speed.
- (C) Yes. See comment, B-4. I would not fly constant angle-of-attack cruise flight.
- (D) More flight-path oscillations than pitch angle. This was the feeling, although pitch attitude and flight-path angle are the same if angle of attack is constant.
 - (E) No. for same reasons as in question B-4.
 - (F) None that were noticeable to the pilot.
 - (G) Not in stabilized flight VFR.
 - (H) No.
- 7. During flare and touchdown, did aircraft response seem right for those maneuvers?

Pilot

- (A) Yes.
- (B) Yes.
- (C) Yes.
- (D) Short period, yes; flight path, no.
- (E) Yes.
- (F) Yes.
- (G) Yes, because the aircraft was flown visually from threshold.
- (H) Yes.
- 8. Did the glide time between flare and touchdown seem right?

Pilot

- (A) Yes.
- (B) Yes.
- (C) It floats a bit if any power is left on.
- (D) Yes.
- (E) Yes.
- (F) Yes.
- (G) Yes, but this factor was somewhat distorted due to shifting wind. At least one landing was downwind.
 - (H) Yes.
- 9. On short-field takeoffs and landings, did angle of attack seem to provide better control feel and response?

- (A) No.
- (B) Takeoff, no; landing, yes. Except at light weight, [where] roll control was inadequate.
 - (C) No, but it quickly indicates a deviation from a desired condition.
 - (D) [No comment.]
 - (E) Landings, yes. Takeoff on angle of attack was absurd.
 - (F) Yes.

- (G) Not good for takeoff. Equal or better than airspeed on landings.
- (H) Same.

C. Slow flight and maneuvering

1. Was angle of attack useful as a stall-warning reference?

- (A) Yes. (B) Yes.
- (C) Not done.
- (D) Yes.
- (E) Very. Primary. It's great.
- (F) Yes, very much so.
- (G) Yes, but aircraft has good buffet warning.
- (H) Yes.
- 2. Was there any noticeable lag time in the needle?

- (A) No.
- (B) No.
- (C) [No comment.]
- (D) No.
- (E) No.
- (F) No. I would say that there was too much response if anything.
- (G) No.
- (H) No.
- 3. Did the needle seem to respond faster or slower than airspeed?

Pilot

- (A) About same.
- (B) Both systems adequate.
- (C) [No comment.]
- (D) Faster, too fast. Produced a tendency to chase it or ignore it completely.
- (E) It responded to wheel motion; airspeed then lagged.
- (F) Faster.
- (G) About same.
- (H) Did not notice.
- 4. Using angle of attack, was less throttle jockeying required to maintain altitude?

Pilot

- (A) About same.
- (B) Not significantly or consistently true.
- (C) [No comment.]
- (D) Yes, plenty.
- (E) No, mainly because I don't jockey the throttles. I set them and jockey the wheel.

1

- (F) It appeared that less throttle jockeying was required.
- (G) No.
- (H) Did not notice.

5. You held altitude best using which system, airspeed or angle of attack?

Pilot

- (A) About same.
- (B) No difference.
- (C) [No comment.]
- (D) Airspeed.
- (E) Neither. I was sloppy either way.
- (F) There appeared to be no difference.
- (G) About same; probably held low speed more accurately with angle of attack.
- (H) Did not notice.

D. ILS approaches

1. Your better performance was with which system, airspeed or angle of attack?

Pilot

- (A) Did not do.
- (B) No difference.
- (C) Angle of attack.
- (D) [No comment.]
- (E) Not applicable.
- (F) Could not tell any difference.
- (G) Not performed.
- (H) [No comment.]
- 2. Did angle of attack seem to alter your technique for any task?

Pilot

- (A) Did not do.
- (B) Turn to final done at lower bank angle and lower airspeed with angle-of-attack system.
- (C) Yes. Power manipulations were fewer and generally in one direction only (i.e., reduction).
 - (D) [No comment.]
 - (E) [No comment.]
 - (F) I did not notice any change in technique.
 - (G) [No comment.]
 - (H) [No comment.]

E. General

1. Would you prefer angle of attack to airspeed for some maneuvers in this aircraft?

- (A) Would rather see both.
- (B) No.
- (C) Yes. Approaches, tight turns, steep climbs, and some IFR work.
- (D) Airspeed for all.
- (E) Yes, on landing approach particularly the very slow approaches. Other phases of flight such as takeoff and cruise are not suited to angle of attack.

- (F) Yes. During approaches I think that this instrument would be very useful.
- (G) For low-speed approaches it might be better, but it would take some getting used to. Possibly both would be best.
 - (H) Yes.
 - 2. Was there a noticeable decrease in pilot workload using angle of attack?

Pilot

- (A) No.
- (B) No.
- (C) Yes. I felt it was a substantial decrease (especially considering the panel layout).
 - (D) More workload.
- (E) On the approaches, yes; also much less nerve-racking on the approaches with angle of attack. Takeoff and cruise, no.
- (F) Yes. I felt that it is somewhat easier to make approaches using angle of attack.
 - (G) Not significant.
 - (H) No.
 - 3. Did angle of attack seem easier to fly?

Pilot

- (A) No.
- (B) No.
- (C) Yes.
- (D) No, harder.
- (E) On the approach, yes; otherwise, no.
- (F) Yes.
- (G) Possibly at low speed.
- (H) Seemed more secure on short-field approaches.
- 4. Did you notice any significant advantages in using angle of attack?

Pilot

- (A) Very good indication of stall margin.
- (B) Good indication of stall margin.
- (C) Yes. Reduces number of gages to scan.
- (D) Trim reference.
- (E) Yes, it made the approach less hairy.
- (F) Automatically compensates for changes in gross weight.
- (G) [No comment.]
- (H) Angle of attack will provide best reference in climbs or descents with changes of weight, etc.
 - 5. Disadvantages?

- (A) The oscillatory nature of the parameter.
- (B) Tendency to concentrate excessively on angle of attack. This did not decrease much with familiarity.
- (C) Yes. If one is fast to very fast, it is difficult to know exactly how fast (assuming no airspeed indicator).

- (D) If there were any advantages, these were marked by phugoid and power effects on trim and control and it all seemed more disadvantageous than advantageous. I would like to try using angle of attack with an aircraft which had a pitch rate command system, free of aerodynamic trim changes and power effects.
 - (E) No.
- (F) I evaluated the instrument as an additional cockpit instrument and not as a replacement. Under these circumstances, I found no disadvantages.
 - (G) [No comment.]
- (H) Short-field approaches in strong, gusty winds could be a problem due to wind gradient and gusts.
 - 6. Suggestions or miscellaneous comments?

- (A) First exposure to angle of attack resulted in "chasing" the needle because it was the center of my attention; angle of attack, like airspeed, is best controlled by controlling attitude.
 - (B) [No comment.]
- (C) None, except that the task would be easier in a single-engine airplane. Whether you want it easier is not known, perhaps it is desired to nearly saturate the pilot.
 - (D) [No comment.]
- (E) The angle of attack is a useful indicator for the approach and landing phase and, as such, could be a significant contribution to safety. During the other phases of flight, it is essentially useless, since airspeed or angle of attack are not primary. (For example, in cruise, power and rate of climb are primary.)
- (F) On the ILS flight there was light-to-moderate turbulence encountered. With this amount of turbulence, I could not tell any difference in the performance of flying the ILS approach. With any turbulence, I would prefer to fly airspeed. It appeared that I was better able to determine when turbulence was changing airspeed than I was able to determine changes in angle of attack due to turbulence.
- (G) After some postflight thought and some discussion, I feel that the major advantage of the angle-of-attack meter would be for low-speed approaches at varying gross weights, particularly in an airplane in which the pilot was not highly experienced. Since the evaluation was flown at essentially constant gross weight, this could not be evaluated. I did not like the angle-of-attack meter on the initial phase of the climbout and I would question its sole use for short-field or obstacle-clearance takeoff. With the airspeed for the initial phases it might be useful, but this was not evaluated. For either high-speed or low-speed cruise, including holding, I use power setting and altitude with the airspeed as a reference only. Therefore, it is doubtful if either the airspeed or angle of attack would be useful here. I didn't really evaluate it completely (I use power and airspeed for stabilized climb), so maybe the angle of attack would be an improvement, particularly for varying gross weights. However, since engine cooling is a consideration here, airspeed would also be required.
 - (H) [No comment.]

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FINAL REPORT

Project No. 560-004-03H

Contract No. FA67WA-1811

ANGLE OF ATTACK PRESENTATION IN PILOT TRAINING



March 1969

ELECTRONIC FORMAT

DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION

Aircraft Development Service Washington, D. C.

FINAL REPORT

ANGLE OF ATTACK PRESENTATION IN PILOT TRAINING

Project No. 560-004-03H

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March 1969

The contents of this report reflect the views of the contractor, who is responsible for the facts and the accuracy of the data presented herein, and do not necessarily reflect the official views or policy of the FAA. This report does not constitute a standard, specification or regulation.

DEPARTMENT OF TRANSPORTATION FEDERAL AVIATION ADMINISTRATION

Aircraft Development Service Washington, D. C.

ABSTRACT

The crucial relation of angle of attack to aircraft performance suggests than an angle of attack instrument would enhance the process of learning to pilot an airplane. Therefore, a project to determine the possible value of angle of attack presentation in addition to other required instruments for flight training in general aviation aircraft was conducted. The project entailed comparing the performance of two similar groups of Embry-Riddle Aeronautical Institute flight students enrolled in the private pilot course. Flight instruction of both groups proceeded concurrently utilizing the same aircraft except the experimental group was trained using an angle of attack instrument in addition to the airspeed indicator. A series of three scored tests was employed to measure the performance of each student on selected maneuvers during and upon completion of the course.

Scores of the experimental group and the control group were tested for significance of difference by the analysis of variance method. A comparison of the derived variance ratios with the corresponding values in the Table of F ratios at the 5% level signified in all instances that the null hypothesis should not be rejected. Consequently, statistical evidence indicated that there was no true difference in the quality of performance of students trained with and without the angle of attack indicator at the private pilot level.

The overall similarity of the performance of the two groups is attributed to the following two conditions. (1) Experimental group students were required to learn the use of the angle of attack indicator in addition to the airspeed indicator. The difficulty certain students experienced early in the program in developing skill in using this instrument tended to compensate for possible enhancing effect which might have been realized in the final stage. (2) At the present state of the development of flight instruction curricula, contact flight is the quintessence of the private pilot program. An instrument capable of producing a significant effect on pilot performance at this level, consequently, would be rare.

Findings of this project indicate that further research in the use of the angle of attack indicator is appropriate. Projects should be conducted to determine the value of angle of attack presentation: (1) when used in lieu of airspeed in private pilot training, and (2) in instrument flight training.

TABLE OF CONTENTS

Introduction	1
Text	9
Conclusions and Recommendations	21
References	22
LIST OF FIGURES	
1. Angle of Attack Indicator Transmitter	4
2. Spill Plate and Angle of Attack Probe on Cessna 150	6
3. Angle of Attack Indicator Dial	7
LIST OF TABLES	
Table I - Score Sets	13
Table II(a) - Score Set Summary (Experimental Group)	14
Table II(b) - Score Set Summary (Control Group)	15
Table III - Summary of Null Hypothesis Tests	16
LIST OF APPENDICES	
Appendix A - Student Completion Schedule	
Appendix B - Test of Significance of Difference Between the Means of Experimental and Control Group CTMM Scores	
Appendix C - Private Pilot Course	
Appendix D - Use of Angle of Attack Indicator	
Appendix E - Performance Analysis Booklet	
Appendix F - Summary Score Sheet	
Appendix G - Detailed Scores	
Appendix H - Data Analysis Theory	

INTRODUCTION

The relation of angle of incidence to aircraft performance was recognized as far back as Wilbur and Orville Wright. However, the importance of angle of attack instrumentation did not become manifest until the advent of the jet airplane, and it appears that renascence of the angle of attack indicator should be attributed to research and development conducted by the U. S. Navy¹.

During the period of transition from propeller driven aircraft to jets, the Navy determined that carrier landing touchdowns must be accomplished at the minimum allowable airspeed. The limitations of shipboard arresting gear and airframe structure were not in consonance with the increase in kinetic energy of jets at point of touchdown as compared to propeller aircraft. The weight of a Navy jet is ten times more than a corresponding piston airplane and the landing speed is as much as 75 knots greater. At the same time as the Navy determined the need for minimum airspeed at touchdown, they discovered that pilots were incapable of accomplishing the required precise control of airspeed in this realm of flight. This condition existed because of one of the inherent characteristics of a turbojet airplane. In the area of optimum approach airspeed, extremely small increments of throttle movement produce proportionally large changes in velocity.

In order to obviate human limitations in jet carrier landings the U. S. Navy Bureau of Aeronautics initiated development of an automatic throttle (Approach Power Compensator). The APC regulates engine power to maintain a constant angle of attack selected for the approach to provide proper speed on landing. Angle of attack is used as an input to the auto-throttle system rather than airspeed because the angle of attack for a prescribed performance parameter remains constant regardless of airplane weight changes, flap settings, angles of bank, "g" forces, or density altitude variations.

Whereas evidence seems to indicate that the problem of jet carrier landings precipitated the rebirth of angle of attack presentation, the Navy found that this instrument contributed substantially to the general enhancement of jet operations to include (1) virtual elimination of accidents caused by premature rotation on take-off, (2) stall warning at high altitude (above 40,000 feet) when executing maneuvers involving high "g" forces, and (3) flight at maximum range and endurance. Many of the advantages of using angle of attack as a primary reference for performance of Navy jets apply to commercial turbojet aircraft. Therefore, widespread use of angle of attack indicators in jetliners and corporate jets is anticipated².

While angle of attack presentation is essential in certain realms of jet flight and is advantageous in others, the need and specific purpose of this instrument in

¹C. H. Tuomela, "Angle of Attack as an Aid to Flying" (paper from U. S. Naval Missile Center read at the Society of Automotive Engineers National Aeronautical Meeting, Washington, D. C., 1965) p. 1.

²"Angle of Attack Device Seen Aid to Piloting", <u>Aviation Week and Space Technology</u>, (September 26, 1966).

propeller driven aircraft are obscure. Except for high altitude and supersonic flight conditions, every advantage of angle of attack presentation for jet aircraft is applicable to piston engine aircraft. However, it would appear that the margin of improvement in propeller aircraft operations attributable to an angle of attack instrument would be less than in jets. The extent of this margin, and whether or not flight training per se is included are unknown. In the interest of progress and safety in general aviation, investigations in these areas are warranted. The possible advantage of angle of attack presentation in the initial stage of pilot training is the basis for this project.

Statement of Problem.

The purpose of this project was to determine the value of angle of attack presentation during private pilot training in addition to other flight instrumentation presently required for general aviation aircraft.

Objectives of the Investigation.

Specific objectives of this inquiry were to determine:

- (1) Whether or not the angle of attack indicator will improve the quality of performance at the private pilot level of persons trained in general aviation aircraft equipped with this device.
- (2) What areas within the private pilot course does angle of attack presentation have the most effect.

History of Accomplishments in Pilot Training Research.

A recent review of research related to pilot training reveals that the majority of the projects in this field were completed during the past twenty years³. However, aviation human factors research conducted under the auspices of the Civil Aeronautics Administration dates back as far as the late 1930's. Since then, research of this nature has been accomplished primarily by the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, the United States Naval School of Aviation Medicine, Pensacola, Florida, and the Human Resources Research Office of the George Washington University. A bibliography of pilot training research containing over 200 references indicates that certain universities and private agencies also have contributed to this effort⁴.

The gamut of pilot training research accomplished to date contains a variety of projects on the various aspects of learning to fly. Particular areas of pilot training research most closely related to the project being reported herein are studies of the effects of the sequence of flight training on student pilot acquisition of flying skills, and the measurement of pilot performance.

³Alfred F. Smode, Eugene R. Hall, and Donald E. Mayer, <u>An Assessment of Research Relevant to Pilot Training</u>, (Wright-Patterson Air Force Base: Aerospace Medical Research Laboratories, U. S. Air Force Systems Command, 1966), p. 211-241.

⁴Ibid.

Projects concerned with the sequence of flight training on student pilot acquisition of flying skills include research in the integration of contact and instrument techniques, and the use of light aircraft during the initial stages of flight training. Smode, Hall, and Mayer's review of available research indicates that the effects of early integration of instrument and contact instruction are neither well defined nor adequately substantiated, and that after approximately 200 hours of flight experience differences between control and experimental groups disappear. A similar condition was found between control and experimental groups in the value of light plane flight training prior to training in heavier high performance aircraft. However, their assessment indicated that pilot training in light planes could be used profitably to predict specific proficiency criteria during the early stages of primary training.

The relationship of research in the measurement of pilot performance and the project reported herein is particularly significant in that pilot performance measurement provides the basis for possible findings of any nature concerning the value of angle of attack presentation in flight training. Smode, Hall, and Mayer assess the development of an adequate system for pilot performance measurement as one of the prime requirements in aviation human factors research. The principal reason for their viewpoint is the close association of training effectiveness to performance measurement effectiveness. This writer would add that new knowledge in the entire scope of aviation psychology, developed and verified by research is dependent on accurate, reliable and valid pilot psychometrics. While objective pilot performance measurement may be lagging, the field is not without a record of research. During the 1940's specific aspects of light plane performance were measured objectively by employing rudimentary flight recorders and photography of flight instrument readings. The equipment used in early pilot performance measurement experiments was bulky, costly, and required specially equipped aircraft. However, the availability of sophisticated, compact, lightweight recording equipment today paves the way for objective inflight scoring of various aspects of pilot performance. For example, recent experimentation indicates that discrimination among pilots of varying proficiency is possible by instrumenting applicable aircraft systems, obtaining systems output recorded on a 4-channel FM tape recorder, converting tape records to digital tape format, and final analysis using an IBM computer.

Narrative.

(1) In early May 1967, contract negotiation with the Federal Aviation Administration revealed the possibility that Embry-Riddle Aeronautical Institute would be one of two recipients of a contract for the angle of attack project, and that Automated Specialties Division of Teledyne, Inc., would ship government furnished equipment consisting of three angle of attack instrument systems. The preliminary plan for completing the project consisted of three phases to be accomplished as follows:

Phase No. Description Duration

I Preparation: Installation and calibration of instruments in aircraft; organization for execution of the project; completion of performance measurement system; training of instructors.

May-August 1967

Phase No.	Description	Duration			
II	Accumulation of data: Selection and assignment of students; flight training and performance measurement; scoring and collating performance measurement information.	SeptDec. 1967			
III	Analysis of data and preparation of report.	JanFeb. 1968			

(2) In response to Embry-Riddle's request, representatives of Automated Specialties visited Daytona Beach May 10-12, 1967, for the purpose of initial coordination, demonstration of the angle of attack instrument, and study of the aircraft to be used for the project. One of the first considerations requiring study was configuration of the installation of the angle of attack instrument system in a Cessna 150. The most critical element of the system effecting installation configuration was the angle of attack transmitter. This component contains a conical probe which senses changes in the aircraft's angle of attack. Normally the probe protrudes from the fuselage of an aircraft perpendicular to the flow of air. A paddle located inside the transmitter housing is attached to the probe (See Fig. 1.). Both the probe and paddle are free to rotate. Two sets of slots in the probe allow pressure variations, caused by changes in airstream direction, to be transmitted through separate air passages to opposite sides of a paddle chamber. When the pressure acting on one side of the paddle is greater than the other, the paddle and the probe rotate until the pressures are equal. The probe thus positions itself to determine the angle of attack of the aircraft. Position of the probe is registered on a dial located on the aircraft's instrument panel through an electrical system.

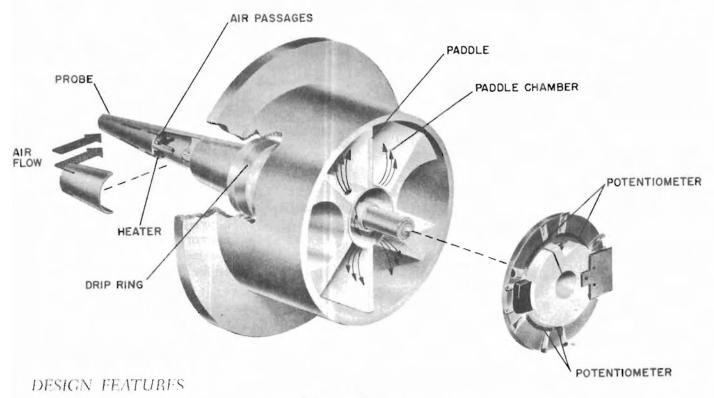


Figure 1. Angle of Attack Indicator Transmitter

In order to function properly the probe must be located at a point free from influences not related to the aircraft's angle of attack. Automated Specialties Division previously had established general criteria for location of the transmitter. The point chosen should be ideally on the side of the fuselage at least two fuselage diameters rear of the nose and at least one wing root chord forward of the leading edge⁵.

However, these rules apply to jets, and the aircraft to be used for this project were propeller driven. Location of the transmitter anywhere on the fuselage of a Cessna 150 would subject the probe to "prop wash". Therefore, it was decided to situate the probe on the wing tip, and to install spill plates to minimize the effect of wing tip vortex. Suitability of the wing tip position of the probe would be determined by a tuft test⁶.

Upon conclusion of preliminary considerations of problems relative to preparation for the project, Automated Specialties Division and Embry-Riddle Aeronautical Institute agreed on the following sequence of events and responsibilities for completing Phase 1:

Task No.	Description	Responsibility of Auto. Spec. E-RAI	
1	Furnish angle of attack system hardward	x	
2	Fabricate spill plates; modify one Cessna 150 accordingly; obtain FAA approval to change classification of this aircraft from utility to experimental category; provide modified airplane for test.	X	
3	Install tufts; conduct in-flight photog-raphy.	X	
4	Provide pilots and second aircraft for photographer.	Х	
5	Analyze test data, determine exact trans- mitter location and possible modifications to spill plates.	x	

⁵Installation and Calibration Instructions for Angle of Attack Transmitter, MR 235B, (Charlottesville; Automated Specialties, A Teledyne Co., 1967), p. 2.

⁶A tuft study for angle of attack transmitter location is conducted by photographing the tuft area from another aircraft flying ... close formation using a long focal length lens. The aircraft under test is flown over the full range of airspeeds available for level flight. Airflow paths are determined by studying the photographs and noting the position of the wool tufts.

Task No.	Description	Responsibility of: Auto. Spec. E-RAI
6	Install angle of attack instrument systems on all three aircraft; provide pilot and aircraft for final flight calibration.	X
7	Furnish technical representation for flight calibration.	Х
8	Obtain Supplemental Type Certificate for Cessna 150 modified with spill plates and angle of attack instrument and accessories installed.	x

(3) Contract FA 67WA-1811 was awarded July 3, 1967, and one Cessna 150 complete with angle of attack system and spill plates was ready for calibration and test on the 15th of July.

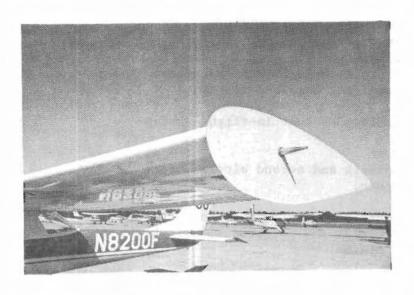


Figure 2.
Spill Plate and Angle of Attack Probe on Cessna 150

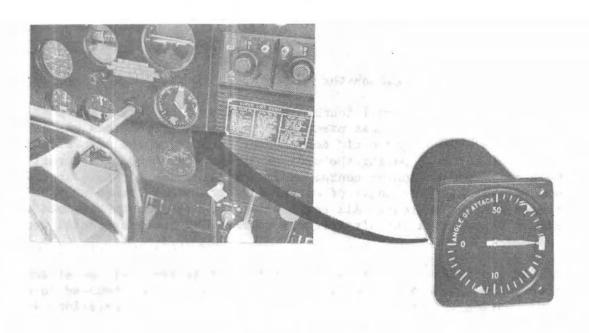


Figure 3. Angle of Attack Indicator Dial

The particular system Automated Specialties Division furnished for this test contained a probe carable of measuring a maximum angle of 30 degrees. However, during the test it was found that the Cessna 150 flight characteristics required the measurement of angles up to 34 degrees. In order to remedy the situation, the system was removed from the airplane and returned to the factory. Automated Specialties Division modified the probes of all three systems accordingly, and returned them to Embry-Riddle. During the remainder of the summer Embry-Riddle completed the following preparatory actions:

- (a) Designation of flight instructors and check pilots.
- (b) Selection and procurement of intelligence test for mental screening of students.
- (c) Submission of application for Supplemental Type Certificate to the FAA Engineering and Manufacturing District Office, Miami, Florida, for modification of a Cessna 150 with spill plates and angle of attack indicating system.
- (4) Whereas initial plans for this project contemplated that flight training of all students would be conducted during the period September-December, 1967, the first group of students did not start until May 1968. The necessity for factory modification of the angle of attack instrument system, and difficulties in satisfying the requirements for a Supplemental Type Certificate for installation of the angle of attack instrument system to include wing tip spill plates in the Cessna 150 were reasons for the delay.
- (5) In early December 1967 an Embry-Riddle representative visited Columbus, Ohio to observe activities relevant to the same type of experiment being conducted at Ohio State University. The most significant information obtained during this visit was the importance to the project of obtaining valid feed-back from the performance measurement system. Therefore, Embry-Riddle personnel reviewed the system intended for use in the project, and determined that the design and planned

utilization method would accomplish the desire purpose.

Ohio State University personnel found that a means of rendering the instrument inoperative by a locking device was needed. The purpose of the lock was to insure that members of the control group did not attempt to operate the aircraft by reference to angle of attack. During the project at Embry-Riddle all aircraft equipped with an angle of attack indicator contained a locking device for this instrument. Keys capable of unlocking the angle of attack indicator were issued only to students in the experimental group. All angle of attack instruments remained in the locked position except when the aircraft was operated by an experimental group student.

- (6) The first group of students available for use in the angle of attack project after award of the Supplemental Type Certificate were scheduled to enroll in early May. During the period 15 March 3 May 1968 final preparations were completed, namely, calibration of all angle of attack instruments by representatives from Automated Specialties Division, procurement of mental aptitude tests for selection of test subjects, orientation of flight instructors in the use of the angle of attack instrument, and completion of the pilot performance measurement system.
- (7) The period early May--mid-November 1968 was devoted to the conduct of flight training for students selected as test subjects and collection of data. A schedule of students completing training under this project is shown in Appendix A. Data collation, analysis, and preparation of preliminary report occurred during the period mid-November--mid-December 1968.

TEXT

Experimental Design

Type of experiment:

Single-variable.

Independent variable:

Introduction of angle of attack indicator

during flight training.

Dependent variable:

Pilot performance as determined by an objective

flight test.

Number samples:

Two (experimental group and control group).

Sample size:

N=15

Basis for selection of sample members:

(1) Scores obtained on a mental aptitude test (California Test of Mental Maturity).

(2) Zero time previous flight training.

Action taken to reduce the influence of factors other than the independent variable:

(1) Flight instructors were assigned an equal number of students in each group.

(2) Instructor differences were minimized by pre-experiment standardization.

(3) Check pilot standardization.

Indication that all test subjects were from the same population as measured by the CTMM: See Appendix B.

Procedures.

Upon completion of the screening process and assignment to either the experimental or control group, student pilots participating in the project attended instruction in Phase I of the Embry-Riddle Professional Pilot Program. This phase consisted of aeronautical training at the private pilot level and included forty-five hours of flight instruction in Cessna 150's (Appendix C) and fifty hours of ground school. The training of each student was identical except flight instruction for the experimental group was conducted using an angle of attack indicator in addition to other instruments contained in the Cessna 150. Information on method of employing the angle of attack indicator in light aircraft flight training during this project is contained in Appendix D. The performance of each student was measured three times during the process of the private pilot course as follows:

- (1) Pre-solo check, flight instruction period #11
- (2) 20-hour check, period #22
- (3) Final check, period #43

Activities relevant to this project were conducted concurrent with the normal flight instruction program of the institution. Ostensibly the only difference between students participating in the project and other Embry-Riddle flight students

was the aircraft used. However, certain other differences existed, viz the use of the angle of attack indicator for students in the experimental group, and the use of a special performance measurement device during check rides for all students participating in the project.

Pilot Performance Measurement.

The design of this project provided for determining the statistical significance of the effects on a dependent variable (pilot performance) by manipulating an independent variable (pilot training method). This determination required that information on performance be recorded and evaluated. A method of describing performance quantitatively, therefore, was necessary. In the interest of producing a valid experiment, these quantitative descriptions must be in consonance with the true ability of the performer. It was concluded that data which accurately describes the performance of the various student pilots for purposes of this experiment were attainable by an objective flight test. However, prepared tests of this nature are neither utilized at this institution, nor were they known to be available from pilot training publications suppliers. Consequently, the construction of an objective flight test was one of the sub-tasks of the angle of attack project. Preparation of this test involved initially an examination of the course of instruction. This study revealed that the objectives of the experiment could be attained by measuring performance during the execution of selected maneuvers contained in the private pilot course. Criteria used for selection of these maneuvers were: (1) requires demonstration of an essential skill of a private pilot except for navigational techniques, and (2) involves angle of attack change.

The following maneuvers were used.

1.	Normal Take-off	10.	Turns about a point
2.	Climbing Turns	11.	Normal Landing
3.	Straight and Level Flight	12.	Missed Approach
4.	Straight and Level Flight at Reduced Airspeed	13.	Cross-Wind Landing
5.	720° Steep Turns	14.	Cross-Wind Take-off
6.	Arrival Stalls	15.	Short Field Landing
7.	Departure Stall	16.	Short Field Take-off
8.	Accelerated Stalls	17.	Soft Field Landing
9.	Gliding Turns	18.	Soft Field Take-off

A Performance Analysis Sheet for each maneuver was prepared. The basic elements of the maneuver were listed on the left hand column of the page. The right hand column contains aphorisms of the most common variations observed among student pilots in executing each maneuver element. An extract of the Performance Analysis Sheet for one of the maneuvers (Straight and Level Flight) used is shown below.

Element or Phase

Manner of Performance

* * * * * * * * * * * *

Altitude Control

- 1. Held proper altitude
- Deviated not more than 100' above
- 3. Deviated more than 100° above
- 4. Deviated not more than 100' below
- 5. Deviated more than 100' below

Power Control

- 1. Regulated power setting as required to maintain proper altitude and airspeed
- 2. Inadequate power control

Heading Control

- 1. Heading held within ±50
- 2. Heading held within ±10°
- 3. Allowed heading to deviate more than $\pm 10^{\circ}$

Performance analysis sheets were assembled into booklets which the examiners used during the three check rides previously described. The pre-solo check involved only maneuvers 1-4, 6, 9 and 11. However, all eighteen maneuvers were scored on the 20-hour and final flight check. A duplicate of the Performance Analysis Booklet

Objectiveness of the performance measurement system used in the project is attributed to the following conditions:

Master Copy is annexed herewith as Appendix E.

- (1) Performance recording and performance scoring were two separate and remote actions.
- (2) Performance recording involved either noting directly the indications of certain aircraft instruments or subjective judgements of only small, well-defined aspects of performance.

Data Collection.

Performance analysis booklets were used to guide the sequence of events of a check ride and provide a means for the examiner to record student performance.

Performance recording was accomplished by placing an "X" over the number of the statement in the right hand column of the appropriate sheet which most accurately described the manner of performance of the particular maneuver element being considered. Only one option was "X-ed" for a given element, but all maneuver elements, as listed in the left hand column of each sheet, were considered for the selection of a performance option.

Upon completion of a specific check ride, the examiner forwarded the Performance Analysis Booklets to the Project Director's office for scoring. The scoring system provided for award of points depending on which items in the right hand column of the various Performance Analysis Sheets were "X-ed". Options warranting award of points, and the number of points allowed are shown in the Master Copy. The number of points per option depends on the relative importance of the particular facet of performance being considered. A zero was awarded for any option "X-ed" in a student's booklet which does not contain an "X" in Appendix E. If the examiner, for example, when considering manner of performance of directional control during takeoff run, had determined that the student veered to the right excessively the examiner would place an "X" over option 1 (See Page E-1). The score for this element of the maneuver, therefore, would be zero. If the examiner "X-ed" option No. 2, the student would receive one point. Additional points for this and other maneuvers were determined by comparing each page of the booklet submitted with the corresponding page of Appendix E. The total score for each maneuver was obtained by adding up the points awarded for the entire maneuver. This score was placed at the lower right hand corner of the final page of the maneuver. Maneuver scores also were transcribed on a Summary Score Sheet, the format of which is contained in Appendix F. Student pilot records relating to this project, therefore, consisted of:

- (1) Student's name
- (2) CTMM score
- (3) Performance Analysis Booklet for pre-solo, 20-hour, and final progress check
 - (4) Completed Summary Score Sheets

A tabulation of scores obtained by all students on the various maneuvers is given in Appendix G. Scores shown in Appendix G were extracted from the individual Summary Score Sheets.

Data Analysis

The significance of the differences between sample means was determined on twenty-two score sets by the analysis of variance method. Score sets used consist of t_1 through t_{18} , X, Y, Z and T, as shown in Table I below.

Table I
Score Sets

	SCORE							
MANEUVER	Pre- Solo	20- Hour	Final	Total				
Normal Take-off				t ₁				
Climbing Turns			_	t ₂				
Straight and Level Flight (Normal Cruise)				t3				
Straight and Level Flight @ Reduced Airspeed				t4				
720 Steep Turns				t5				
Arrival Stalls				t6				
Departure Stalls			-	t7				
Accelerated Stalls				t8				
Gliding Turns				t9				
Turns About a Point		-		±10				
Normal Landing			_	t11				
Missed Approach				t12				
Cross Wind Take-off				±13				
Cross Wind Landing				t14				
Short Field Take-off				t15				
Short Field Landing				t16				
Soft Field Take-off				t17				
Soft Field Landing				t18				
Totals	Х	Y	Z	T				

Score set quantitative values taken from the Summary Score Sheet for each student are summarized in the following tables.

Table II(a)
Score Set Summary

Score Set	101	102	103	104				t al (111	112	113	114	115	Mean	
	_															1	
t1	15	14	10	14	13	11	13	13	8	12	12	14	13	9	15	12.40	
t2	10	14	10	9	10	8	14	14	14	11	9	9	12	12	12	11.20	
t3	18	14	8	11	11	15	13	16	8	11	15	14	17	12	14	13.13	
t4	12	8	15	10	9	12	5	15	9	9	13	11	13	9	14	10.93	-
t5	9	13	5	10	8	10	9	14	10	11	12	13	6	9	9	9.86	
t6	13	15	10	12	15	12	15	18	16	14	18	15	15	10	6	13.60	
t7	9	10	4	10	9	12	12	12	10	12	10	12	12	9	7	10.00	
t8	9	12	3	9	7	12	9	12	12	12	9	6	9	11	. 6	9.20	
t9	11	14	7	12	10	11	11	12	12	10	12	8	10	12	13	11.00	
t10	5	10	4	7	7	7	5	6	6	4	6	5	5	5	6	5.86	
t11	30	27	16	26	15	21	22	26	22	26	23	29	28	17	26	23.60	
t12	7	7	6	6	6	7	8	6	6	7	7	7	5	7	7	6.60	
t13	10	9	6	10	7	9	7	9	6	10	8	9	10	7	7	8.26	
t14	16	11	6	16	7	14	12	15	9	14	10	15	16	13	11	12.33	
t15	8	7	7	10	7	8	8	9	6	6	8	7	10	8	9	7.86	
t16	13	12	8	11	14	11	15	16	13	10	12	11	15	12	11	12.26	
t17	10	7	4	7	6	10	9	7	6	9	8	6	9	8	8	7.60	
t18	11	13	12	13	13	13	15	14	11	14	14	15	15	11	13	13.13	
x	40	34	35	24	27	16	33	31	16	21	26	22	39	17	27	27.20	
Y	79	85	49	92	60	90	77	97	103	89	89	92	87	65	82	82.40	
z	97	98	57	87	87	97	92	106	65	92	91	92	94	99	85	89.26	
T	216	217	141	203	174	203	202	234	184	202	206	206	220	181	194	198.86	

Table II(b)
Score Set Summary

Score Set	201	202	203	204	205			1 Gr 208		210	211	212	213	214	215	Mean	
t1	14	7	13	14	12	14	15	14	13	9	10	13	12	8	13	12.06	
t2	13	8	9	8	10	10	13	12	10	9	9	12	11	9	11	10.26	
t3	14	8	13	13	15	16	10	16	13	10	13	17	14	15	18	13.66	
t4	14	6	12	12	15	15	· 8	16	14	7	10	8	13	13	14	11.80	
t5	9	7	12	11	13	13	7	13	9	9	10	10	13	11	11	10.53	
t6	18	7	15	18	12	13	8	18	15	17	12	15	15	16	7	13.73	
t7	12	6	12	12	12	10	5	12	12	10	12	9	12	12	10	10.53	
t8	9	6	12	9	12	6	4	12	9	11	12	12	12	12	12	10.00	
t9	12	7	14	10	11	13	11	13	9	12	11	14	10	10	12	11.26	
t10	3	7	9	5	10	7	7	7	6	5	5	9	7	6	7	6.66	
t11	20	19	27	30	17	28	21	29	24	16	18	20	24	23	24	22.66	
t12	8	4	7	8	8	6	5	8	7	7	6	8	8	7	6	6.86	
t13	10	5	6	4	10	10	5	9	9	8	9	10	9	8	10	8.13	
t14	7	7	14	16	12	14	13	15	6	10	14	13	14	13	11	11.93	
t15	7	3	7	6	10	10	6	9	9	8	8	9	10	7	9	7.86	
t16	8	5	11	14	12	14	9	14	9	15	14	8	14	15	10	11.46	
t17	9	4	5	7	10	8	5	9	8	6	10	5	9	8	4	7.13	
t18	8	6	16	16	9	15	13	16	12	13	15	14	16	15	8	12.80	
x	37	19	26	36	15	28	30	39	34	20	8	24	21	20	30	25.80	
Y	86	9	101	95	90	101	84	101	75	82	93	86	102	93	94	86.13	
z	72	94	87	82	105	93	51	102	85	80	97	96	100	95	73	87.46	
T	195	122	214	213	210	222	165	242	194	182	198	206	223	208	197	199.40	

		N = 30	K	= 2				
Score Set	Source	Mean Sq. Variance	Derived F	F-ratio .05 df 1&28	Null Hypothesis Failed to Reject Rejected			
t ₁	SSm SSw	.83 11.11	.0749	4.2	x			
t ₂	SSm SSw	6.53 7.79	.8381	4.2	x			
t ₃	SSm SSw	2.13 17.62	.1210	4.2	x			
t ₄	SSm SSw	5.63 19.79	.2845	4.2	x			
t ₅	SSm SSw	3.33 11.34	.2938	4.2	x			
t ₆	SSm SSw	.13 26.96	.0049	4.2	×			
t ₇	SSm SSw	2.13 11.21	.1903	4.2	x			
t ₈	SSm SSw	4.79 16.18	.2965	4.2	×			
t ₉	SSm SSw	.53 7.45	.0715	4.2	x			
^t 10	SSm SSw	4.79 5.92	.8096	4.2	x			
^t 11	SSm SSw	6.53 45.14	.1447	4.2	x			
t ₁₂	SSm SSw	.53 2.25	.2363	4.2	x			
t ₁₃	SSm SSw	.13 7.12	.0187	4.2	x			
t ₁₄	SSm SSw	1.19 21.86	.0548	4.2	x			
t ₁₅	SSm SSw	0.00 5.65	.0000	4.2	x			

Table III (continued)

		Mean Sq.		F-ratio	Null Hypothesis Failed to			
Score Set	Source	Variance	Derived F	.05 df 1&28	Reject	Rejected		
t ₁₆	SSm	4.79						
	SSw	15.43	.3109	4.2	x			
t ₁₇	SSm	1.63						
17	SSw	7.94	.2054	4.2	ж			
^t 18	SSm	.83						
-10	SSw	14.77	.0563	4.2	x			
X	SSm	14.70						
	SSw	151.90	.0967	4.2	x			
Y	SSm	104.53						
1	SSw	785.79	.1330	4.2	x			
Z	CC	24.20						
L	SSm SSw	24.29 393.58	.0617	4.2	ж			
	554	373123	1002,					
T	SSm	2.13						
	SSw	1387.17	.0015	4.2	· x			

^{*}Analysis of variance computations were accomplished by a FORTRAN IV program on an IBM 1130 computer. All numerical quantities are truncated to two places. A summary of the theory concerning analysis of data and use of null hypothesis used in this project is attached herewith as Appendix H.

Instructor Evaluation.

After final check rides for all students participating in the project were completed, the opinion of instructors and check pilots concerning the angle of attack instrument in pilot training was obtained. A total of 10 instructors and check pilots responded to the following questions in the manner indicated:

(1) Question

Your observations of student performance when using an angle of attack instrument in pilot training at the private pilot level indicates that, in general, this instrument:

()	Aids the student.
()	Neither helps nor hinders.

() Is a detriment.

Response

- 2 checked "Aids the student"
- 6 checked "Neither helps nor hinders"
- 2 checked "Is a detriment"

(2) Question

Would a different presentation of angle of attack information than the method provided during this project improve use of this information in pilot training at the private pilot level.

() Yes.

() No.

Response

- 6 checked "Yes"
- 3 checked "No"
- 1 undecided

Opinions on how to change the display varied between a circular display with clock-wise rotation of the needle, and a vertical display.

(3) Question

According to your observation students developed skill in one or more specific maneuvers more readily when learning with the angle of attack indicator.

() Yes.

() No.

Response

6 checked "Yes"

4 checked "No"

The consensus of opinion among instructors responding affirmatively was that the angle of attack instrument materially assisted in maneuvers involving steep ascent and descent.

(4) Question

Would an acceptable angle of attack indicator facilitate learning during any other phase of pilot training that would warrant installation of this instrument and accessories in general aviation aircraft.

() Yes.

() No.

Response

Seven out of ten instructors were of the opinion that the angle of attack indicator would facilitate acquisition of pilot skills during the commercial and instrument phases of training to a degree that would warrant installation of this instrument in general aviation aircraft.

Rational Analysis.

Statistical analysis of the scores obtained during this project indicates unequivocally that the experimental group and the control group were two random samples from the same normally distributed population. On the other hand, the nature of the angle of attack indicator tends to challenge the certainty of this finding. This instrument provides direct reading of the relative wind with reference to the wing which is accurate throughout the speed range of the aircraft. Consequently, the angle of attack indicator reveals performance data directly which only can be approximated using the airspeed indicator. Possible insight relevant to causes for this unharmonious situation may be obtained by consideration of certain factors not evident from an examination of scores.

Information obtained from instructors participating in the project evinced that certain experimental students appeared at times to be confused by the angle of attack indicator. These students all received instruction in the concept of the angle of attack and use of the instrument. However, they were required to develop skill in the use of this instrument in addition to the airspeed indicator and other instruments. Whereas the basic premise of this experiment postulates that the angle of attack indicator will simplify learning to fly, this premise is valid only at such time as the student pilot has acquired a certain minimum ability to properly use the instrument.

An examination of the mean scores tends to verify the initial deleterious effect of having to learn to use the angle of attack indicator in addition to other instruments. The greatest difference in mean scores of score sets X, Y and Z occurred at

the 20-hour check (score Y). The experimental group mean score was 82.4, but the control group attained a mean of 86.13. However, on the final check, the experimental group was superior. They obtained an 8.32% increase in performance on the final check over the 20-hour check. The control group increase in performance was only 1.54%.

This evidence seems to support the assumption that learning to use the angle of attack instrument in addition to other instruments might have impeded the experimental students during the initial moiety of the private pilot program. A method of obviating this possible condition in determining the value of the angle of attack presentation in flight training at the private pilot level appears feasible by substituting angle of attack indicator for the airspeed indicator.

A second consideration which explains the irrational statistical findings is the fact that the private pilot course predominately involves "contact flight techniques", i.e., perception of the attitude of an airplane by visual reference to the horizon. Reference to instruments is required to a slight degree during all phases of private pilot training, and approximately three hours are devoted to piloting "on instruments", but, the total effect of the use of instruments in developing pilot skills at the private pilot level is meager. A significant difference in performance among private pilots attributed to the angle of attack indicator or any other instrument, therefore, would be unusual.

Instrument flight training, conversely, is conducted exclusively by reference to instruments. Upon reaching this stage of training, student pilots are in a better position to appreciate the significance of angle of attack than at the private pilot stage, and learning to use the instrument would be comparatively simple. These facts substantiate the opinion of several of the flight instructors and examiners who participated in this project that the full potential of the angle of attack indicator in flight training could be realized at the instrument pilot level.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that:

- (1) There is no significant difference between students trained in general aviation aircraft at the private pilot level with an angle of attack indicator in addition to other required instruments and students trained in identical aircraft without the angle of attack indicator.
- (2) There are no specific exercises requiring maneuvering skills at the private pilot level that students trained with angle of attack indicator in addition to other required instrumentation could perform better significantly than students trained without this instrument.
- (3) The use of an angle of attack indicator in lieu of the airspeed indicator is a potential method of determining the true value of angle of attack presentation in pilot training at the private pilot level.
- (4) A project to determine the value of angle of attack presentation in instrument flight training would provide a setting for the advantages of this instrument to be realized.

It is recommended that:

- (1) No further consideration be given to using an angle of attack indicator in addition to airspeed for the purpose of improving flight training at the private pilot level.
- (2) Research in the use of angle of attack presentation in flight training be continued.
- (3) Projects be conducted to: (a) determine the value of the angle of attack indicator in place of the airspeed indicator in private pilot training, and (b) determine the value of the angle of attack indicator in instrument flight training.

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STUDENT COMPLETION SCHEDULE

	CONTROL GROUP					EX		TAL GROUP	
***		CTMM					CTMM		
NO.	IDENT*	SCORE	STARTED	COMPLETED**	NO.	IDENT*	SCORE	STARTED	COMPLETED**
1	206	147	6 May 68	10 July 68	1	115	191	6 May 68	12 July 68
2	205	141	6 May 68	10 July 68	2	113	184	15 July 68	20 Sept. 68
3	215	195	6 May 68	27 June 68	3	106	149	5 Aug. 68	1 Nov. 68
4	209	156	5 Aug. 68	21 Nov. 68	4	102	122	5 Aug. 68	31 Oct. 68
5	213	189	5 Aug. 68	11 Oct. 68	5	105	147	5 Aug. 68	16 Nov. 68
6	212	176	5 Aug. 68	7 Oct. 68	6	107	152	5 Aug. 68	18 Nov. 68
7	201	109	5 Aug. 68	12 Sept. 68	7	101	112	5 Aug. 68	19 Sept. 68
8	211	169	5 Aug. 68	19 Sept. 68	8	110	154	5 Aug. 68	30 Oct. 68
9	204	135	5 Aug. 68	21 Nov. 68	9	104	133	5 Aug. 68	31 Oct. 68
10	208	154	5 Aug. 68	21 Nov. 68	10	108	153	9 Sept. 68	19 Nov. 68
11	207	153	9 Sept. 68	6 Nov. 68	11	109	153	9 Sept. 68	11 Nov. 68
12	202	123	9 Sept. 68	21 Nov. 68	12	114	190	9 Sept. 68	15 Oct. 68
13	214	193	9 Sept. 68	28 Oct. 68	13	111	160	9 Sept. 68	15 Oct. 68
14	203	134	9 Sept. 68	5 Nov. 68	14	112	163	9 Sept. 68	16 Nov. 68
15	210	158	9 Sept. 68	15 Nov. 68	15	103	133	9 Sept. 68	20 Nov. 68

^{*}Computer identification number...based on relative standing on CTMM **Date of final check ride

NOTE: A total of 38 students participated in the project, but eight were dropped because of disenrollment or unusually long interruptions in attendance.

TEST OF SIGNIFICANCE OF DIFFERENCE
BETWEEN THE MEANS OF EXPERIMENTAL AND CONTROL GROUP CTMM SCORES

	Experi	mental	<u>Control</u>				
	<u>X</u>	<u>x</u> ²	<u>Y</u>	<u>y</u> ²			
	112	12,544	109	11,881			
	122	14,884	123	15,129			
	133	17,689	134	17,956			
	133	17,689	135	18,225			
	147	21,609	141	19,881			
	149	22,201	147	21,609			
	152	23,104	153	23,409			
	153	23,409	154	23,716			
	153	23,409	156	24,336			
	154	23,716	158	24,964			
	160	25,600	169	28,561			
	163	26,569	176	30,976			
	184	33,856	189	35,721			
	190	36,100	193	37,249			
-	<u>191</u>	<u>36,481</u>	<u>195</u>	38,025			
Sum of X= 2	2,296	Sum of $X^2 = 358,860$	Sum of $Y=2,332$	Sum of $Y^2 = 371,638$			
N=	15		N= 15				
Mx=	153.06		My= 155.47				
$Mx^2=23$	3,427.36		$My^2 = 24,170.92$				
Sx=	22.28		Sy= 24.59				
Smx=	5.96		Smy= 6.57				
		S 1 2 5 5 0 0 7					

Sdiff=8.87 CR= .2717 Not Significant at the 5% Level Table of t ratios: df=14

EMBRY-RIDDLE AERONAUTICAL INSTITUTE

PRIVATE PILOT COURSE

(Angle of Attack Project)

EMBRY-RIDDLE AERONAUTICAL INSTITUTE

DAYTONA BEACH, FLORIDA

PROFESSIONAL PILOT FLIGHT TRAINING SYLLABUS PRIMARY & BASIC FLIGHT

<u>PURPOSE</u>: To qualify the student in fundamental maneuvers and techniques required for solo flight; basic maneuvers, techniques and flight knowledge required for control of the aircraft by visual and instrument reference; flight planning and air navigation techniques necessary for the conduct of safe cross-country flight during daylight hours; elementary night operation; and the procedures necessary for the award of a private pilot's certificate.

NOTE: This syllabus standardizes the primary & basic flight course within limitations. The syllabus should not be considered a rigid blueprint to be strictly adhered to under all circumstances. The instructor recognizing the individual differences do exist among students, should feel free to make adjustments to take these differences into account. However, satisfactory completion of all materials contained in the syllabus is prerequisite to the advanced flight course and must therefore be accomplished by the student within the prescribed time.

LESSON NO. 1 ORAL

A discussion of the forces acting on the aircraft in flight, axes, function of the controls (including trim-tabs and flaps), instruments and their elementary functions. Demonstration and instruction of complete preflight procedures in detail; explanation of check list and its use.

READING ASSIGNMENT: Chapters 1 thru 7, Student Pilot Flight Manual

THIS PERIOD: Dual Solo S.I.* Oral

TOTAL

LESSON NO. 2 DUAL

REVIEW:

- (1) Preflight procedures; visual inspection of aircraft
- (2) Use of checklist

DEMONSTRATE: (Orientation Flight)

- (1) Engine starting and stopping
- (2) Taxiing
- (3) Pre-take-off procedures
- (4) Radio procedures
- (5) Effect and use of controls
- (6) Pitch and Bank reference to straight and level flight VR, IR
- (7) Medium banked turns
- (8) Orientation to practice area (point out landmarks and physical features he can use for orientation)

*S.I.--Simulated Instruments

(1) Importance of being orientated (2) Being relaxed (3) Looking around (4) Flying safety READING ASSIGNMENT: Chapters 8 & 9 (pages 39-53) Student Pilot Flight Manual. THIS PERIOD: Dual 1.0 Solo S.I. Oral TOTAL (1.0)LESSON NO. 3 DUAL REVIEW: (1) Visual inspection; use of Checklist (2) Starting and stopping engine(3) Taxiing technique and use of brakes (4) Pre-take-off procedures (5) Use of controls DEMONSTRATE: (1) Take-off (2) Climbs and climbing turns; correction torque, "P" factor, etc. (3) Level off procedure (4) Straight and level flight (5) Gentle and medium turns (6) Use of trim (7) Altitude and directional control by visual reference (8) Altitude and directional control by instrument reference (9) Glides and gliding turns PRACTICE: (1) Altitude and directional control (2) Climbs and climbing turns (3) Glides and gliding turns (4) Level off from climbs (5) Level off from glides (6) Level turns (7) Division of attention; looking around (8) Use of trim (9) Use of section lines for turns STRESS: (1) Looking around (2) Staying relaxed (3) Remaining oriented READING ASSIGNMENT: Chapter 12, Student Pilot Flight Manual. THIS PERIOD: Dual 1.0 Solo S.I. .2 Oral .2) LATOT (2.)LESSON NO. 4 DUAL REVIEW: (1) Visual check (2) Material given in Lessons 2 and 3

STRESS:

(3) Visual reference and instrument reference for four fundamentals of flight

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- (1) Slow flight without flaps VR, IR
- (2) Use of flaps
- (3) Confidence maneuvers
- (4) Coordination exercises

PRACTICE:

- (1) Climbs and glides; climbing turns and gliding turns(2) Level flight and turns
- (3) Use of trim tabs
- (4) Coordination of pitch and power
- (5) Level offs from climbs and glides; directional control STRESS:
 - (1) Alertness and division of attention looking around
 - (2) Use of control pressure and not movement in the air
 - (3) Proper torque correction
 - (4) Use of Checklist

READING ASSIGNMENT: Review Chapters 9, 10 and 12 Student Pilot Flight Manual.

THIS PERIOD: Dual 1.0 Solo S.I. .2 Oral TOTAL. (3.0)(.4)

LESSON NO. 5 DUAL

REVIEW:

- (1) Coordination Exercises
- (2) Four fundamentals of flight

DEMONSTRATE:

- (1) Power off stalls
- (2) Power on stalls
- (3) Stall demonstration as instructor feels necessary
- (4) Simple F.L. and emergency procedures

PRACTICE:

- (1) Climbs and glides; climbing and gliding turns
- (2) Straight and level flight at various airspeeds
- (3) Power off and power on stalls
- (4) Coordination exercises

STRESS:

- (1) Division of attention head out of cockpit
- (2) Staying relaxed and ways to accomplish this
- (3) Use of pressure on controls
- (4) Altitude, directional and bank control by visual reference
- (5) Good safe flying habits

READING ASSIGNMENT: Chapter 11, Student Pilot Flight Manual and FAR's 61 and 91 Complete pilot's questionnaire - Primary Trainer

THIS PERIOD: Dual 1.0 Solo S.I. Oral LATOT (4.0)(.4)

LESSON NO. 6 ORAL

Discussion of local ground and air traffic patterns and rules; engine out and radio failure emergencies; communications procedures and light signals. Review pertinent sections of FAR's 61 and 91.

READING ASSIGNMENT: Chapters 13 and 14, Student Pilot Flight Manual
THIS PERIOD: Dual Solo S.I. Oral TOTAL (4.0) (.4)
LESSON NO. 7 DUAL, REVIEW:
(1) Basic flying techniques - four fundamentals(2) Power on and off stalls
DEMONSTRATE:
(1) Wind drift correction (2) S Turns
(3) Rectangular courses
 (4) Spacing by reference to aircraft on rectangular course at 800' (5) Engine failure on take-off (6) Steep turns
PRACTICE:
 (1) As necessary to begin to understand wind drift, "S" turns, rectangular course (2) Forced landings; emergency procedures (3) Forced landings on take-off STRESS:
(1) Proper drift correction
(2) Any maneuver or procedure that needs emphasis(3) Staying oriented; looking around
READING ASSIGNMENT: Review chapters 12 and 13, Student Pilot Flight Manual
THIS PERIOD: Dual 1.0 Solo S.I. Oral TOTAL (5.) (.4)
LESSON NO. 8 DUAL REVIEW:
(1) Wind drift correction, "S" turns, rectangular course
(2) Climbing and gliding turns
(3) Power on and off stalls (4) Slow flight
DEMONSTRATE:
(1) Take-off (2) Slips, forward and side
(3) Accelerated stalls
(4) High altitude emergencies (5) Power approach and landing
PRACTICE:
(1) Power off stalls
(2) Rectangular course (3) Forward and side slips
STRESS:
(1) Wind drift correction as related to rectangular course (traffic pattern)(2) Visualizing flight path over the ground
READING ASSIGNMENT: None
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THIS PERIOD: Dual 1.0 Solo S.I2 Oral TOTAL (6.0) (.6)

LESSON NO. 9 DUAL

REVIEW:

(1) All basic maneuvers - instructor will work with student in any area necessary to improve basic flying technique

DEMONSTRATE:

- (1) Aborted take-off
- (2) Overshooting and undershooting procedures
- (3) Go-around procedures
- (4) Slip method of drift correction on final approach
- (5) Full stall landings

PRACTICE:

- (1) All previous lessons as necessary
- (2) Take-offs and landings
- (3) Traffic pattern and traffic pattern entry
- (4) (If cross wind) Slip method of drift correction on final approach STRESS:
 - (1) Torque corrections as necessary for proper coordination
 - (2) Alertness on ground and in the air

 - (3) Keeping area cleared
 (4) Altitude and airspeed control in traffic
 - (5) Proper drift correction in traffic pattern (crab)
 - (6) Proper spacing
 - (7) Proper radio procedure

READING ASSIGNMENT: None

THIS PERIOD: Dual 1.0 Solo S.I. Oral TOTAL (7.0).6)

LESSON NO. 10 DUAL

REVIEW:

- (1) Traffic patterns
- (2) Proper spacing in traffic
- (3) Any weak points student may have
- (4) Take-off and landing

DEMONSTRATE:

- (1) Elevator trim tab stall demonstration at instructor's discretion
- (2) Cross-control stalls; departure stalls; arrival stalls
- (3) Turns about a point
- (4) Slow flight with flaps
- (5) Stalls with flaps

PRACTICE:

- (1) Slow flight
- (2) Power on and power off stalls
- (3) Traffic pattern and landings
- (4) Go-arounds

STRESS:

- (1) Traffic entry
- (2) Spacing in traffic(3) Flying traffic pattern in a rectangular pattern
- (4) Courtesy and common sense
- (5) Necessity of being alert

READING ASSIGNMENT: Review Part 91, FAR, in preparation for solo flight

THIS PERIOD: Dual 1.0 Solo S.I. Oral TOTAL (8.0) (.6)

NOTE: Before Lesson No. 11 can be given, student must have passed the E-R pre-solo written on FAR, aircraft operation, local rules and regulations and must have passed a blindfold cockpit check given by his instructor. (It is suggested that the instructor let the student sit in the aircraft for a few minutes to familiarize himself with the particular aircraft in which the cockpit check will be given.)

LESSON NO. 11 PRE-SOLO PROGRESS CHECK

PURPOSE:

- (1) To see if the student will be able to solo and to continue in the program. A grade of no less than "C" is necessary for the student to continue. Less than a "C" will require that the student be given a minimum of two hours additional training before he can continue with regular program.
 MANEUVERS:
 - (1) Student will demonstrate his ability to perform any of the maneuvers that have been covered to this point.

READING ASSIGNMENT: None

THIS PERIOD: Dual .7 Solo S.I. Oral TOTAL (8.7) (.6)

LESSON NO. 12 DUAL AND SOLO (OR DUAL)

REVIEW:

- (1) As necessary to prepare student for first supervised solo flight PRACTICE:
- (1) Basic maneuvers in which student is weak STRESS:
 - (1) Good basic flying and correct techniques. Student should be able to correct bad landings, abort take-off that is not correct, go around instead of landing
 - (2) His responsibility in traffic, clearing runway, etc.

NOTE: If the student is ready for solo, the instructor should have previously taken care of all tests and paper work. If student does not solo during this lesson he must be soloed on extra training slips. Lessons No. 13 and 14 will be the 2nd and 3rd supervised solo.

READING ASSIGNMENT: Chapter 18, Page 115, Flap Operation, Student Pilot Flight Manual

THIS PERIOD: Dual .6 Solo .7 S.I. Oral TOTAL (9.3) (.7) (.6)

LESSON NO. 13 SOLO (SUPERVISED)

READING ASSIGNMENT: None

THIS PERIOD: Dual .5 Solo .7 S.I. Oral (9.8) (1.4) (.6)

LESSON NO. 14 SOLO (SUPERVISED)

READING ASSIGNMENT: None

THIS PERIOD: Dual .5 Solo .6 S.I. Oral TOTAL (10.3) (2.0)(.6) LESSON NO. 15 SOLO This is the student's first completely solo flight. Instructor will supervise preflight activity and determine satisfactorily weather conditions and that student will remain in the traffic pattern during this period and practice landings and take-offs. At least five landings and take-offs should be accomplished. READING ASSIGNMENT: None THIS PERIOD: Dual 1.0 S.I. Solo Oral (3.0)TOTAL (10.3)LESSON NO. 16 SOLO Student will remain in the traffic pattern and practice take-offs and landings. At least five take-offs and landings will be completed. READING ASSIGNMENT: None THIS PERIOD: Dual Solo 1.0 S.I. Oral (10.3)(4.0)TOTAL LESSON NO. 17 DUAL (AREA CHECKOUT) REVIEW: (1) Power on and off stalls (2) Steep turns (3) Slow flight(4) Boundaries of practice area **DEMONSTRATE:** (1) VOR basic orientation, tracking to the station (2) IR - turns by magnetic compass (3) Use of map by student in practice area STRESS: (1) Traffic pattern entry (2) Correct spacing in pattern (3) Remaining alert at all times READING ASSIGNMENT: Review chapters 9, 12 (pages 63-71), 13 and 14, Student Pilot Flight Manual THIS PERIOD: Dual 1.0 Solo S.I. .3 Oral (11.3) (4.0) (.9)TOTAL

LESSON NO. 18 SOLO

REVIEW AND PRACTICE:

- (1) Climbs and climbing turns
- (2) Clearing turns (Prior to flow flight and stalls minimum altitude for recovery from stalls is 1500' AGL)
- (3) Slow flight 090° 180° turns with and without flaps
- (4) Accelerated stalls, power on and off stalls
- (5) As directed by instructor

READING ASSIGNMENT: None

THIS PERIOD: Dual Solo 1.0 S.I. Oral

TOTAL (5.0)(11.3)(.9)

LESSON NO. 19 SOLO

REVIEW:

(1) As directed by instructor

READING ASSIGNMENT: None

THIS PERIOD: Dual Solo 1.0 S.I. Oral

(11.3)(6.0) (.9)TOTAL

LESSON NO. 20 DUAL

REVIEW:

- (1) Turns about a point
- (2) All stalls, arrival, accelerated, departure stall entry
- (3) Slow flight with and without flaps (4) Forward and side slips
- (5) Steep turns of 360° to be increased to 720° when student is ready DEMONSTRATE:
 - (1) Around pylon 8's
 - (2) More complicated forced landings than those given previously
- (3) Short field take-offs and landings, soft field take-offs and landings PRACTICE:
- (1) As necessary for above named flight maneuvers STRESS:
 - (1) Student's weak points
 - (2) Precision flying
 - (3) Alertness and division of attention

READING ASSIGNMENT: Review chapters 12, 14 and 15, Student Pilot Flight Manual

.2 Oral 1.0 Solo THIS PERIOD: Dual s.I. (6.0)TOTAL (12.3)

LESSON NO. 21 SOLO

PRACTICE:

(1) As directed by instructor

READING ASSIGNMENT: Chapters 9 (pages 51-53), 11, 13 and 18 (pages 113-114)

Student Pilot Flight Manual

THIS PERIOD: Dual Solo 1.0 S.I. Oral TOTAL (7.0)(1.1)(12.3)

LESSON NO. 22 PROGRESS CHECK

During this period the student shall demonstrate to the check pilot his knowledge of all techniques and procedures learned in the preceding periods of dual instruction. The student will be evaluated on the basis of judgment, planning, knowledge of procedures, coordination and smoothness. The student must achieve an overall grade of average on this progress check prior to continuation of the program. In the event of an unsatisfactory grade the individual instructor will give the student at least two hours of additional dual instruction followed by a re-check. This progress check must be successfully completed prior to the start of Lesson No. 23.

READING ASSIGNMENT: None

THIS PERIOD: Dual .7 Solo S.I. Oral TOTAL (13.0) (7.0) (1.1)

LESSON NO. 23 SOLO

PRACTICE:

(1) As directed by instructor

READING ASSIGNMENT: None

THIS PERIOD: Dual Solo 1.0 S.I. Oral TOTAL (13.0) (8.0) (1.1)

LESSON NO. 24 SOLO

PRACTICE:

(1) Student will practice particular maneuvers as specified by the instructor using techniques for correcting errors he suggests

READING ASSIGNMENT: None

THIS PERIOD: Dual Solo 1.0 S.I. Oral TOTAL (13.0) (9.0) (1.1)

LESSON NO. 25 ORAL

Discussion shall include map preparation, checking weather prior to departure, use of computor, Airman's Information Manual and other publications necessary for cross-country planning and preparation, flight log preparation, completion of flight plan form, methods of filing flight plan and a review of cross-country procedures as outlined in the school student operations manual. The instructor should emphasize to the student the importance of observing changes in the weather from forecast conditions while enroute and of avoiding flying over cloud formations. Procedures to follow when lost or when inadvertently entering instrument flight conditions should be reviewed in detail. Use of radio aids to navigation with emphasis on VOR should be included.

READING ASSIGNMENT: Chapter 21 (pages 129-131 VOR), Student Pilot Flight Manual

THIS PERIOD: Dual Solo S.I. Oral TOTAL (13.0) (9.0) (1.1)

LESSON NO. 26 DUAL (CROSS-COUNTRY)

Pre-flight disucssion shall include pre-flight planning, plotting of the course, pre-paring flight log, weather briefing, filing flight plan (FVFR and explanation of DVFR), procedures to follow when lost. During the flight, the instructor will super-vise and instruct the student in dead reckoning navigation, pilotage, communications procedures to include position reporting, obtaining weather information, making changes of flight plan enroute and the use of radio navigation aids. At least one landing will be made at a strange field during the course of the flight. In instances

where the home base or point of departure is not equipped with a control tower, the flight will be planned so that the required strange field landing is made at an airport served by a control tower and requiring the use of functioning two-way radio communications. Planned duration of this flight is three hours.

READING ASSIGNMENT: Review thoroughly Part 4 (pages 119-156), Student Pilot Flight Manual

THIS PERIOD: Dual 3.0 Solo S.I. .3 Oral TOTAL (16.0) (9.0) (1.4)

LESSON NO. 27 SOLO

PRACTICE:

- (1) Climbs and climbing turns to altitude
- (2) Slow flight with full flaps
- (3) Climb at slow flight
- (4) Descents at slow flight
- (5) Short field take-offs and landings as directed by instructor
- (6) Soft field take-offs and landings as directed by instructor

READING ASSIGNMENT: FAA Flight Training Handbook (as directed by instructor)

THIS PERIOD: Dual Solo 1.0 S.I. Oral TOTAL (16.0) (10.0) (1.4)

LESSON NO. 28 SOLO

PRACTICE:

- (1) Climb and climbing turns to altitude
- (2) Departure stalls, arrival stalls, accelerated stalls
- (3) Spiral Right and left to 1500'
- (4) Around pylon 8's
- (5) As directed by instructor

READING ASSIGNMENT: FAA Flight Training Handbook (as directed by instructor)

THIS PERIOD: Dual Solo 1.0 S.I. Oral TOTAL (16.0) (11.0) (1.4)

LESSON NO. 29 DUAL

Review:

- (1) Basic instrument flying techniques straight and level, standard rate turns, constant airspeed climbs and descents and turns, magnetic compass
- (2) VOR turning and tracking
- (3) High and low level emergency
- (4) Around pylon 8's rectangular course, "S" turns, 720'/pt
- (5) All stalls
- (6) Slow flight full flaps
- (7) Stalls with flaps
- (8) 360° Overhead

DEMONSTRATE:

- (1) Spirals, 1080° overhead
- (2) Short field take-offs and landings with cross-wind
- (3) Soft field take-offs and landings with cross-wind

- (4) Accuracy landings
- (5) 180° side approach

PRACTICE:

- (1) As demonstrated by instructor
- (2) As needed by particular student STRESS:
 - (1) Looking around
 - (2) Planning and judgment
 - (3) Positive aircraft control

READING ASSIGNMENT: FAA Flight Training Handbook and E-RAI Basic Instrument Handbook (as directed by instructor)

THIS PERIOD: Dual 1.0 Solo S.I. .2 Oral TOTAL (17.0) (11.0) (1.6)

LESSON NO. 30 SOLO

PRACTICE:

(1) As directed by instructor

READING ASSIGNMENT: FAA Flight Training Handbook and E-RAI Basic Instrument Handbook (as directed by instructor)

THIS PERIOD: Dual Solo 1.0 S.I. Oral TOTAL (17.0) (12.0) (1.6)

LESSON NO. 31 SOLO

PRACTICE:

(1) As directed by instructor

READING ASSIGNMENT: FAA Flight Training Handbook and E-RAI Basic Instrument Handbook (as directed by instructor)

THIS PERIOD: Dual Solo 1.0 S.I. Oral TOTAL (17.0) (13.0) (1.6)

LESSON NO. 32 ORAL

The instructor will discuss with the student the essential differences between day and night vision, the preservation of night vision, proper cockpit lighting, the importance of having within reach a serviceable flashlight, navigation lights and interpretation and the use of landings lights. Prior to night flight, the student should be able to accomplish satisfactorily a blindfold cockpit check in the aircraft to be utilized. Discussion should be terminated with a review of airport and obstruction lighting systems.

READING ASSIGNMENT: None

THIS PERIOD: Dual Solo S.I. Oral TOTAL (17.0) (13.0) (1.6)

LESSON NO. 33 DUAL (NIGHT)

Introduce and discuss and practice runway alignment and take-offs techniques, controlled "sink-rate" approaches, and night landing techniques, with and without the

use of landing light. Practice take-offs and landings until the student is safe for solo night flight.

READING ASSIGNMENT: Chapters 23, 24 and 25 Student Pilot Flight Manual

THIS PERIOD: Dual 1.0 Solo S.I. .2 Oral TOTAL (18.0) (13.0) (1.8)

LESSON NO. 34 PROGRESS CHECK

The student shall demonstrate his knowledge of pre-flight planning and the actual application of cross-country flying techniques and procedures to the check pilot. He must complete this progress check with an overall grade of average or above before he can continue with his solo cross-country requirements.

READING ASSIGNMENT: None

THIS PERIOD: Dual 1.0 Solo S.I. Oral TOTAL (19.0) (13.0) (1.8)

LESSON NO. 35 SOLO (CROSS-COUNTRY)

This will be the student's first solo cross country flight. All pre-flight planning, etc. will be personally and strictly supervised by the instructor. The flight shall be over a triangular course and of two hours total duration. The course shall be selected so as to provide maximum utilization of dead reckoning and pilotage techniques and at least one leg utilizing radio aids shall be included.

READING ASSIGNMENT: None

THIS PERIOD: Dual Solo 2.5 S.I. Oral TOTAL (19.0) (15.5) (1.8)

LESSON NO. 36 DUAL (OR PROGRESS CHECK - See Lesson No. 43 if Progress Check) REVIEW:

(1) All private pilot maneuvers including ground reference maneuvers

READING ASSIGNMENT: None

THIS PERIOD: Dual 1.0 Solo S.I. .2 Oral TOTAL (20.0) (15.5) (2.0)

LESSON NO. 37 SOLO

PRACTICE:

(1) As directed by instructor

READING ASSIGNMENT: None

THIS PERIOD: Dual Solo 1.0 S.I. Oral TOTAL (20.0) (16.5) (2.0)

LESSON NO. 38 SOLO (CROSS-COUNTRY)

This is the student's second solo cross-country flight. The flight shall be conducted over a course of at least three legs, one of which is to be a destination located at a distance equal to 1.5 hours of flight at cruising speed, no wind, in the aircraft used from the point of departure. Dead reckoning combined with pilotage

and radio aids shall be the means of navigation. The flight should be of 3.5 hours duration.

READING ASSIGNMENT: None

THIS PERIOD: Dual Solo 3.5 S.I. Oral

(20.0) (20.0) (2.0)

LESSON NO. 39 DUAL

REVIEW:

(1) All maneuvers VR, IR as given in this program

READING ASSIGNMENT: None

s.I. 1.0 Solo THIS PERIOD: Dual .3 Oral

TOTAL (21.0) (20.0)(2.3)

LESSON NO. 40 SOLO

PRACTICE:

(1) As directed by instructor

READING ASSIGNMENT: None

THIS PERIOD: Dual Solo 1.0 S.I. Oral

TOTAL (21.0)(21.0) (2.3)

LESSON NO. 41 DUAL

REVIEW AS NEEDED:

- (1) All stalls including stalls with flaps
 (2) 720° steep turns
- (3) Slow flight at minimum controllable airspeed
- (4) Coordination exercises(5) Spirals, 1080 overhead, forced landings
- (6) Around pylon 8's, 720/pt
- (7) Short and soft field take-off's and landings, slips
- (8) Power approaches, accuracy landings

READING ASSIGNMENT: Private Pilot's Test Guide, Private Pilot's Manual, Student

Pilot Flight Manual, E-RAI Basic Instrument Handbook, FAA Flight

Training Handbook and FAA 61-21

THIS PERIOD: Dual 1.0 Solo .2 Oral s.I.

(22.0) (21.0) (2.5)TOTAL

LESSON NO. 42 SOLO

PRACTICE:

(1) As directed by instructor

READING ASSIGNMENT: None

1.0 S.I. TOTAL PERIOD: Dual Solo Oral

(22.0) (22.0) (2.5)TATOT

LESSON NO. 43 PROGRESS CHECK

The primary and basic flight program is now complete and during this period the student should demonstrate to the check pilot his knowledge of flight, with the proficiency of a private pilot. This check shall be conducted in accordance with the procedures outlined in Federal Aviation Agency Advisory Circular 61-3. The check pilot shall indicate in his final report any and all areas in which the student is below average. The student must receive a final overall grade of average or "C" in order to successfully complete the program. Should the student fail to satisfactorily accomplish any phase of this final check, the individual instructor may give two hours of additional dual instruction to correct the student's weaknesses. A re-examination in these phases will then be required. Upon unsatisfactory completion of this final check the instructor will complete the student's files including the FAA Form 355 and cumulative flight record. The student will then be recommended for the private pilot's flight test with the appropriate FAA representative.

READING ASSIGNMENT: None

THIS PERIOD: Dual 1.0 Solo S.I. .3 Oral

TOTAL (23.0) (22.0) (2.8)

USE OF THE ANGLE OF ATTACK INDICATOR

The following extracts were taken from a Memorandum to flight instructors and students of the experimental group on use of the angle of attack indicator:

* * * * * * * * * * * *

The dial of the instrument is graduated in thirty units. These units are not degrees of angle of attack, but are purely arbitrary reference units. Use of the instrument requires knowledge of which reference unit pertains to the particular maneuver contemplated. The first reference indicates zero lift and is located at the 5 unit index. Since this index corresponds to the angle of attack for zero lift, flight at this reading would be impossible. The second index is at the 15 unit mark. This is called the approach roger. This index is the optimum approach angle and is based on an airspeed of 1.3 VSO. The 15 unit mark also is the angle of attack for the best rate of climb. The next index on the dial (18½ units) indicates the angle of attack for the best glide. This reading also is the same for the angle of attack for maximum range. The last marked index on the dial is the stall index at 25 units. When the pointer reaches the 25 mark the stall warning horn is actuated automatically.

4. USE OF THE ANGLE OF ATTACK INDICATOR (AAI)

During the conduct of this project there must be no deviation from the prescribed syllabus, either with Control students or Experimental. This tends to eliminate all differences between the two groups except for the AAI. Members of the Experimental Group will be instructed in use of the AAI as described in the following maneuvers:

- a. Straight and Level Flight—A power setting of 2450 rpm will be used as standard which will give an average indicated airspeed of 97 mph at 2,000 feet. The angle of attack reading is 12 units. It should be pointed out that the difference between zero lift (5 units) and 12 units is the angle of attack needed to support the aircraft in flight at one "G". Any change in weight or thrust would require a corresponding change in the angle of attack which would be reflected by the AAI.
- b. Straight and Level at Reduced Airspeed--This will be accomplished at 60 mph, approximately 2,100 rpm, AAI 21 units.
- c. Turns—Turns will be practiced with varying degrees of bank—up to 45 in level flight. It should be pointed out that during a turn centrifugal force increases the load factor. Therefore additional lift is required which may be obtained by increasing the angle of attack. Banks and turns for purposes of this project will be executed as shown below:
 - (1) Gliding Turns (30° bank) 70 mph, AAI 15 units
 - (2) Climbing Turns (20° bank) 75 mph, AAI 15 units
 - (3) 720° Steep Turns (45° bank) 80 mph, AAI 16.4 units

- d. Stalls—Standard procedures for entry and recovery from all stalls will be employed to include power on and power off stalls with all flap configurations. The comparative reliability of the angle of attack indicator to the airspeed indicator when operating in the stall range should be noted.
- e. Climbs—Normal climbs will be accomplished at 75 mph, AAI 14 units. Best rate of climb will be at the speed of 72 mph, AAI 15 units. Best angle of climb will be at 52 mph, AAI 20 units. Power settings for all climbs will be full throttle.
- f. Approaches—Normal approaches will be made with 20° of flaps, 65 mph airspeed, and AAI 15 units. Short field approaches will be made with 40° of flaps, 58 mph, AAI at 15 units as in the Approach Roger. Here emphasis should be placed on holding the AAI pointer on the approach index which also will provide proper airspeed. Power must be adjusted and coordinated to control descent.

When an angle of attack indicator is installed and calibrated for a given airplane design the instrument should give the same readings for specific maneuvers for all airplanes of the same type. However, slight differences in the rigging of airplanes of the same model produce inequities which are reflected in the AAI. Also, the angle of attack instrument is sensitive to rough air. There is a dampening mechanism incorporated in the system, but rough air still causes the pointer to fluctuate. Therefore, use average indications. Instructors are cautioned to be alert for the student who has a tendency to concentrate his attention on the AAI rather than cross checking with other instruments and flying the airplane with reference to the horizon.

EMBRY-RIDDLE AERONAUTICAL INSTITUTE

PERFORMANCE ANALYSIS BOOKLET

(Master Copy)

NAME OF	STUDENT:			
DATE: _				
PROGRESS	CHECK:	Pre-Solo,	20-Hr.,	Final

Take-off (Normal, Cross-wind, Short Field, Soft Field) Maneuver: Element or Phase Manner of Performance Directional Control during take-off 1. Veered to right or left excessively run / X. Maintained straight path Lift-off as requred by type of 1. Too soon or too late take-off being executed / S. At proper time Attitude immediately after lift-off 1. Nose too high considering type of take-off 2. Nose too low / X. Correct attitude Climb-out flight path 1. Drifted to right 2. Drifted to left / ★. Maintained proper ground track (extension of runway) Attitude during climb-out 1. Nose too high 2. Nose too low 3. Nose oscillated Held correct attitude for maximum rate of climb or angle of climb as

SCO	RE		
	NL		

specified.

Maneuver:

Climbing Turns--Gliding Turns

Element or Phase	Manner	of Performance
Angle of Bank	/ %. Held constant	
	2. Varied excess	ively
Number of degrees of angle of bank	1. 50	6. 30°
	2. 10°	7. 35°
	3. 15°	8. 40°
	/ ж. 20°	
	5. 25°	
Airspeed	/ X. Held constant	
	2. Varied excess	ively
Average Indicated Airspeed	1. 50 /	%. 75
	2. 55	7. 80
	3. 60	8. 85
	4. 65	9. 90
	5. 70	

Climbing Turns--Gliding Turns

Straight and Level Flight (Normal Cruise) Maneuver: Element or Phase Manner of Performance Pitch Attitude Control / \$. Held constantly correct 2. Nose high tendency 3. Nose low tendency Nose position oscillated excessively Altitude Control Held proper altitude 2 X. / X. Deviated not more than 100' above 3. Deviated more than 100' above / X. Deviated not more than 100' below 5. Deviated more than 100' below / **%**. Power Control Regulated power setting as required to maintain proper altitude and airspeed 2. Inadequate power control 2 X. Held heading within ±5° Heading Control / X. Held heading within ±10°

SCORE .	
---------	--

3. Allowed heading to deviate more

than ±10°

maneuver: Si	traight and Level	Flight	at	Reduced Airspeed
<u>Eler</u>	ment or Phase			Manner of Performance
Pitch Attitude (Control	•	水 .	Proper nose position for specified airspeed
			2.	Nose tended to be too high
	· .		3.	Nose tended to be too low
			4.	Nose position oscillated excessively
Altitude Control	1	2	X.	Held proper altitude
			X .	Deviated not more than 100' above
	•		3.	Deviated more than 100' above
•		,	X.	Deviated not more than 100' below
			5.	Deviated more than 100' below
Power Control		,	% .	Regulated power setting as required to maintain proper altitude and airspeed
			2.	Inadequate power control
Heading Control		2	X.	Held heading within ±50
		1	X.	Held heading within ±10°
			3.	Allowed heading to deviate more than $\pm 10^{\circ}$

Stalls (Arrival, Departure and Accelerated)

Element or Phase	•	Manner of Performance
Pre-Stall Procedure	<i>3</i> \$.	Proper sequence
	2.	Inadequate
Recognition of Stall	/ \$.	Recognized at proper time
	2.	Excessive time to recognize
	3.	Did not recognize
Recovery Technique	2 X.	Proper sequence and timing
	2.	Inadequate timing and sequence

Maneuver:

Stalls (Arrival, Departure and Accelerated)

Element or Phase	•	Manner of Performance
Pre-Stall Procedure	<i>3</i> %.	Proper sequence
	2.	Inadequate
Recognition of Stall	/ % .	Recognized at proper time
	2.	Excessive time to recognize
	3.	Did not recognize
Recovery Technique	2 %.	Proper sequence and timing
	2.	Inadequate timing and sequence

SCORE____

Maneuver:

Stalls (Arrival, Departure and Accelerated)

Element or Phase		Manner of Performance
Pre-Stall Procedure	3 X.	Proper sequence
•	2.	Inadequate
Recognition of Stall	/ X.	Recognized at proper time
·	2.	Excessive time to recognize
	3.	Did not recognize
Recovery Technique	2 ×.	Proper sequence and timing
	2.	Inadequate timing and sequence

Maneuver:

720° Steep Turn

Element or Phase

Manner of Performance

Establishment of Turn

- 1. Failed to coordinate elevators with ailerons and rudder while establishing bank
- / X. Established proper angle of bank and turn smoothly and timely with proper power control
 - 3. Insufficient angle of bank or excessive time in establishing bank
 - 4. Failed to add power

Altitude Control During Turn

- / ★. Held proper altitude within ±100'
 - 2. Deviated more than 100' above
 - 3. Deviated more than 100' below

Coordination

*At any time during turn

2 X.



/ **%**.



This or This*

3.



This or This*

Angle of Bank During Turn

- / X. Proper steepness and constant angle
 - 2. Varied excessively

720° Steep Turn

Element or Phase

Manner of Performance

Recovery Heading

- 2 Z. At proper point
- / X. Within ±100 of proper point
 - 3. More than 100 to right or left of proper point

Execution of Roll-Out

- / **K.** Properly coordinated and terminated with nose in proper position with respect to the horizon, and proper power control
 - 2. Properly coordinated, but terminated with nose too high or too low
 - 3. Poor coordination and improper pitch attitude at termination of maneuver (nose too high or too low), and improper power control

SCORE

Maneuver:

Climbing Turns--Gliding Turns

Element or Phase	Manner of Performance
Angle of Bank	/ X. Held constant
	2. Varied excessively
Number of degrees of angle of bank	1. 5° / % . 30°
	2. 10° 7. 35°
	3. 15° 8. 40°
	4. 20°
	5. 25°
Airspeed	/ X. Held constant
	2. Varied excessively
Average Indicated Airspeed	1. 50 6. 75
	2. 55 7. 80
	3. 60 8. 85
	4. 65 9. 90
	/ %. 70

Climbing Turns--Gliding Turns

Element or Phase	•		Manner of Performance
Coordination		2 X	
		/ %.	This or This
		3.	
			This or This

Maneuver: Turns About a Point			
Element or Phase			Manner of Performance
Altitude Control	2	¥.	Altitude varied not more than ±50'
	/	X.	Altitude varied not more than ±100'
		3.	Altitude varied more than ±100'
Coordination	2	¥.	
	,	X.	
			This or This
•		3.	
			This or This
Ground Track	2	¥ .	Perfectly symmetrical, circular and at constant distance from given point
	/	£ .	Moderately symmetrical, circular and at constant distance from given point
		3.	Fairly symmetrical, circular, but inadequate correction for wind drift (center point not same distance from all points on circle)
		4.	Ground track unsymmetrical or not a circle

Landing (Normal, Cross-Wind, Short Field, Soft Field) Maneuver:

			• • • • • •
Element or Phase			Manner of Performance
Traffic Pattern Entry	′	≭ .	At proper angle of intersection with downwind leg, at proper altitude, and proper distance from runway
		2.	Poor entry
Downwind Leg	,	% .	In proper direction and parallel to runway
		2.	Not in proper direction
		3.	Not parallel to runway
Base Leg (considering other traffic)	1	ĸ	Proper position with proper correction for wind drift
		2.	Too close
		3.	Too far out
Turn Onto Final	/	X .	At sufficient safe altitude
		2.	Excessively low
		3.	Excessively high
Alignment with Runway Centerline	,	% .	Properly Aligned
Upon Completion of Turn Onto Final		2.	Too far to right
		3.	Too far to left
Glide Path	,	X .	With proper directional control and proper descent to touchdown at designated

- ated point
 - 2. Erratic glide path
 - 3. Landed when missed approach should have been executed, i.e., landed beyond first 1/3 of runway
 - 4. Had to drag it in

Element or Phase Manner of Performance Round-out and touchdown X. Smooth and accurate 2. Excessive speed and bounce 3. Stall and drop-in Ground Run X Straight with proper use of brakes 2. Veered to right or left Airspeed Control during entire Constant and correct amount for approach and landing type of landing 2. Varied excessively Power Control during entire Properly applied or reduced power to adjust rate of descent as required approach and landing 2. Failed to use power properly

Maneuver: Missed Approach

Initial Sequence of Actions

/ **. Proper sequence

2. Improper sequence

Transition from Descent to Climb

/ **. Smooth and positive

2. Erratic

3. Excessive delay in establishing climb

Heading Control on Climb-Out

**. Held heading within ±50

/ **. Held heading within ±100

3. Allowed heading to deviate more than ±100

Maneuver:

Landing (Normal, Cross-Wind, Short Field, Soft Field)

Element or Phase			Manner of Performance
Base Leg (considering other traffic)	/	¥.	Proper position with proper correction for wind drift
		2.	Too Close
		3.	Too far out
Turn Onto Final	1	¥.	At sufficient safe altitude
		2.	Excessively low
		3.	Excessively high
Alignment with Runway Centerline Upon Completion of Turn Onto Final	/	¥ .	Properly aligned
opon completion of furn onco rinar		2.	Too far to right
		3.	Too far to left
Glide Path	/	¥ .	With proper directional control and proper descent to touchdown at designated point
		2.	Erratic glide path
		3.	Landed when missed approach should have been executed, i.e., landed beyond first 1/3 of runway
		4.	Had to drag it in
Round-out and touchdown	,	K.	Smooth and accurate
		2.	Excessive speed and bounce
		3.	Stall and drop-in

Ground Run

/ X. Straight with proper use of brakes

2. Veered to right or left

Landing (Normal, Cross-wind, Short Field, Soft Field)

Airspeed Control during entire approach and landing Power Control during entire approach and landing / **L Properly applied or reduced power to approach and landing 2. Failed to use power properly

Take-off (Normal, Cross-wind, Short Field, Soft Field) Maneuver: Element or Phase Manner of Performance Directional Control during take-off Weered to right or left excessively run / X. Maintained straight path Lift-off as required by type of 1. Too soon or too late take-off being executed / S. At proper time Attitude immediately after lift-off 1. Nose too high considering type of take-off 2. Nose too low / %. Correct attitude 1. Drifted to right Climb-out flight path 2. Drifted to left / S. Maintained proper ground track (extension of runway) Attitude during climb-out 1. Nose too high 2. Nose too low 3. Nose oscillated Held correct attitude for maximum rate of climb or angle of climb as specified.

SCORE	
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Maneuver:

Landing (Normal, Cross-Wind, Short Field, Soft Field)

Element or Phase

Manner of Performance

Base Leg (considering other traffic) / % Proper position with proper correction for wind drift

- 2. Too Close
- 3. Too far out

Turn Onto Final / %. At sufficient safe altitude

- 2. Excessively low
- 3. Excessively high

Alignment with Runway Centerline
Upon Completion of Turn Onto Final

- / X. Properly aligned
 - 2. Too far to right
 - 3. Too far to left

Glide Path

- / * With proper directional control and proper descent to touchdown at designated point
 - 2. Erratic glide path
 - 3. Landed when missed approach should have been executed, i.e., landed beyond first 1/3 of runway
 - 4. Had to drag it in

Round-out and touchdown

- / X. Smooth and accurate
 - 2. Excessive speed and bounce
 - 3. Stall and drop-in

Ground Run

- / *. Straight with proper use of brakes
 - 2. Veered to right or left

Landing (Normal, Cross-wind, Short Field, Soft Field)

Element or Phase

Manner of Performance

Airspeed Control during entire approach and landing

- / **%.** Constant and correct amount for type of landing
 - 2. Varied excessively

Power Control during entire approach and landing

- / *. Properly applied or reduced power to adjust rate of descent as required
 - 2. Failed to use power properly

Take-off (Normal, Cross-wind, Short Field, Soft Field) Maneuver: Element or Phase Manner of Performance Directional Control during take-off 1. Veered to right or left excessively run / & Maintained straight path Lift-off as required by type of 1. Too soon or too late take-off being executed / %. At proper time Attitude immediately after lift-off 1. Nose too high considering type of take-off 2. Nose too low / % Correct attitude Climb-out flight path 1. Drifted to right 2. Drifted to left / %. Maintained proper ground track (extension of runway) Attitude during climb-out 1. Nose too high 2. Nose too low

3. Nose oscillated

/ X. Held correct attitude for maximum rate

of climb or angle of climb as specified.

Maneuver:

Landing (Normal, Cross-Wind, Short Field, Soft Field)

Element or Phase

Manner of Performance

Element of Phase			Manner of Performance
Base Leg (considering other traffic)	1	% .	Proper position with proper correction for wind drift
		2.	Too Close
		3.	Too far out
Turn Onto Final	/	\$.	At sufficient safe altitude
		2.	Excessively low
	,	3.	Excessively high
Alignment with Runway Centerline Upon Completion of Turn Onto Final	1	\$.	Properly aligned
opon completion of fain onto final		2.	Too far to right
		3.	Too far to left
Glide Path	1	¥.	With proper directional control and proper descent to touchdown at designated point
		2.	Erratic glide path
		3.	Landed when missed approach should have been executed, i.e., landed beyond first 1/3 of runway
		4.	Had to drag it in
Round-out and touchdown	1	x .	Smooth and accurate
		2.	Excessive speed and bounce
		3.	Stall and drop-in
Ground Run	1	*	Straight with proper use of brakes
·		2.	Veered to right or left

Landing (Normal, Cross-wind, Short Field, Soft Field)

Element or Phase

Manner of Performance

Airspeed Control during entire approach and landing

- / *. Constant and correct amount for type of landing
 - 2. Varied excessively

Power Control during entire approach and landing

- / * Properly applied or reduced power to adjust rate of descent as required
 - 2. Failed to use power properly

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Maneuver: Take-off (Normal, Cross-wind, Short Field, Soft Field) Element or Phase Manner of Performance Directional Control during take-off 1. Veered to right or left excessively run / & Maintained straight path Lift-off as required by type of 1. Too soon or too late take-off being executed / X. At proper time Attitude immediately after lift-off 1. Nose too high considering type of take-off Nose too low Correct attitude 1. Drifted to right Climb-out flight path 2. Drifted to left **X.** Maintained proper ground track (extension of runway) Attitude during climb-out 1. Nose too high 2. Nose too low 3. Nose oscillated / W. Held correct attitude for maximum rate

SCORE

of climb or angle of climb as specified.

SUMMARY SCORE SHEET

NAME	CTMM	RAW	SCORE	
GROUP - Experimental or Control				

MANEUVER		SCO	DRE	
MANEOVEK	Pre- Solo	20 Hour	Final	Total
Normal Take-off				
Climbing Turns				
Straight and Level Flight (Normal Cruise)				
Straight and Level Flight @ Reduced Airspeed				
720 Steep Turns				
Arrival Stalls				
Departure Stalls				
Accelerated Stalls				
Gliding Turns				
Turns About a Point			_	
Normal Landing				
Missed Approach				
Cross-wind Take-off				
Cross-wind Landing				
Short Field Take-off				
Short Field Landing				
Soft Field Take-off				
Soft Field Landing				
Totals				

DETAILED SCORES PRE-SOLO FLIGHT CHECK

							Ex	peri	menta	1 G:	roup											C	ontr	01 G	roup						
Maneuver	Max. Score	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215
Normal T-O	5	5	5	5	4	5	2	5	4	1	4	3	4	5	2	5	5	2	3	5	2	4	5	5	5	2	0	3	3	4	4
Climbing Turn	6	4	3	4	4	3	2	6	4	4	3	3	0	4	3	2	4	2	3	3	1	3	5	4	3	2	0	3	2	2	1
S&L Flt.(Nor. Cr.)	6	6	5	5	3	5	3	4	4	0	2	4	3	6	3	3	5	2	3	5	4	5	2	6	5	2	3	5	4	4	6
S&L Flt.(Reduced A/S)	6	5	1	6	0	2	4	3	3	0	1	3	2	5	2	3	5	1	2	4	5	5	2	5	6	2	1	3	2	1	3
720 ⁰ Steep Turns																															
arrival Stalls	6	6	6	6	3	6	0	6	6	4	2	6	3	6	1	1	6	1	4	6	0	1	3	6	6	5	0	3	3	4	3 ·
eparture Stalls																															
ccelerated Stalls																															•
Cliding Turns	6	4	6	3	4	3	2	5	4	4	2	3	0	4	2	4	4	2	4	3	2	2	4	4	3	4	4	4	2	1	4
urns About a Pt.																															
ormal Landing	10	10	8	6	6	3	3	4	6	3	7	4	10	9	4	9	8	9	. 7	10	1	8	9	9	6	3	0	3	5	4	9
issed Approach		•	•																										. •		
ross-Wind T-O																															
cross-Wind Ldg.																															
Short Field T-O																															
hort Field Ldg.																															
oft Field T-O																															
oft Field Ldg.																	•														

DETAILED SCORES 20-HOUR FLIGHT CHECK

									menta															o1 G							
Maneuver	Max. Score		102	103	104	105	106	107	108	109	110	111	112	113	114	115	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215
Normal T-O	5	5	4	2	5	3	4	3	4	5	4	5	5	4	4	5	4	0	5	4	5	5	5	4	4	3	5	5.	5	1	5
Climbing Turn	. 6	3	5	3	3	4	2	4	5	6	4	3	4	5	4	5	5	2	3	3	4	3	3	4	5	4	6	4	3	3	5
S&L Flt.(Nor. Cr.)	6	6	5	3	6	2	6	3	6	6	5	5	6	5	3	5	4	0	4	6	5	6	3	5	5	5	6	6	5	5	6
S&L Flt.(Reduced A/S)	6	1	5	4	6	5	5	2	6	5	. 3	4	6	3	3	6	5	1	4	5	5	5	3	5	3	4	5	1	6	6	6
720° Steep Turns	8	3	6	3	6	3	6	3	7	7	5	6	7	3	3	4	4	1	7	6	6	6	5	7	3	7	4	3	6	7	6
Arrival Stalls	6	6	3	1	3	3	6	3	6	6	6	6	6	3	3	1	6	0	5	6	6	6	4	6	3	6	6	6	6	6	3
Departure Stalls	6	3	4	1	4	3	6	6	6	6	6	6	6	6	3	4	6	0	6	6	6	4	4	6	6	6	6	3	6	6	6
Accelerated Stalls	6	3	6	0	6	1	6	3	6	6	6	3	3	3	5	0	6	0	6	3	6	6	4	6	3	6	6	6	6	6	. 6
Gliding Turns	6	3	4	3	5	4	4	4	3	5	4	4	4	4	5	5	5	2	5	5	5	5	3	6	2	3	4	5	4	4	4
Turns About a Pt.	6	2	5	2	3	4	3	4	3	5	3	3	3	2	2	4	2	2	6	2	4	3	4	4	3	3	3	5	. 3	3	4
Normal Landing	10	10	9	5	10	2	9	9	10	9	9	10	10	10	4	9	7	1	10	10	6	10	10	10	8	5	8	9	9	10	10
Missed Approach	4	3	3	2	3	2	3	4	4	3	3	3	4	1	3	4	4	0	4	4	4	3	4	4	3	4	3	4	4	4	3
Cross-Wind T-O	`5	5	4	3	5	4	4	2	4	5	5	4	5	5	4	3	5	0	5	4	5	5	4	4	4	4	4	5	5	3	5
Cross-Wind Ldg.	8	8	4	4	8	2	7	4	7	7	7	4	8	8	5	6	5	0	8	8	5	8	6	7	3	3	6	7	8	6	6
Short Field T-0	5	3	4	2	5	4	3	3	4	4	4	4	2	5	3	4	2	0	4	4	5	5	4	4	5	4	3	5	5	3	5
Short Field Ldg.	8	7	6	3	6	7	5	7	8	7	4	8	5	8	5	5	6	0	8	7	5	8	7	6	6	8	6	3	8	7	6
Soft Field T-O	5	5	2	2	2	1	5	5	2	4	4	4	1	4	3	4	4	0	3	4	5	5	4	5	4	2	5	3	5	5	2
Soft Field Ldg.	8	3	6	6	6	6	6	8	6	7	7	7	7	8	3	8	6	0	8	8	3	8	7	8	5	5	7	6	8	8	6

DETAILED SCORES FINAL FLIGHT CHECK

										al G														o1 G							
Maneuver	Max. Score		102	103	104	105	106	107	108	109	110	111	112	113	114	115	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215
Normal T-0	5	5	5	3	5	5	5	5	5	2	4	4	5	4	3	5	5	5	5	5	5	5	5	5	4	4	5	5 .	4	3	4
Climbing Turn	6	3	6	3	2	3	4	4	5	4	4	3	5	3	5	5	4	4	3	2	5	4	5	4	2	3	3	5	6	4	5
S&L Flt.(Nor. Cr.)	6	6	4	0	2	4	6	6	6	2	4	6	5	6	6	6	5	6	6	2	6	5	5	5	3	3	4	6	5	6	6
S&L Flt.(Reduced A/S)	6	6	2	5	4	2	3	0	6	4	5	6	3	5	4	5	4	4	6	3	5	5	3	6	5	1	4	4	5	6	5
720° Steep Turns	8	6	7	2	4	5	4	6	7	3	6	6	6	3	6	5	5	6	5	5	7	7	2	6	6	2	6	7	7	4	5
Arrival Stalls	6	1	6	3	6	6	6	6	6	6	6	6	6	6	6	4	6	6	6	6	6	6	1	6	6	6	6	6	6	6	1
Departure Stalls	6	6	6	3	6	6	6	6	6	4	6	4	6	6	6	3	6	6	6	6	6	6	1	6	6	4	6	6	6	6	4 .
Accelerated Stalls	6	6	6	3	3	6	6	6	6	6	6	6	3	6	6	6	3	6	6	6	6	0	0	6	6	5	6	6	6	6	6
Gliding Turns	6	4	4	1	3	3	5	2	5	3	4	5	4	2	5	4	3	3	5	2	4	6	4	. 3	4	5	3	5	4	5	4
Turns About a Pt.	6	3	5	2	4	3	4	1	3	1	1	3	2	3	3	2	1	5	3	3	6	4	3	3	3	2	2	4	4	3	3
Normal Landing	10	10	10	5	10	10	9	9	10	10	10	9	9	9	9	8	5	9	10	10	10	10	2	10	10	8	10	8	10	9	5
Missed Approach	4	4	4	4	3	4	4	4	2	3	4	4	3	4	4	3	4	4	3	4	4	3	1	4	4	3	3	4	4	3	3
Cross-Wind T-0	5	5	5	3	5	3	5	5	5	1	5	4	4	5	3	4	5	5	1	0	5	5	1	5	5	4	5	5	4	5	5
Cross-Wind Ldg.	8	8	7	2	8	5	7	8	8	2	7	6	7	8	8	5	2	7	6	8	7	6	7	8	3	7	8	6	6	7	5
Short Field T-0	5	5	3	5	5	3	5	5	5	2	2	4	5	5	5	5	5 -	3	3	2	5	5	2	5	4	4	5	4	5	4	4
Short Field Ldg.	8	6	6	5	5	7	6	8	8	6	6	4	6	7	7	6	2	5	3	7	7	6	2	8	3	7	8	,5	6	8	4
Soft Field T-O	5	5	5	2	5	5	5	4	5	2	5	4	5	5	5	4	5	. 4	2	3	5	3	. 1	4	4	4	5	2	4	3	2
Soft Field Ldg.	8	8	7	6	7	7	7	7	8	4	7	7	8	7	8	5	2	6	8	8	6	7	6	8	7	8	8	8	8	7	2

DATA ANALYSIS THEORY

Introduction

In order to promote an understanding of the method of data analysis used in this project, a review of the basic problem and procedures is suggested. The fundamental problem was to determine the value of the angle of attack indicator in flight training at the private pilot level in general aviation aircraft. The approach to the problem provided for training two samples of student pilots under identical conditions in the same course of instruction except one group (experimental) acquired pilot skills using the angle of attack instrument in addition to the aircraft instruments common to both groups. The performance of all students was observed and recorded during and at the termination of the course of instruction. Performance recordings then were converted into numerical scores for the purpose of comparing the two groups of students. However, direct comparison of scores will not produce valid information of differences between the two groups because errors of measurement and chance variations are inevitable. Insight as to the difference between these two groups, on the other hand, may be obtained by statistical inference. This process entails the utilization and application of certain tools and principles described in the following paragraphs.

Mean (M)

The arithmetic mean is the sum of the scores divided by the number of scores. The mean of the experimental or control group on any score set, therefore, is the sum of the scores comprising the set divided by 15, i.e., the number of scores or sample size.

Significance of the Difference of the Means

The difference of the means of the experimental group and control group scores on any score set is significant when the difference is presumed to denote a true difference between the groups. This occurs when the difference is assumed not to be attributed to chance factors. An experimentor should never completely eliminate the possibility that a difference in mean scores may be imputed to chance, but if he determines that the probability of chance is 1:20 or less, he may ascribe the difference to other causes. There are various techniques of making this determination, and in this report the analysis of variance method was used.

Null Hypothesis

The null hypothesis is one of the tools used in psychological research. It asserts that the difference between the means of two samples of the same population are accidental differences caused by errors of measurement and other chance variations. Repeated performance by the two samples on the same test could result in better scores by sample no. 1 in the first instance, and in the second instance sample no. 2 could excel. In this project, the null hypothesis was assumed, i.e., any differences in the performance of the experimental group and the control group on any score set was imputed to the factor of chance. The purpose of data analysis involving the use of inferential statistics, therefore, was to determine if the premise of the null hypothesis should be retained or rejected.

The approach to this determination was to calculate the probability that differences in the scores was due to chance. If it were found that the probability was 1:20 or less that the differences could be attributed to accident, then the null hypothesis would have been rejected. Recantation of the null hypothesis would have implied—as far as this test is concerned—that differences in the scores of the

experimental group and the control group were caused by factors other than chance, and that the two groups were from different student pilot populations. However, by design both groups initially were samples of the same populations. It would have been assumed, therefore, that the only reason for the change in homogeneity of the samples was the effect of training with the angle of attack indicator. Statistical calculations accomplished in connection with this project, on the other hand, revealed in all instances that the difference of the means of the two groups in successive measurements would have been caused by chance factors more than once in every twenty measurements. The null hypothesis, consequently, was not rejected.

Embry-Riddle Aeronautical Institute, Daytona Beach, Florida.

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