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Enhancing General Aviation Aircraft Safety With Supplemental Angle Of Attack Systems

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ENHANCING GENERAL AVIATION AIRCRAFT SAFETY WITH
SUPPLEMENTAL ANGLE OF ATTACK SYSTEMS

by

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A Dissertation

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

Grand Forks, North Dakota

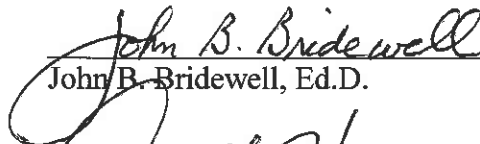
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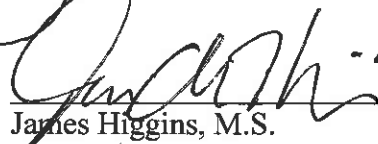
This dissertation, submitted by David E. Kugler in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.




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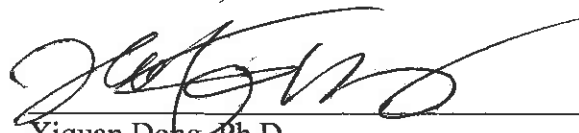
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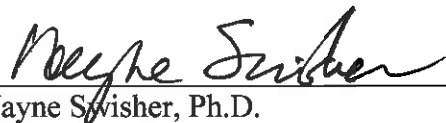


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Wayne Swisher, Ph.D.
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Date

PERMISSION

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To Dawn, Alyssa, Lucas, Andrew, Katrina, Mom & Dad
The best ground and flight crews ever!

ABSTRACT

Between 2001 and 2010, the Federal Aviation Administration determined 40.2 percent of fatal general aviation accidents in the United States, or 1,259 accidents, were caused by inflight loss of control. General aviation accidents continue to be responsible for more than 440 fatalities each year in the United States, and approximately 40 percent of these are caused by loss of control, mainly stalls. This sequential mixed methods study tested the theory that the number of stalls in the traffic pattern in light general aviation aircraft can be reduced when aircraft are equipped with supplemental angle of attack instrumentation designed to provide the pilot continuous situational awareness regarding remaining lift available for the current aircraft configuration and flight conditions. Quantitative research questions first addressed the relationship between stabilized approaches and installation of supplemental AOA systems through multiple regressions. Safety surveys of flight instructors and students were then used to probe significant findings regarding AOA system contributions to flying stabilized approaches. These follow up surveys were designed to better understand the quantitative results as well as collect information useful to developing future training. Over the course of 1,616 analyzed approaches flown between October 1, 2013 and December 31, 2014, the addition of supplemental angle of attack systems alone did not significantly increase the likelihood of subject pilots flying a stabilized approach. The overall regression models for airspeed and altitude elements of stabilized approaches were significant, but no significant effect of supplemental AOA systems was observed. Likewise, checking each

individual AOA system for influence on approach performance against the control group of unmodified aircraft yielded no significant effects. Technical limitations of flight data collection equipment and lack of formal training for subject pilots were identified as possible masks of AOA system effects. Recommendations for formal training and future research are made based on these limitations.

CHAPTER I

INTRODUCTION

Between 2001 and 2010, the Federal Aviation Administration (FAA) determined 40.2 percent of fatal general aviation accidents in the United States, or 1,259 accidents, were caused by inflight loss of control (FAA GAJSC, 2012). Of all these fatal accidents, the Aircraft Owners and Pilots Association's (AOPA) Air Safety Institute claims stalls and spins during the base to final turn accounted for seven percent while other loss of control while maneuvering made up another 13 percent (Hirschman, 2011). General aviation accidents continue to be responsible for more than 440 fatalities each year in the United States, and approximately 40 percent of these are caused by loss of control, mainly stalls (FAA InFO, 2014).

An aircraft's angle of attack, or AOA, is defined as the angle between the wing's chord line and the relative wind (Figure 1). The chord is a line drawn between the wing's leading edge and its trailing edge. The relative wind refers to the direction at which a vehicle in flight meets the oncoming airstream. While many texts display the relative wind horizontally, and perhaps contribute to common confusion between pitch angle (the angle between the aircraft's longitudinal axis and the Earth's surface) and AOA, the relative wind is not necessarily parallel to the Earth's surface, particularly when the aircraft is not in level flight. Relative wind is also known as freestream velocity, or the velocity of the airflow far enough in front of the aircraft that it is not affected by the

aircraft passing through it (Scott, 2004). A complete list of aviation terms used in this study is included at Appendix A.

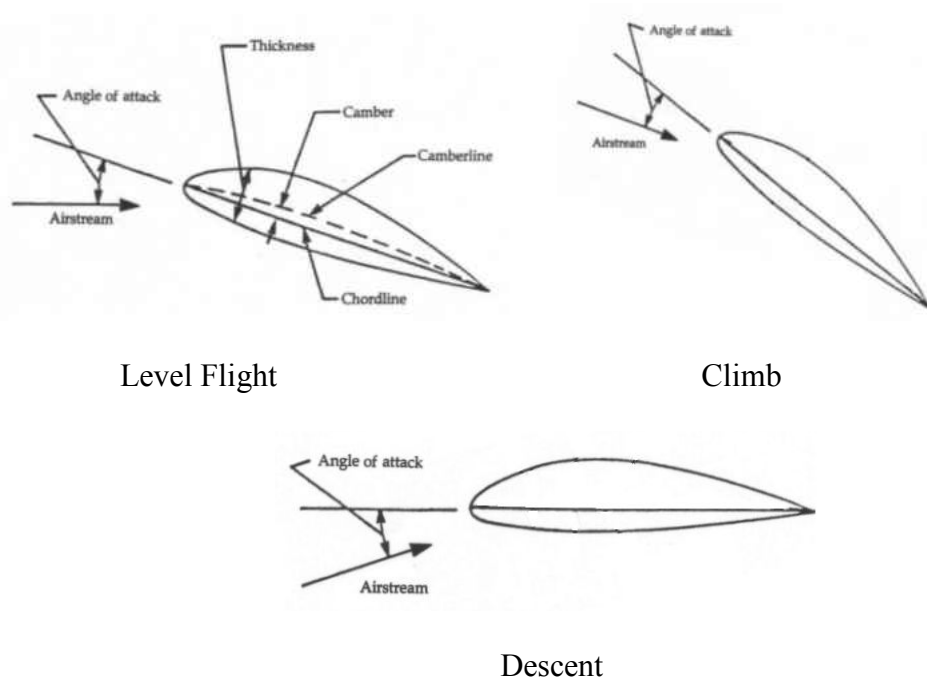


Figure 1. AOA in level flight, climb, and descent (Scott, 2004)

The lift produced by the wing increases as AOA increases until airflow traveling over the wing's upper surface begins to separate. Once this separation occurs, lift is drastically reduced. Critical AOA (Figure 2) is that AOA at which the wing's maximum lift is achieved, beyond which there is a significant loss of lift and increase in drag, where the wing "stalls" (FAA, 2008 and McCormick, 1979).

Regardless of airspeed, the wing always stalls at the same AOA independent of aircraft attitude. For airfoils used in light general aviation aircraft wings (often NACA 2412 airfoils), the critical AOA is typically approximately 15 degrees. The actual stalling airspeed varies, and depends on such factors as weight, loading, acceleration, and bank angle. AOA systems make it simpler for pilots to maintain situational awareness during

critical or high-workload phases of flight. AOPA’s manager of regulatory affairs, David Oord, claims AOA systems will help general aviation pilots maintain control “regardless of weight, airspeed, bank angle, density altitude, configuration, or center of gravity” (Namowitz, 2014, p. 1).

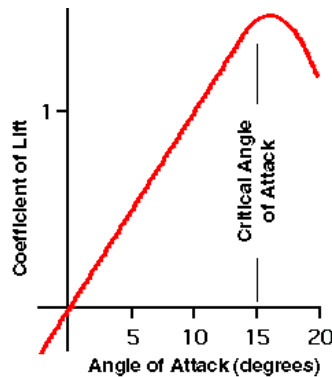


Figure 2. Relationship between lift and angle of attack

Nevertheless, few light general aviation airplanes are equipped with real time AOA instrumentation. Unless they have flown more advanced aircraft, general aviation pilots’ knowledge of AOA concepts remains limited to what was learned in ground school, and may not easily translate to everyday flying. Light general aviation aircraft pilots rely on indicated airspeed and/or control “feel” and are left to guess exactly when the airplane will stall based on a known stall speed for an unaccelerated straight flight condition, inflight experience gained while learning stall recoveries, and academic discussions of aerodynamic theory they might have had during ground training. Installing instrumentation to continuously display AOA regardless of weight, air density, aircraft attitude, turbulence, ground effect, or flap/landing gear configuration increases the pilot’s awareness of lift available prior to stall (Hirschman, 2011). Theoretically, supplemental AOA instrumentation should reduce the number of loss of control accidents by more clearly alerting the pilot prior to stalling the aircraft.

In response to concern about overall general aviation safety, the FAA created its General Aviation Joint Steering Committee (GAJSC) during the mid-1990s to parallel the existing Commercial Aviation Safety Team. After becoming inactive for several years, it was reestablished in 2011. FAA and industry representatives agreed to pursue a one percent annual reduction in the general aviation fatal accident rate based on the period 2006-2008, arriving at a rate no greater than one fatal accident per 100,000 flying hours by 2018. The committee's Loss of Control Work Group studied accident subsets of experimental amateur-built airplanes, certified piston engine airplanes, and turbine engine powered airplanes in an attempt to identify focus areas for new safety initiatives. The group examined 279 approach and landing accidents recorded between 2001 and 2010, and randomly selected 60 representing each subset. They then examined the first 30 well documented accidents from each list in detail. Subject matter experts provided the group briefings about AOA indicators, electronic recovery control systems, upset recovery training, and prescription and over-the-counter drugs used by pilots. The Loss of Control Work Group approved 23 individual safety enhancement projects in 2012. The top two priority projects focus on AOA systems for new and current production aircraft, and for the existing general aviation fleet (FAA GAJSC, 2012). Kevin Clover, National FAA Safety Team operations lead, explained the overall goal of the work group's suggested enhancements: "Outcomes for these strategies will likely evolve into aviation technology changes and/or enhancements. Other strategies will focus on enhanced training and educational outreach and will involve a greater working relationship with the FAA Safety Team" (Hoffmann, 2012, p. 29). Current FAA training in AOA awareness is found in

Advisory Circular AC120-109, “Stall and Stick Pusher Training,” but expanded training literature for general aviation applications will be needed (Namowitz, 2012).

Although there has been limited interest in AOA instrumentation for general aviation aircraft for the last 30 years, little research has been done to investigate any measurable safety enhancement realized by its use. Fred Scott, a pilot who lost friends in a stall/spin accident, and Tom Rosen, American Bonanza Society director, have funded initial testing of AOA instrumentation manufactured by Alpha Systems, a Minnesota firm which began developing and selling AOA equipment for general aviation in the 1980s (Hirschman, 2011). Embry-Riddle Aeronautical University recently installed AOA indicators on its entire fleet of 61 Cessna training aircraft at its Daytona Beach and Prescott campuses. In an unpublished demonstration, the university conducted 30 trial flights prior to installation to qualitatively determine which AOA display would be most effective and gather flight instructor feedback on which maneuvers would be most improved for student pilots. Initial findings indicated student knowledge of aircraft performance improved, particularly at slower airspeeds. Future research will be aimed at identifying best practices and learning methodologies for integrating AOA technology into flight education (Van Buren, 2013).

Purdue University is currently the lead organization for a general aviation AOA equipment research project funded by the FAA’s Partnership to Enhance General Aviation Safety, Accessibility and Sustainability (PEGASAS). With assistance from researchers at Ohio State University and Florida Institute of Technology, this project aims to develop AOA educational materials for general aviation as well as conduct a

cost/benefit/risk analysis of various supplemental AOA systems for general aviation aircraft. Results of this study are expected in 2015 (PEGASAS, 2014).

A limitation inhibiting more detailed quantitative research is the lack of flight data monitoring systems on most general aviation aircraft. Even where flight data recording was and is available, previous and current work has been limited to “snapshot data” of specific points in time. Investigators were forced to build a picture of dynamic flight conditions by interpreting static data. As part of the University of North Dakota’s Flight Data Monitoring program, snapshot data of all training flights has been collected on Garmin G1000 secure digital (SD) cards and more recently by Appareo flight data recorders. To overcome previous static data limitations, the university recently developed a tool designed to analyze dynamically produced data all along an airplane’s approach path and then used it for an initial investigation of turns from base to final preceding the approach, since this flight regime represents a worst “low and slow” case, where insufficient altitude might be available to recover from an inadvertent stall. This initial study examined approaches before and after AOA system installation on the same aircraft. Data analyzed represented 11,324 turns to final at eight different airports and on 20 different runways. Subjects flying the aircraft were unaware their performance was being measured, no training in use of the AOA instrumentation was provided, and no pilot surveys were administered as part of the resultant analysis. During the turn to final, AOA-equipped aircraft lowered the nose more and experienced more aggressive G loading than non-AOA-equipped aircraft. Both of these findings imply AOA equipment might be providing enhanced pilot situational awareness of the wing’s full performance envelope—lowering the nose to reduce AOA during flight near the critical AOA, but

flying more aggressively when excess lift performance is available. Some conflicting results appeared based on seasonal differences, specifically in varying combinations of outside air temperature and pressure altitude, so initial results were considered encouraging, but not conclusive (Higgins, 2014).

Despite having only a small collection of quantifiable data illustrating the safety enhancement provided by AOA instrumentation in general aviation aircraft, the Loss of Control Work Group issued recommendations for use based on a long period of military experience with AOA systems and the intuitive benefits provided by increased situational awareness. “The GA community should embrace to the fullest extent the stall margin awareness benefits of these systems. To help the GA community understand the safety benefits of AOA systems, a public education campaign should be developed...”

(Namowitz, 2013, p. 1). The GAJSC does seek to make its work data driven to ensure analytical credibility that would allow the FAA and industry to plan for implementation (FAA GAJSC, 2012). The present study expands on initial University of North Dakota research to enhance the quality and quantity of data available to the FAA as well as provide a basis for the public education campaign called for by Namowitz.

Background--Genesis in Military Aviation

High performance military aircraft have incorporated AOA systems into their avionics for many years. Rob Hickman, founder of Advanced Flight Systems, a manufacturer of supplemental AOA systems, uses this experience as a main sales point for his products by explaining that AOA has long been the main measure used by U.S. Navy aircraft approaching carriers (Hirschman, 2011).

An aircraft and AOA system representative of military high performance aircraft in general is the Northrop T-38 Talon, a two-seat, twin-engine supersonic jet trainer flown by the U.S. Air Force, U.S. Navy Test Pilot School, and NASA.

The T-38 AOA system includes a heated vane transmitter on the right forward fuselage (Figure 3), a CPU-115/A computer, and in each cockpit, an AOA indicator,



Figure 3. Northrop T-38 Talon

indexer, and indexer lights dimmer control (Figure 4). The AOA system compensates for flap and landing gear configurations, and presents the following displays in each cockpit: optimum AOA for final approach, AOA when buffet and stall will occur, and approximate AOA for maximum range and maximum endurance (USAF, 1978).

An AOA dial (Figure 4) on the upper left of each instrument panel is calibrated in units of 0.1 counterclockwise from 0 to 1.1. Each unit represents approximately 10 percent of aircraft lift. The dial is marked with maximum range (.18), maximum endurance (.3), optimum final approach (.6), buffet warning (.9-1.0), and stall warning

AOA (1.0-1.1). AOA indexer lights (Figure 4) mounted on each glare shield are operative in the landing configuration with flaps up or down, or when landing gear is up and flaps are extended 5 percent or more. The high speed indexer is inoperative when landing gear and flaps are up to eliminate continuous illumination during cruise flight. All three symbols illuminate to indicate system failure (USAF, 1978).

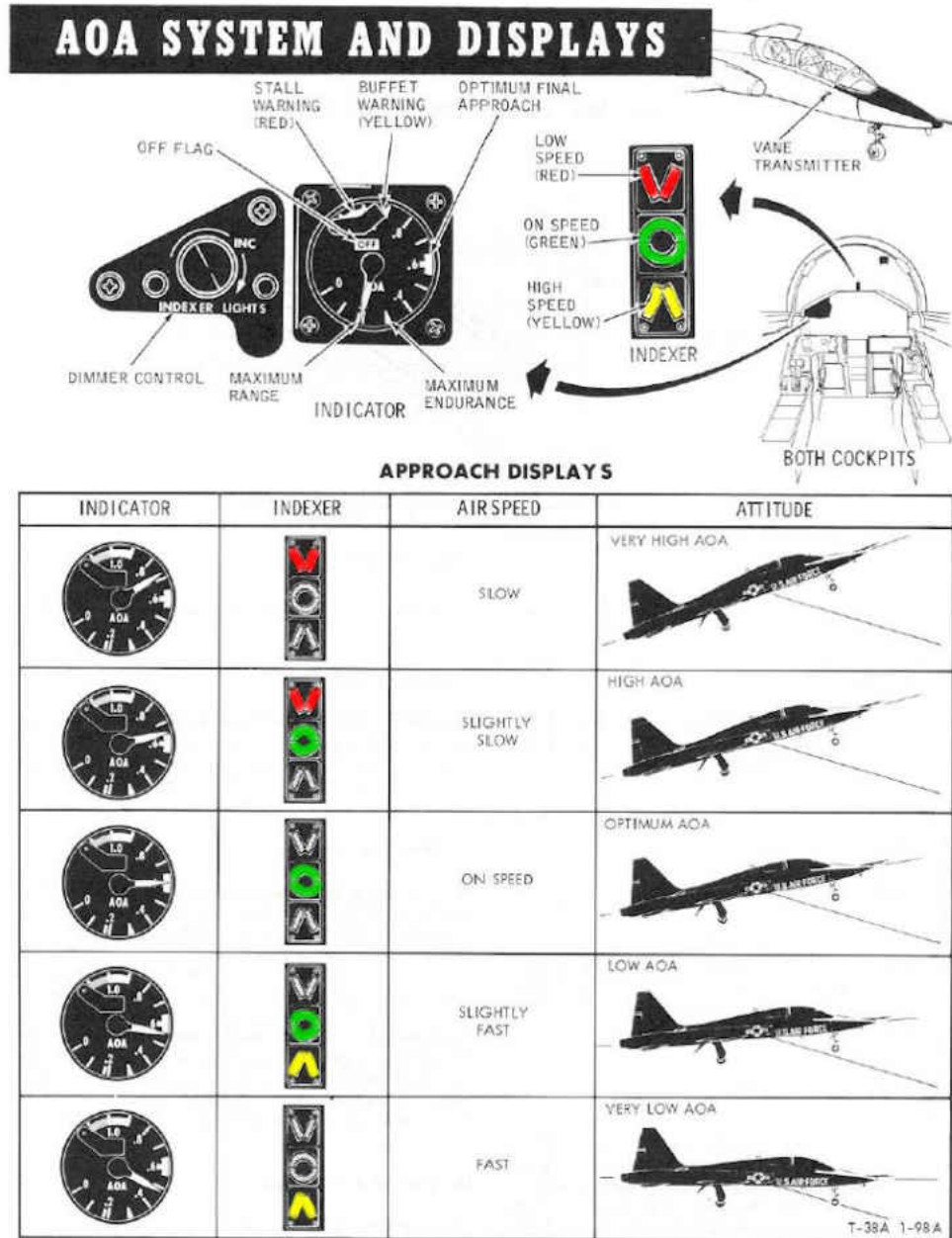


Figure 4. T-38 Flight Manual--AOA System and Displays (USAF, 1978, p. 4-10)

Bringing Supplemental Add-On AOA Systems to General Aviation

In its Safety Enhancement 1, the Loss of Control Work Group's Statement of Work recommends,

To reduce the risk of inadvertent stall/departure resulting in LOC [loss of control] accidents, the GA community should install and use AOA based systems for better awareness of stall margin...GA aircraft manufacturers should work to develop cost effective AOA installations for new and existing designs currently in production. Owners and operators of GA aircraft should be encouraged to have AOA systems installed in their aircraft (FAA GAJSC, 2012, p. 16)

In response to this recommendation, the FAA sought to simplify the approval process for post-production equipment to be installed on previously certified aircraft. FAA Memorandum AIR100-14-110-PM01 established design requirements for supplemental AOA systems. An AOA system must be a stand-alone unit and must not interface with a currently certificated system, with the exception of an electrical power supply. AOA instruments must contain markings or placards stating "Not for use as a primary instrument for flight." Finally, supplemental AOA systems may not be installed on commuter or transport category airplanes (Hempe & Seipel, 2014).

Traditional systems sense AOA through external heated vanes mounted on the side of the fuselage. While these systems are precise, they are also expensive, and may be cost prohibitive for light general aviation aircraft use. Non-Technical Standard Order systems for general aviation aircraft as described in the FAA memorandum are usually sold as kits costing \$600 to \$1500. Rather than a vane, these systems employ other means of detecting angle of attack. A fixed, under-wing mast completely separate from the aircraft's pitot/static system with ports measuring differential air pressure may be used. Static ports installed on the top and bottom of the wing surface measure differential air pressure without an external probe. Other systems use a pitot tube and static port

combination to measure differential air pressure. Finally, the wing leading edge stall warning tab can be replaced by a heated lift transducer designed to transmit AOA data to a primary flight display and/or AOA instrument. Because they are separate from existing aircraft systems, any of the AOA systems designed for supplemental general aviation use can provide backup information to safely recover the aircraft in the event of a blocked pitot tube or failed airspeed indicator (Hirschman, 2011).

Existing AOA Systems for General Aviation

Companies currently manufacturing AOA indicators for general aviation include Advanced Flight Systems, Alpha Systems, BendixKing, Dynon, Garmin, InAir Instruments, and Safe Flight Instrument Corporation. Descriptions of each of these AOA systems follow.

Advanced Flight Systems Pro III and Sport

Advanced Flight Systems, Inc., a Dynon Avionics company, manufactures two different standalone systems, the AOA Pro III and AOA Sport (Figure 5). Both sense dynamic pressures with two pressure ports in the installed probe mounted under the wing.



Figure 5. left to right: Advanced Flight Systems AOA probe, Pro III, and Sport (Advanced Flight Systems, 2014)

The AOA Pro III is a liquid crystal display with 26 colored segments. It includes a voice warning system announcing high AOA and landing gear position errors. AOA is

displayed in both digital and analog formats (Advanced Flight Systems AOA Pro III, 2014). The AOA Pro III has a retail price of \$1,495. The AOA Sport is designed for tight instrument panels and can be installed between instruments or on the glare shield. It has a retail price of \$890 (Advanced Flight Systems Products, 2014).

Alpha Systems

The Alpha Systems AOA system was designed to meet the objective of FAA Advisory Circular AC23.1309-1C to improve the safety of the general aviation airplane fleet as a standalone device increasing pilot situational awareness when operating at high angles of attack. An AOA probe is mounted under the wing, replacing an existing inspection cover. The probe faces forward at approximately a 50 degree downward angle from the horizontal. Two sensor ports measure the differential pressure. A control module interprets the AOA probe data and sends it to one of a variety of displays installed in the cockpit (Alpha Systems, 2014).

Griffin, Falcon, Eagle

Griffin, Falcon, and Eagle (Figure 6) are “top of the glare shield” displays designed to provide accurate real time AOA indications in the pilot’s line of sight in a



Figure 6. left to right: Alpha Systems Griffin, Falcon, Eagle (Alpha Systems, 2014)

manner similar to military systems. Each kit weighs less than three pounds and has a retail price of \$1,995.

Valkyrie Heads Up Display Adapter

The Valkyrie Heads Up Display (HUD) adapter takes the Griffin, Eagle, or Falcon display and projects it as a HUD display (Figure 7). The retail price is \$500.



Figure 7. Alpha Systems Valkyrie HUD (Alpha Systems, 2014)

Condor, Hawk, Dragon, Merlin

Condor, Hawk, Dragon, and Merlin (Figure 8) provide a “lift reserve” display in circular and rectangular formats. Condor and Hawk are flush mounted instrument panel



Figure 8. left to right: Alpha Systems Condor, Hawk, Dragon, bottom Merlin (Alpha Systems, 2014)

displays, while Dragon is a dash mount version of the Hawk. Merlin is a light bar display suitable for amounting above or below the glare shield. Each kit weighs less than three pounds and has a retail price of \$1,995.

Bendix King KLR 10

The BendixKing KLR 10 measures differential air pressures at two points on an AOA probe mounted to the wing, converts the pressures into an electronic signal in the KLR 10 IF module, and transmits an electronic signal to a 2.25 inch LED indicator mounted on top of the airplane's glare shield (Figure 9). Mutable audio warnings of



Figure 9. BendixKing KLR 10 (BendixKing, 2014)

“Check AOA;” “Caution, Too Slow;” and “Too Slow! Too Slow!” are added to the visual indications as the aircraft approaches critical AOA. A photo cell in the instrument detects ambient light changes and automatically switches from daytime to nighttime brightness presets. Manual control allows the pilot to fine tune instrument brightness. The system draws less than 250mA of electrical power, and if an optional probe heater is added, requires less than eight amps at 12 or 24VDC to operate. A calibrated system will have +/- three percent accuracy, which is maintained over a sideslip range of +/- 15 degrees. The KLR 10 installation kit has a retail price of \$1,450 (BendixKing, 2014).

Dynon Avionics FlightDEK-D180

Dynon Avionics offers AOA/pitot probes to support AOA instrumentation integral to various Electronic Flight Instrument Systems (EFIS). Rather than serving as an add-on sensor, the AOA/pitot probe is designed to replace the standard pitot tube on experimental aircraft and provide inputs to both airspeed indicators and AOA indicators included on supported EFIS. The normal pitot pressure port is on the front face of the tube, while the second pressure port is on an angled surface below the pitot port (Figure 10). Separate air lines run to the avionics, where they are translated into AOA (Dynon Avionics, 2014).

Three versions of the AOA/Pitot tube are available: standard L-shaped tubes in heated and unheated versions, and a boom-mount version (Figure 11). Retail prices range from \$200 to \$450 (Dynon Avionics, 2014).

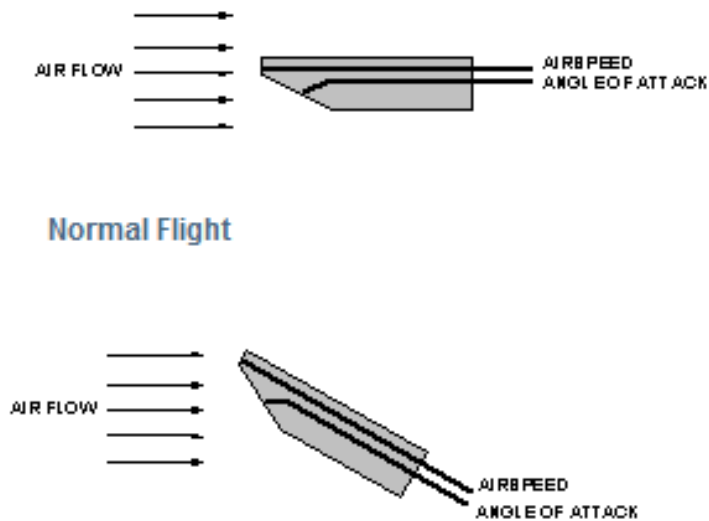


Figure 10. Dual purpose Dynon Avionics AOA/Pitot tube operation (Dynon Avionics, 2014)



Figure 11. Dynon Avionics AOA/Pitot tubes (Dynon Avionics, 2014)

Garmin GI 260

The Garmin GI 260 calculates AOA using pitot, AOA, and static air pressure inputs. The system consists of the GI 260 indicator, GAP 26 probe, and the GSU 25 air data computer (Figure 12). The probe sends pitot and AOA air pressures to the GSU 25. The air data computer then combines this data with an independent static source to calculate AOA and sends it to the indicator.

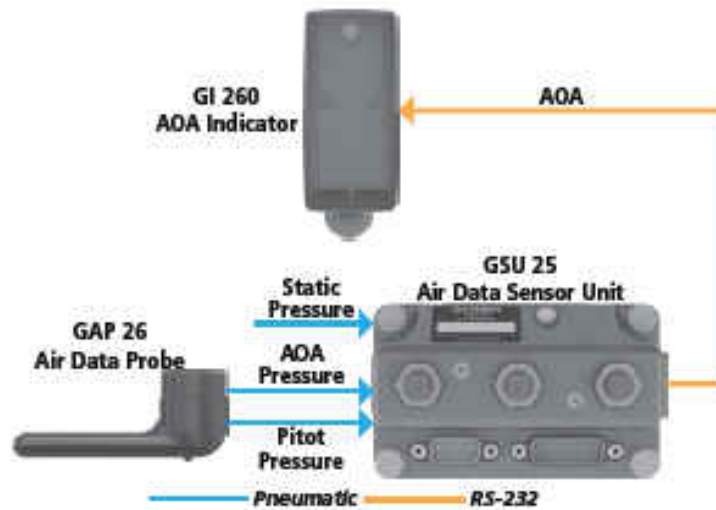


Figure 12. Garmin AOA system components (Garmin, 2014)

The GI 260 indicator displays AOA information via ten color-coded LED annunciators (Figure 13). When connected to an audio system, it generates aural alerts as the aircraft approaches critical AOA (Garmin, 2014).

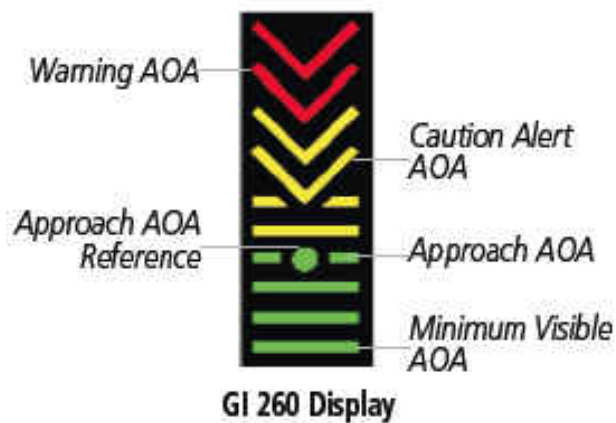


Figure 13. Garmin GI 260 display (Garmin, 2014)

The system automatically arms as the aircraft accelerates past 50 knots. Visual displays begin immediately after arming and aural warnings become active 15 seconds after arming to avoid premature alerts during the takeoff roll. The Garmin AOA system retail price is \$1,649 (Garmin, 2014).

InAir Instruments Lift Reserve Indicator

InAir Instruments' Lift Reserve Indicator (Figure 14) integrates both airspeed and AOA into a single continuous readout. The system includes a rectangular airstream probe mounted on the underside of a wing and a display gauge. Two air pressure ports on the probe are piped to the instrument display, which calculates lift reserve from the differential pressure. The LRI is complementary to the airplane's airspeed indicator and can serve as a backup in the event of a primary system failure. Retail price for a system with an unheated probe is \$450. The heated system has a \$550 retail price (InAir Instruments, 2014).



Figure 14. InAir Instruments Lift Reserve Indicator (InAir Instruments, 2014)

Safe Flight SCx

In July 2014, Safe Flight Instrument Corporation announced a new leading edge AOA system designed for the experimental, homebuilt, and kit plane market called the SCx (Figure 15).



Figure 15. Safe Flight SCx Lift Transducer and Indexer Computer (Safe Flight, News Release, 2014)

The SCx was to be followed by the SCc system for FAA certificated aircraft in late 2014. Like other AOA systems, the SCx provides improved high AOA situational awareness through a combined visual display and audio output. Unique to the SCx however, is the lift transducer mounted at the leading edge of the wing to measure the leading edge stagnation point and air flow field (Safe Flight news release, 2014). The stagnation point refers to the area where airflow divides to flow over the top and bottom wing surfaces.

Local air flow at this point has maximum pressure and zero airspeed, and its location is uniquely related to the wing's angle of attack. As distance from the stagnation point increases, so does local airspeed. The lift transducer measures the force of local airspeed with respect to the stagnation point (Safe Flight, 2013).

By correlating lift with airflow characteristics at the stagnation point on the wing, the SCx Lift Transducer measures precise changes in AOA and provides the output interpreted and displayed by the SCx Indexer Computer...By placing the sensing element where the action is—at the leading edge, you have the most accurate and dependable measurement of AOA (Safe Flight SCx, 2014, p. 1).

Best speeds for maximum range, maximum endurance, short field landing speed, etc. are actually *best angles of attack*. Aircraft speeds listed in the Pilot's Operating Handbook are always calculated for the airplane's maximum gross weight, and are merely the corresponding airspeed for a specific angle of attack (Safe Flight, 2013). Flying at lesser weights without supplemental AOA instrumentation leaves the pilot with no way to measure these *best speeds* with precision.

Purpose

The intent of this two-phase, sequential mixed methods study is to test the theory that the number of stalls in the traffic pattern in light general aviation aircraft can be reduced when aircraft are equipped with supplemental angle of attack instrumentation designed to provide the pilot continuous situational awareness regarding remaining lift available for the current aircraft configuration and flight conditions. In the first phase, quantitative research questions addressed the relationship between stabilized approaches and installation of supplemental AOA systems. Independent variables include AOA system installed, presence of vertical guidance system, time of day (day or night), outside air temperature, presence of an air traffic control tower, and length and width of runway.

Three dependent variables measure aspects of approach stability—airspeed differential from optimum, height differential from optimum, and cross track error from extended runway centerline. Information from this first phase was explored further in a second qualitative phase. Safety surveys of flight instructors and students were used to probe significant findings regarding AOA system contributions to flying stabilized approaches. These follow up surveys were designed to better understand the quantitative results as well as collect information useful to developing future training.

Research Questions

1. Are general aviation pilots more likely to fly a stabilized approach in aircraft equipped with supplemental AOA systems than in aircraft not so equipped?
 - a. Does the presence of vertical guidance systems (visual such as VASI or PAPI lighting or electronic such as ILS) affect stabilized approach rates?
 - b. Does time of day (day or night) affect stabilized approach rates?
 - c. Does outside air temperature affect stabilized approach rates?
 - d. Does the presence of an air traffic control tower affect stabilized approach rates?
 - e. Do runway characteristics (length and width) affect stabilized approach rates?
 - f. Does the type of AOA system installed on the aircraft affect stabilized approach rates?
2. Are general aviation pilots who fly AOA-equipped aircraft more likely to execute a go-around if they encounter an unstable approach than those flying aircraft not so equipped?

3. How do pilots not previously trained with AOA instrumentation react to the presence of AOA systems on their aircraft and what revised training do they recommend?

CHAPTER II

METHOD

Subjects

As part of its flight data monitoring program, the University of North Dakota records inflight data from Cessna 172 Garmin 1000 avionics on to Secure Digital (SD) cards. More recently, Appareo flight data recorders have also been introduced. These systems allow for collection of many inflight variables useful to providing safety analysis for the university's flight training program. An integral part of any aviation safety program is avoiding using safety analysis as an enforcement tool against pilots who may have violated FAA regulations or local training rules since it would discourage acceptance of flight data monitoring systems and full disclosure of safety information helpful to analysis and future safety lessons learned. In order to protect the integrity of the safety analysis system, the University of North Dakota designed its flight data monitoring data base to protect the identity of involved pilots.

For the quantitative phase of this study, subjects were student pilots and instructors assigned to fly University of North Dakota Cessna 172s, but specific identifying data for each flight describing other characteristics such as flight experience, gender, or ethnic group, were not directly available. Since all subject aircraft flights of relevant airframes were examined during the time period of interest, demographic characteristics of those enrolled in university flying training programs in general will serve as a substitute to describe the general aviation certificated pilots and student pilots

whose performance was examined. Students participating in the flight program are those enrolled in the following academic programs: commercial aviation, air traffic control, airport management, aviation management, aviation technology management, flight education, and Unmanned Aircraft Systems operations. Table 1 illustrates the gender and ethnic group representation of students enrolled in these seven academic programs during the fall semester of 2012, the most recent academic year for which published data is available (University of North Dakota Institutional Research, 2015).

During the qualitative phase of this study, safety surveys of the university's students and flight instructors were completely anonymous. The only demographic data provided by these surveys was level of pilot certification, from student pilot through flight instructor. This data is included with survey results in Chapter III.

Equipment

The University of North Dakota has equipped three of its Cessna 172 aircraft, each with a different AOA system: a Bendix King KLR 10 was installed on aircraft N529ND on March 18, 2014 (Figure 16); a pre-production Safe Flight SCx was installed on aircraft N524ND on April 17, 2014 (Figure 17); and a Garmin GI 260 was installed on aircraft N525ND on May 28, 2014 (Figure 18) (Higgins, 2014). Each of these aircraft is equipped with G1000 SD cards or Appareo recorders identical to the rest of the university's aircraft fleet of 63 Cessna 172s.

The University of North Dakota's flight data monitoring program is the secure repository for all inflight data. A proprietary "turn-to-final" analysis tool was used to analyze each turn to final in terms of airport and runway, date, outside air temperature, day or night light conditions, turn direction, time in turn, altitude-

Table 1. Aviation Undergraduate Students by Ethnicity and Gender Fall 2012.

Program	Ethnicity												Total	
	White		Black		Hispanic		Asian		Other		Non-Resident Alien			
	gender		gender		gender		gender		gender		gender			
	F	M	F	M	F	M	F	M	F	M	F	M		
Commercial Aviation	52	486	3	16	3	24	2	25	8	43	6		299	967
Air Traffic Control	36	225	0	5	4	8	2	4	6	18	4		29	341
Airport Management	2	34	1	1	0	2	0	4	0	1	5		3	53
Aviation Management	9	42	0	1	0	1	1	1	0	4	1		5	65
Aviation Technology Management	1	7	0	0	0	1	0	0	0	1	0		2	12
Flight Education	2	14	0	0	0	0	0	0	0	0	0		0	16
UAS Operations	5	86	0	0	0	2	0	1	1	4	0		0	99
Total All Programs	107	894	4	23	7	38	5	35	15	71	16		338	1553



Figure 16. Bendix King KLR 10 Installation on N529ND



Figure 17. Safe Flight Prototype Installation on N524ND



Figure 18. Garmin GI 260 Installation on N525ND

start/stop/maximum/minimum, indicated airspeed-start/stop/maximum/minimum, vertical speed indication-start/stop/maximum/minimum, pitch-start/stop/maximum/minimum, roll-start/stop/maximum/minimum, engine RPM-start/stop/maximum/minimum, and groundspeed. “Start/stop/maximum/minimum” refers to measurements of the specific variable taken from the beginning of the turn to final (start) until the turn is completed (stop). Maximum and minimum refer to the largest and smallest values of the variable measured during the turn. Similarly, a proprietary “dynamic approach” analysis tool translated approach data from 200 feet above ground level (AGL) until approximately four seconds prior to touchdown, measured at a 1Hz rate, into a dynamic picture of each approach. Four seconds prior to touchdown was chosen as an end point because equipment limitations preclude measuring the exact point of touchdown. Flight data monitoring does not include radar altitude (aircraft are not equipped with a radar altimeter), weight on wheels determination is not available, and flap position is not recorded. Data points collected include: airport and runway, outside air temperature, day or night light conditions, height above touchdown differential (desired vs. actual), cross track error, date, time, time spent on final, indicated airspeed differential (desired vs. actual), and wind component.

Procedure

In the quantitative phase of this study, data collected and analyzed was extracted from the University of North Dakota’s flight data monitoring program database. All data was recorded in a naturalistic flight training environment with all subjects unaware of what performance parameters were measured. Once quantitative data collection was

complete, a qualitative safety survey was administered to expand on initial findings and focus on future training requirements.

This study analyzes aircraft traffic patterns, flown from base leg to final approach through completion of the approach (full stop landing, touch and go landing, or low approach) between October 1, 2013 and December 31, 2014 (n = 1,644) for the three University of North Dakota Cessna 172 aircraft modified with supplemental AOA instrumentation. Knowing the AOA equipment installation date for each aircraft and choosing an analysis period beginning in advance of modification allowed data to be compared for unmodified and modified aircraft where the only configuration change was installation of supplemental AOA instrumentation. Data for the entire subject population is available, so sampling procedures designed to select a subset of the population were not required.

While many similar operational definitions are in use, no standardized definition of *stabilized approach* exists. For purposes of this study, *stabilized approach* was determined by an analyzed approach meeting the following parameters: airspeed 56-71 KIAS (+10/-5 knots of optimum approach speed), altitude +/-33 feet of desired glide slope, and cross track error of less than +/-100 feet. The airspeed parameter reflects the FAA's acceptable final approach standard for private pilots (FAA, 2011). The altitude parameter is equivalent to reaching full scale deflection of the ILS glide slope display at 200 AGL or *high* (all white lights)/*low* (all red lights) on visual approach lighting systems (PAPI or VASI). The cross track error parameter is equivalent to full-scale deflection of the course display for a commonly installed localizer signal at approximately 3,800 feet

from the ILS glide slope point of intercept with the runway (where the aircraft is at approximately 200 AGL on a three-degree glide slope).

For training, the University of North Dakota uses a slightly more strict definition. By 200 AGL, all checklists must be complete, the aircraft must be on course centerline and glideslope, configured for landing, and at an airspeed of 61 KIAS -0/+5 with power set. An altitude of 200 AGL represents approximately 45 seconds prior to aircraft touchdown. This “time to go” to landing is similar to stabilized approach checkpoints used by larger professional operators at higher altitudes and airspeeds where an approach must be stable in order to continue to a landing (Kugler, 2014). Figure 19 displays typical stabilized approach checkpoints used by the University of North Dakota flying training program, some Part 135 operators, some Part 121 operators, and some U.S. Air Force commands.

The independent variable *AOA status* was determined by the aircraft tail number and date of the flight. The airport and runway to which an approach was flown was determined by GPS position. From this information, independent variables *vertical guidance*, *air traffic control present*, *runway length*, and *runway width* were determined. Time and date stamp allowed the independent variable *day or night* to be determined. Measured outside air temperature was selected to study previously observed seasonal effects.

Design

This study is a two-phase, sequential mixed methods design. Quantitative measures of performance parameters in a naturalistic setting were collected and analyzed to address the first two research questions about AOA instrumentation performance.

These questions were addressed in terms of supplemental AOA systems generally, and also specifically in terms of the three systems installed on University of North Dakota aircraft. A qualitative safety survey collected data from pilots in the University of North

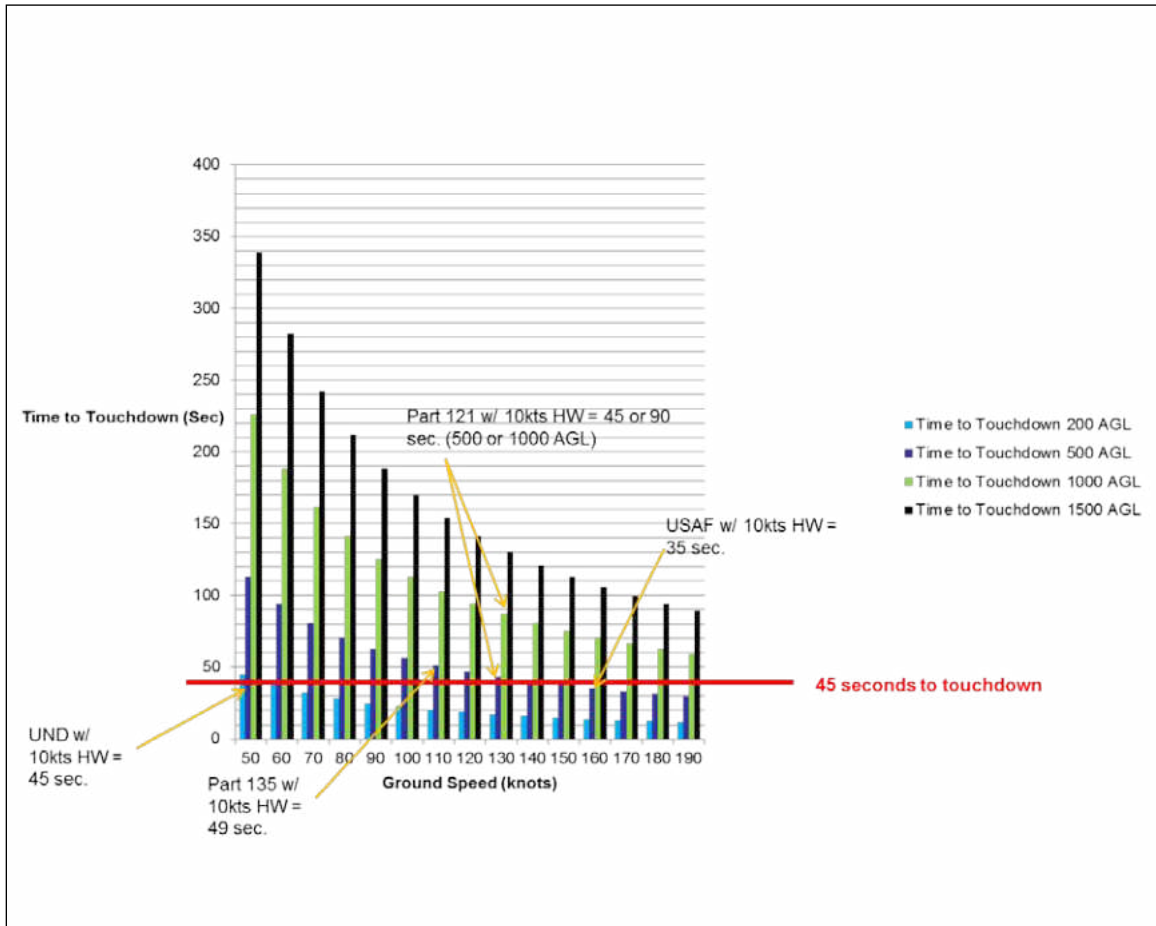


Figure 19. Approach speed vs. time to touchdown for typical stabilized approach checkpoints (Kugler, 2014)

Dakota flight training program to examine the second and third research questions as well as provide additional perspective to conclusions reached from quantitative analysis.

Statistical Analysis

With three continuous dependent variables describing stabilized approaches considered one parameter at a time (*speed differential*, *height differential*, and *cross track error*), and seven categorical or continuous independent variables, multiple regression is

the appropriate statistical test. Main effects were examined for the independent variables for all aircraft in the population. Specific AOA systems were also examined separately to see if they influenced performance against the control (unmodified aircraft).

CHAPTER III

RESULTS

Flight Data Monitoring Analysis

The primary flight data analysis was conducted using simultaneous multiple regressions. This type of regression analysis tests the significance of each independent variable after all other predictors are included in the model. Independent variables included AOA modification status, presence of vertical guidance, day or night lighting conditions, outside air temperature, presence of air traffic control, runway length and runway width. Dependent variables represent elements of stabilized approach: speed differential, height differential, and cross track error. Means, standard deviations, and ranges for each of the continuous independent variables and dependent variables are listed in Table 2. Frequencies for each of the categorical independent variables are presented in Table 3.

Table 2. Means, Standard Deviations, and Ranges.

	Mean	Standard Deviation	Range
Speed Differential (kts.)	4.25	4.53	-51.19 - 25.31
Height Differential (ft.)	6.45	26.13	-203.04 - 148.19
Cross Track Error (ft.)	0.57	34.53	-504.35 - 472.57
Temperature (deg C)	6.22	14.24	-28.07 - 44.12
Runway Length (ft.)	4,576.67	1,411.85	3,199.00 - 7,351.00
Runway Width (ft.)	90.03	30.65	60.00 - 150.00

Table 3. Frequencies.

	<u>not modified</u>	<u>SafeFlight</u>	<u>Garmin</u>	<u>BendixKing</u>
AOA Status	814	285	183	362
Vertical Guidance present	<u>no</u> 59			<u>yes</u> 1,585
Day or Night	<u>night</u> 209			<u>day</u> 1,435
ATC present	<u>no</u> 242			<u>yes</u> 1,402

Data was gathered for 1,644 approaches flown to 14 different runways at four different airports (Grand Forks International Airport, Grand Forks, ND; Crookston Municipal Kirkwood Field, Crookston, MN; Hutson Field, Grafton, ND; and Warren Municipal Airport, Warren, MN). Diagrams of each airport, similar to those found in the FAA’s Airport/Facility Directory, are available in Appendix C.

Outliers

Simple boxplots were constructed for each continuous variable to identify outliers in the data. A boxplot defines outliers by these criteria: values that are 1.5 times the interquartile range greater than the 75th percentile or 1.5 times the interquartile range less than the 25th percentile for each variable. Among the dependent variables, 16 outliers were identified for speed differential (Figure 20), 22 outliers were identified for height differential (Figure 21), and 36 outliers were identified for cross track error (Figure 22). Each of the outlier cases among the dependent variables was examined in more detail using additional flight data collected for that approach. Of these outliers, 28 appeared to be possible go-arounds in progress (see data measurement limitations in Chapter IV), and were eliminated from the data set because the approach appears to have been terminated. Some of the possible go-arounds were grouped by date in such a way that they may represent instrument training in progress where intentional low or missed approaches are

common as part of the training curriculum. Eight other outliers remained unexplained by comparison with other data for the same approach. In these cases, scores were changed to the mean plus two standard deviations in the direction of the discrepancy, where they yielded logical values for the applicable variable (Field, 2009).

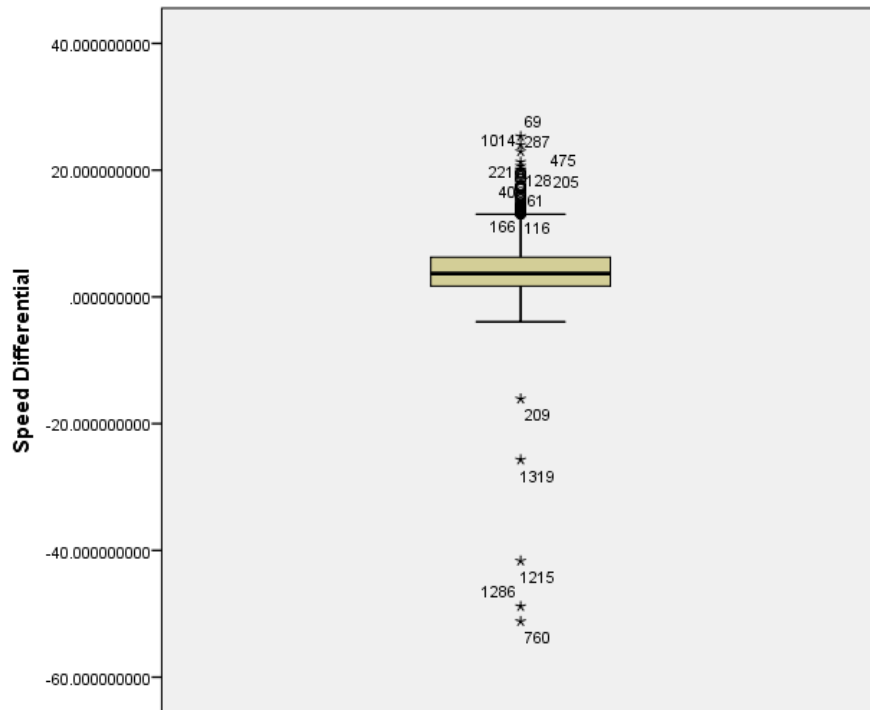


Figure 20. Speed Differential Outliers

Among the independent variables, no outliers were identified for outside air temperature. For runway length (Figure 23), 12 outliers were identified, and for runway width (Figure 24), 15 outliers were identified, but all cases represented actual runways included in the data and thus, remain included for analysis. Their actual values just happened to be extreme within this data set.

Adjusted means, standard deviations, and ranges for each of the continuous independent variables and dependent variables, after accounting for outliers, are listed in

Table 4. Adjusted frequencies for each of the categorical independent variables are presented in Table 5.

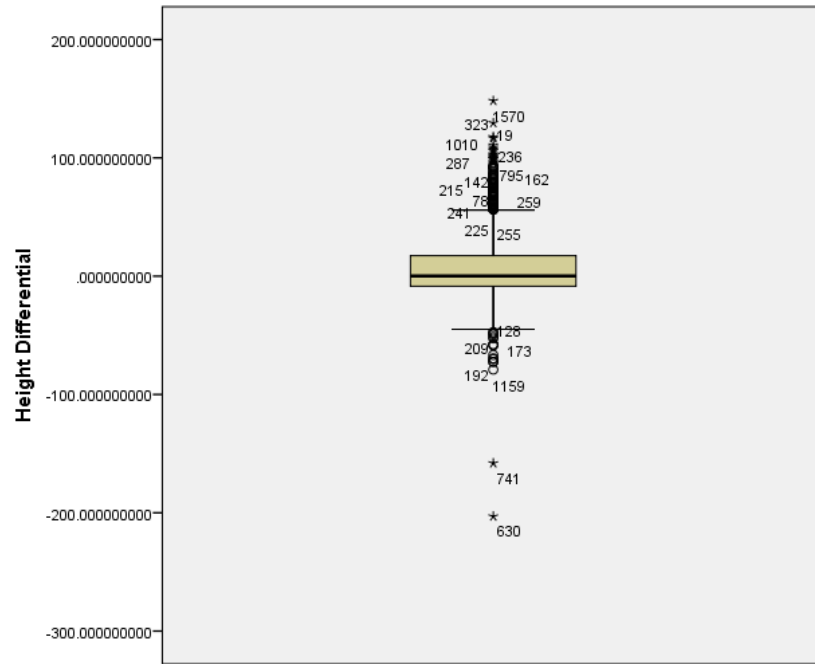


Figure 21. Height Differential Outliers

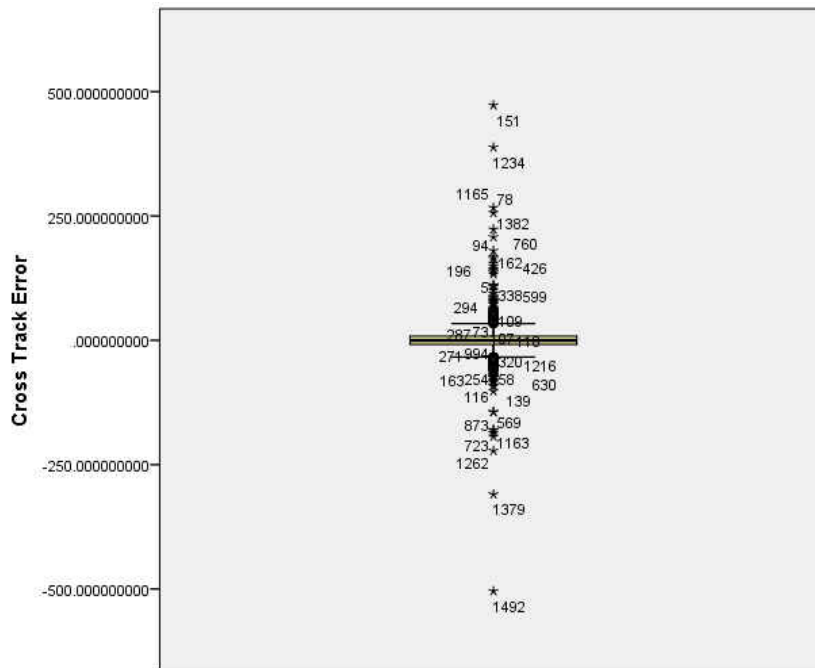


Figure 22. Cross Track Error Outliers

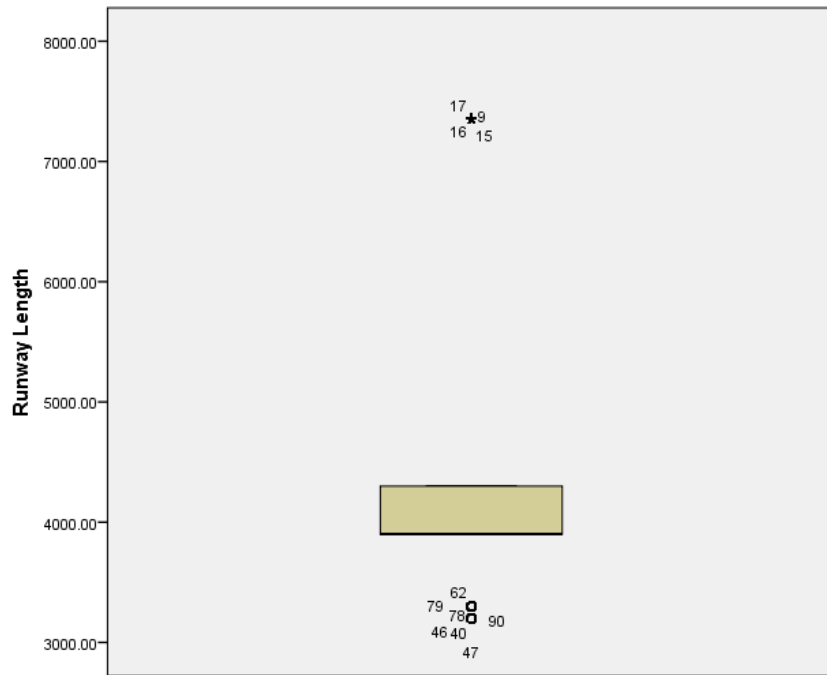


Figure 23. Runway Length Outliers

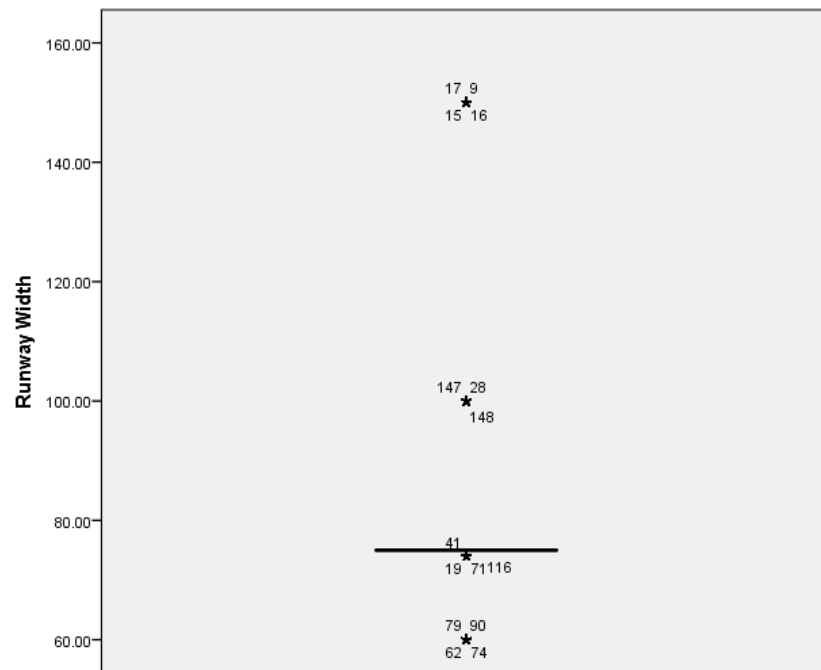


Figure 24. Runway Width Outliers

Table 4. Adjusted Means, Standard Deviations, and Ranges.

	Mean	Standard Deviation	Range
Speed Differential (kts.)	4.25	3.78	-4.81 - 23.98
Height Differential (ft.)	5.77	24.14	-79.00 - 129.50
Cross Track Error (ft.)	0.47	24.14	-185.75 - 266.77
Temperature (deg C)	6.31	14.20	-28.07 - 44.12
Runway Length (ft.)	4,588.72	1,417.49	3199.00 - 7351.00
Runway Width (ft.)	90.24	30.81	60.00 - 150.00

Table 5. Adjusted Frequencies.

	<u>not modified</u>	<u>SafeFlight</u>	<u>Garmin</u>	<u>BendixKing</u>
AOA Status	798	279	181	358
Vertical Guidance present	<u>no</u> 52	<u>yes</u> 1,564		
Day or Night	<u>night</u> 203	<u>day</u> 1,413		
ATC present	<u>no</u> 231	<u>yes</u> 1,385		

Correlation and collinearity

In multiple regression analysis, the independent variables should approach independence (Field, 2009). Bivariate correlations between the independent variables and the dependent variables are presented in Table 6. These correlations suggest an acceptable level of collinearity, except for the strong correlation between runway length and runway width. To avoid errors in the multiple regression analysis, runway width was eliminated from the regression analysis.

Table 6. Correlations of Independent and Dependent Variables.

	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>
1. Speed Diff.	--									
2. Height Diff.	.147**	--								
3. Cross Track Error	.034	.038	--							
4. AOA Status	.002	.048	-.001	--						
5. Vertical Guidance	-.026	-.270**	-.044	-.037	--					
6. Day or Night	.117**	.019	.050*	-.005	-.048	--				
7. Air Temperature	-.013	.080**	.013	.494**	.006	-.032	--			
8. Presence of ATC	-.061*	-.211**	-.036	-.059*	.446**	.032	.014	--		
9. Runway Length	.155**	-.186**	.036	-.041	.179**	.010	.020	.185**	--	
10. Runway Width	.156**	-.163**	.037	-.046	.090**	.006	.024	.206**	.987**	--
** Correlation is significant at the 0.01 level (2-tailed).										
* Correlation is significant at the 0.05 level (2-tailed).										

Normality

The continuous variables speed differential, height differential, cross track error, temperature, and runway length were tested for normality using the Kolmogorov-Smirnov (K-S) test after adjustments were made to the data set to account for outliers. The test statistic for the K-S test is signified by D and the degrees of freedom are placed in parentheses after the D. Variables speed differential, $D(1616) = .08, p < .05$, height differential, $D(1616) = .12, p < .05$, cross track error, $D(1616) = .14, p < .05$, temperature, $D(1616) = .072, p < .05$, and runway length, $D(1616) = .38, p < .05$, were all significantly

non-normal. In large samples however, the Kolmogorov-Smirnov test can be significant even when the scores are only slightly different from a normal distribution (Field, 2009). To further investigate normality, Q-Q plots of each continuous variable were constructed and are presented in Figures 25 through 29.

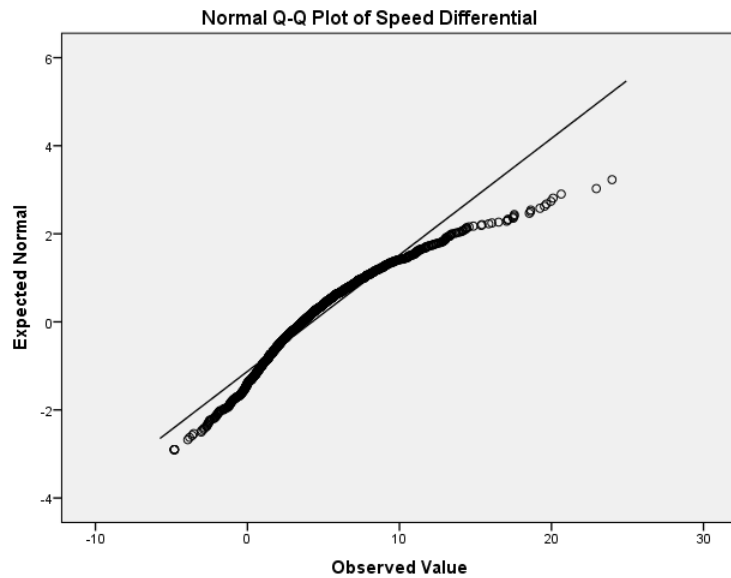


Figure 25. Q-Q plot of Speed Differential

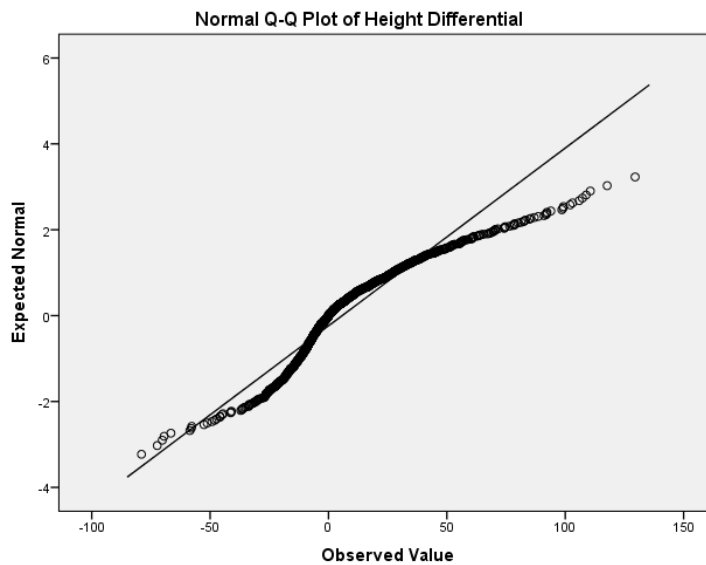


Figure 26. Q-Q plot of Height Differential

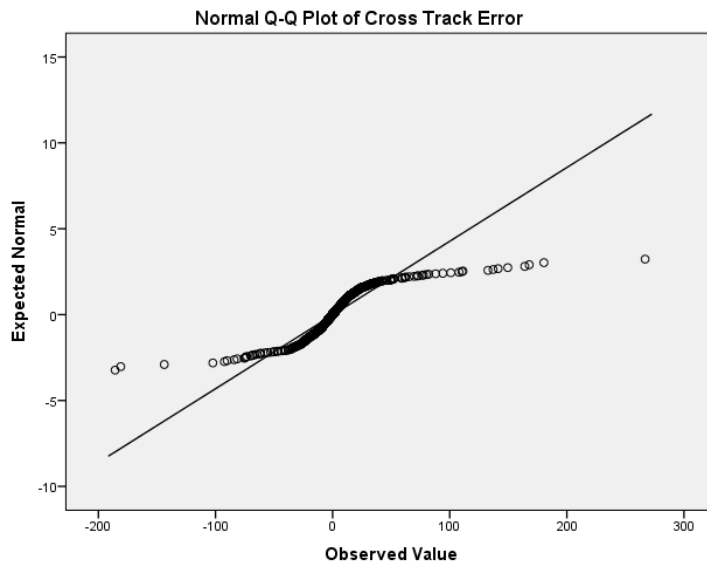


Figure 27. Q-Q plot of Cross Track Error

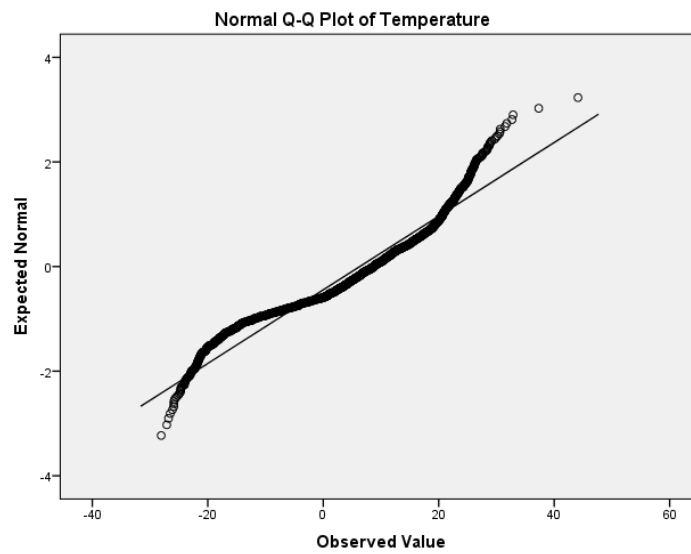


Figure 28. Q-Q plot of Temperature

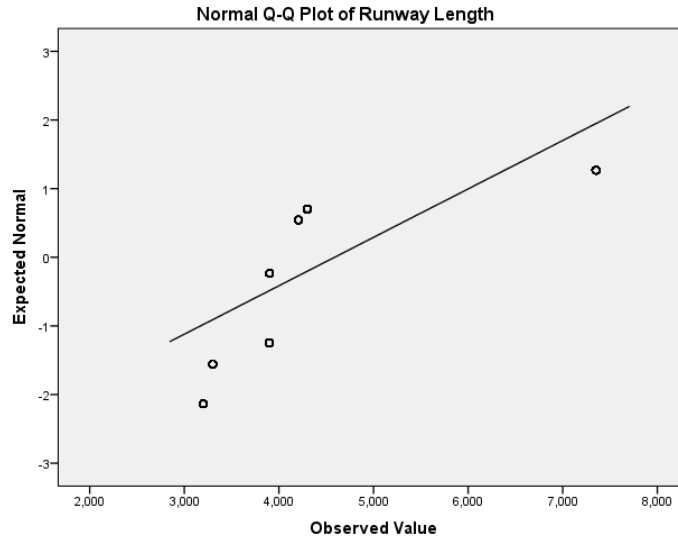


Figure 29. Q-Q plot of Runway Length

Examining the Q-Q plots reveals that each of the continuous variables seems to deviate only slightly from a normal distribution. Normal distribution of speed differential, height differential, cross track error, temperature, and runway length was assumed for further analysis.

Multiple Regression Analysis

The six independent variables were entered into a multiple regression analysis by the forced entry method, where all independent variables were placed into the regression model simultaneously. This results in each independent variable being tested after all other variables have been entered into the model. Separate analyses were conducted for each of the dependent variables. Results are reported in Tables 7 through 9. The significance of each independent variable was tested with degrees of freedom of 1 and 1615. The regression coefficient (b) estimates the amount of change in the dependent variables associated with one unit change in the independent variable. This value also indicates how much a specific independent variable affects the dependent variable if all

other independent variables are held constant. Beta weight (β) is a standardized slope coefficient allowing comparison of each of the independent variables' predictive strength. Beta indicates the number of standard deviations the dependent variable will change for one standard deviation change in the independent variable. The t-test measures whether the independent variable is making a significant contribution to the regression model. Larger values of t indicate larger contributions of that independent variable to the model. The squared semi-partial correlation (part r) represents the proportion of variance in the dependent variable accounted for by each of the independent variables after all other variables were included in the regression equation.

For analysis, each independent variable was coded numerically for entry into the regression formula. AOA status was coded as zero for an unmodified airplane and one for a modified airplane. No vertical guidance available for the runway analyzed was coded zero and coded one for the presence of glide path guidance, whether guidance was via a lighting system or via radio signal from the instrument landing system. For day or night, night was coded as zero and day was coded as one. Outside air temperature was entered as a continuous variable in degrees Celsius. Presence of air traffic control referred to whether an operating control tower was on the airport being analyzed. No ATC was coded as zero and ATC present was coded as one. Finally, runway length was entered as a continuous variable with a value measured in feet.

The dependent variable speed differential refers to the deviation in knots indicated airspeed from the optimum 61 KIAS approach airspeed for the Cessna 172. A positive value denotes an approach at faster than optimum airspeed and a negative value denotes an approach slower than optimum airspeed.

Table 7. Regression Results for Speed Differential.

	B	β	t	part r
AOA modified	.0884	.0117	.3750	.0001
Vertical Guidance	-.3032	-.0142	-.5163	.0001
Day or Night	1.3077	.1147	4.7019*	.0131
Temperature	-.0038	-.0141	-.4528	.0001
ATC Present	-.8905	-.0825	-3.0079*	.0054
Runway Length	.0005	.1739	6.9684*	.0288
* significant at the .05 level				

The overall regression model for speed differential was significant, $R^2 = .05$, $R^2_{adj} = .04$, $F(6,1615) = 12.87$, $p = .00$. Day or night, presence of air traffic control, and runway length significantly contributed to the regression model. Day approaches resulted in higher speed differential. The presence of air traffic control resulted in lower speed differential. Longer runways resulted in higher speed differential.

The dependent variable height differential refers to the deviation in feet from the optimum 200 AGL where the approach was analyzed. A positive value denotes an approach higher than optimum altitude and a negative value denotes an approach lower than optimum altitude.

The overall regression model for height differential was significant, $R^2 = .11$, $R^2_{adj} = .10$, $F(6,1615) = 31.84$, $p = .00$. Vertical guidance, temperature, presence of air traffic control, and runway length significantly contributed to the regression model. Presence of vertical guidance resulted in a lower height differential. Higher outside air temperature resulted in a higher height differential. Presence of air traffic control resulted in a lower

Table 8. Regression Results for Height Differential.

	B	β	t	part r
AOA modified	-1.3180	-.0273	-.9044	.0005
Vertical Guidance	-28.1043	-.2055	-7.7428*	.0333
Day or Night	.5512	.0076	.3206	.0001
Temperature	.1602	.0942	3.1277*	.0054
ATC Present	-6.5378	-.0948	-3.5720*	.0071
Runway Length	-.0022	-.1314	-5.4415*	.0165
* significant at the .05 level				

height differential. Longer runways resulted in a lower height differential.

The dependent variable cross track error refers to the deviation right or left of the extended runway centerline measured in feet. A positive value denotes an approach right of centerline and a negative value denotes an approach left of centerline.

The overall regression model for cross track error was not significant, $R^2 = .01$, $R^2_{adj} = .00$, $F(6,1615) = 2.03$, $p = .06$. Day approaches significantly reduced cross track error in the regression model. No variables significantly predicted effects on cross track error.

Additional analysis was conducted for each of the dependent variables considering the AOA status in more detail. AOA status was divided into four categories, unmodified aircraft, aircraft with the SafeFlight system installed, aircraft with the Garmin system installed, and aircraft with the BendixKing system installed. A dummy code system was established to represent each of these variables in terms of zeros and ones.

Table 9. Regression Results for Cross Track Error.

	B	β	t	part r
AOA modified	-.5220	-.0112	-.3523	.0001
Vertical Guidance	-5.8176	-.0441	-1.5763	.0015
Day or Night	-3.6769	-.0523	-2.1032*	.0027
Temperature	.0313	.0191	.6002	.0002
ATC Present	-1.8087	-.0272	-.9719	.0006
Runway Length	.0008	.0480	1.8864	.0022
* significant at the .05 level				

The baseline, or control, group, assigned all zeros, was unmodified aircraft. Three variables were created to see how each of the individual AOA systems might have had an influence on performance against the control (unmodified aircraft). Dummy variable A1 represented the SafeFlight system. Dummy variable A2 represented the Garmin system, and dummy variable A3 represented the Bendix King system. The dummy coding assignments are presented at Table 10. Results are reported in Tables 11 through 13. The significance of each independent variable was tested with degrees of freedom of 1 and 1615.

Table 10. Dummy Coding Assignments.

	A1	A2	A3
No modification	0	0	0
SafeFlight AOA	1	0	0
Garmin AOA	0	1	0
BendixKing AOA	0	0	1

The regression slopes and beta weights listed in Tables 11 through 13 compare each of the AOA systems to the control group of unmodified aircraft. A one unit change represents the difference between the mean of the group specified and the mean of the control group.

Table 11. Regression Results for Speed Differential (AOA).

	B	β	t	part r
SafeFlight AOA	-.0768	-.0077	-.2920	.0001
Garmin AOA	-.0660	-.0055	-.2120	.0000
BendixKing AOA	.0377	.0041	.1568	.0000
* significant at the .05 level				

The regression model for speed differential was not significant, $R^2 = .00$, $R^2_{adj} = .00$, $F(3,1615) = .06$, $p = .98$. None of the independent variables significantly contributed to the regression model. None of the variables significantly predicted speed differential.

Table 12. Regression Results for Height Differential (AOA).

	B	β	t	part r
SafeFlight AOA	3.1469	.0493	1.8765	.0022
Garmin AOA	.1384	.0018	.0697	.0000
BendixKing AOA	3.3520	.0577	2.1854*	.0029
* significant at the .05 level				

The best and only significant predictor of height differential was the BendixKing system with a very small correlation coefficient of .045. The regression model for height

differential was not significant, $R^2 = .00$, $R^2_{adj} = .00$, $F(3,1615) = 2.32$, $p = .07$, even though the BendixKing system was statistically significant by itself. Given the very small correlation of the BendixKing system with height differential and the lack of significance of the overall regression model, none of the variables appeared to have predicted height differential.

Table 13. Regression Results for Cross Track Error (AOA).

	B	β	t	part r
SafeFlight AOA	.4327	.0070	.2668	.0000
Garmin AOA	-.1591	-.0022	-.0829	.0000
BendixKing AOA	-.0367	-.0007	-.0248	.0000
* significant at the .05 level				

The regression model for cross track error was not significant, $R^2 = .00$, $R^2_{adj} = .00$, $F(3,1615) = .03$, $p = .99$. None of the independent variables significantly contributed to the regression model. None of the variables significantly predicted cross track error.

To check for effects on overall approach stability, each dependent variable representing an element of a stabilized approach was converted to a z-score and then the sum of those z-scores was entered into the original regression. The additional dependent variable zsum refers to the sum of the z-scores for speed differential, height differential, and cross track error. Regression results are reported in Table 14.

The overall regression model for zsum was significant, $R^2 = .05$, $R^2_{adj} = .05$, $F(6,1615) = 13.58$, $p = .00$. Vertical guidance and ATC present significantly contributed to the regression model. Both vertical guidance and ATC present resulted in smaller

Table 14. Regression Results for zsum.

	B	β	t	part r
AOA modified	-.0536	-.0145	-.4643	.0001
Vertical Guidance	-1.4941	-.1423	-5.1941*	.0160
Day or Night	.2110	.0377	1.5484	.0014
Temperature	.0070	.0535	1.7208	.0018
ATC Present	-.5840	-.1103	-4.0265*	.0096
Runway Length	.0001	.0488	1.9571	.0022
* significant at the .05 level				

deviations from the optimum approach, so contributed positively to stabilized approaches.

Safety Survey

An online survey of students and instructors flying University of North Dakota Cessna 172 aircraft was conducted from February 23 through March 10, 2015. Survey web pages are included in Appendix B. Surveys were submitted by 98 participants.

Of 97 participants responding to the question “Which of the following is the highest level FAA pilot certificate you hold?” 14 (14.43%) were student pilots, 36 (37.11%) were private pilots, seven (7.22%) were commercial pilots, and 40 (41.24%) held flight instructor certificates (Figure 30). When questioned about all the various types of training received covering angle of attack instrumentation, 97 participants

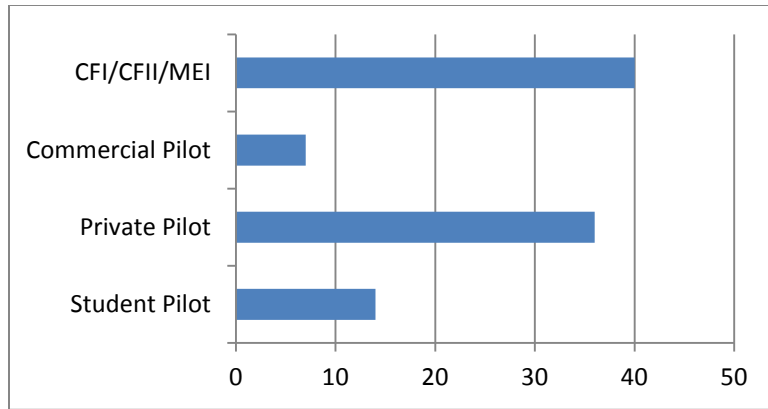


Figure 30. Safety Survey Respondents by Highest Level Pilot Certificate responded. Over one quarter of the pilots responding reported having received no training regarding AOA instrumentation on their aircraft (26 or 26.8%). Of the remaining 71 responding pilots (73.2%), 51 (52.58%) reported learning about AOA instrumentation from self-study or discussion with other pilots, 24 (24.74%) had received ground training about AOA instrumentation from a flight instructor, and 18 (18.56%) had received flight training with AOA instrumentation from a flight instructor (Figure 31).

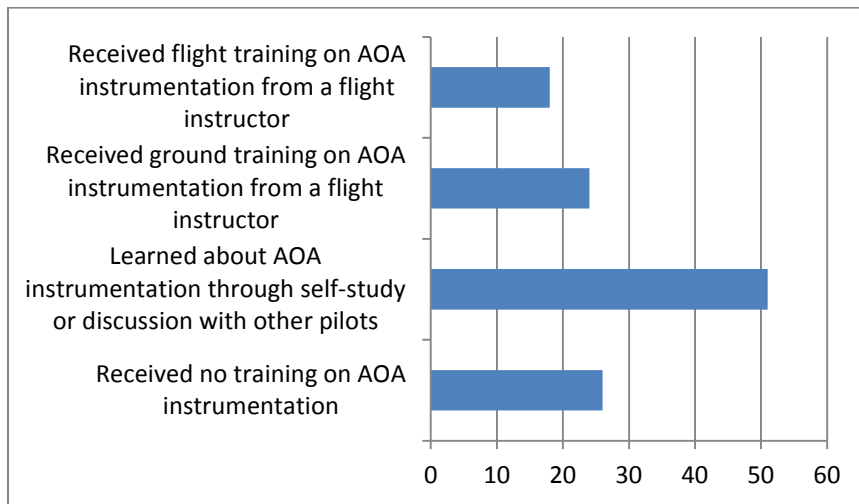


Figure 31. All Types of Training Received on AOA Instrumentation

Respondents were informed that three University of North Dakota Cessna 172s had been modified with AOA instrumentation during the last year. They were asked if

they had flown any of these aircraft. Of 98 pilots responding, 59 (60.2%) said they had flown modified aircraft, 30 (30.61%) had not, and nine (9.18%) did not remember or did not know if they had flown modified aircraft (Figure 32).

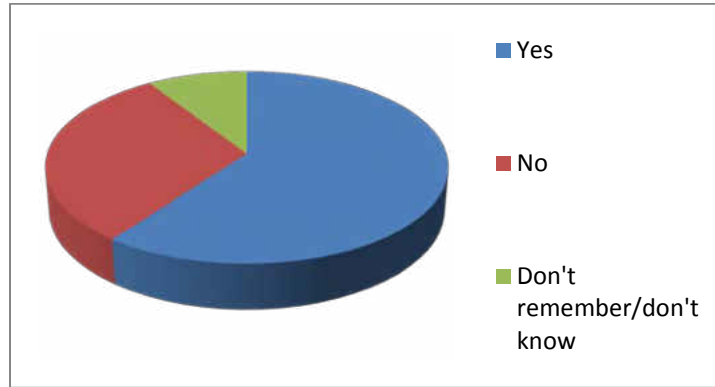


Figure 32. Responding pilots having flown AOA modified aircraft

When asked to describe their experience flying AOA modified aircraft, 98 pilots responded. Forty (40.82%) reported having not flown or did not remember flying a modified aircraft. Interestingly, this is one more than reported not flying or not remembering flying modified aircraft in the preceding question. Of the remaining 58 pilots, 41 (41.84%) reported flying a modified aircraft, but claimed to have ignored the AOA instrumentation; 11 (11.22%) reported flying a modified aircraft and using the AOA instrumentation for supplemental information during approach and landing; 6 (6.12%) reported flying a modified aircraft and using the AOA instrumentation throughout the flight; none claimed to have flown modified aircraft many times and used AOA instrumentation extensively (Figure 33).

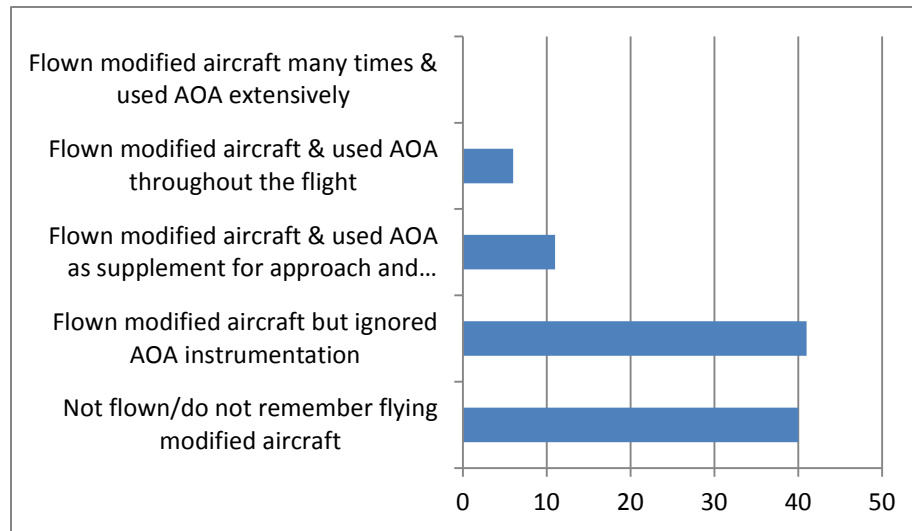


Figure 33. Experience flying AOA modified aircraft

Based on their training and experience, pilots were asked to choose applicable statements indicating or comment about practical uses of AOA instrumentation. Of 88 responding, 47 (53.41%) chose “avoiding departure stalls,” 41 (46.59%) chose “avoiding stalls in the traffic pattern,” 29 (32.96%) chose “avoiding stalls while maneuvering inflight,” 12 (13.64%) chose “determining best range or best endurance conditions inflight,” and 20 (22.73%) don’t believe there are any practical uses of AOA instrumentation on light aircraft (Figure 34). Additional comments were received from 14 (15.91%) of respondents. Two themes were evident in these comments. First, lack of training caused some pilots to choose not to use installed AOA instrumentation or not to comment about practical uses of a system with which they were not familiar. “Due to the lack of information about how to use them, I do not know how, so I don't use them,” and “I'm not educated on it enough to make an informed decision.” The second theme was an expressed concern about over-reliance on instrumentation at the expense of the implied higher importance of learning to fly by feel. “Pilots should learn to fly by feel in this stage of training,” or “It is too early for this ‘cheap’ technology. Manufacturers are

calculating AOA differently.” Other comments referred to seeing AOA vs. airspeed relationships and suggested different instrument displays from those installed. At the opposite end of the *learn to fly by feel* argument was this statement: “Inexperienced pilots could benefit from these instruments in avoiding stall conditions, however, I do not believe they add much for an experienced pilot who flies regularly.”

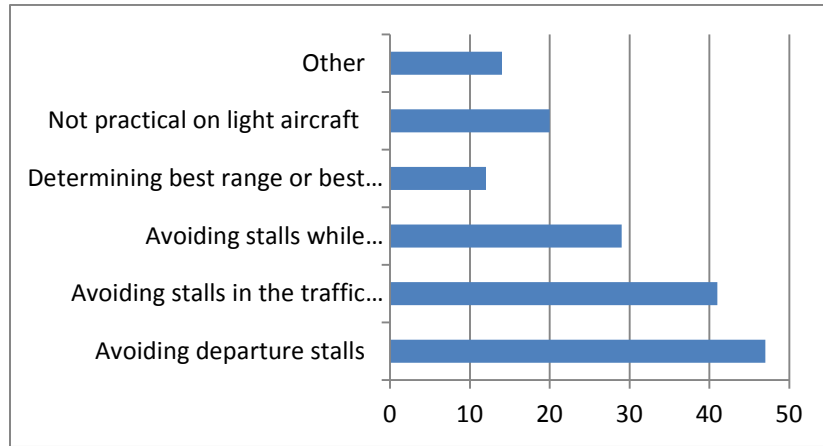


Figure 34. Practical Uses of AOA Instrumentation

Respondents were asked if, in their opinion, general aviation pilots were more likely to fly a stabilized turn from base leg to final and a stabilized final approach in aircraft equipped with supplemental AOA instrumentation than in aircraft not so equipped. Of the 97 responses received, 33 (34.02%) said yes, 41 (42.27%) said no, and 23 (23.71%) had no opinion or preferred not to answer (Figure 35).

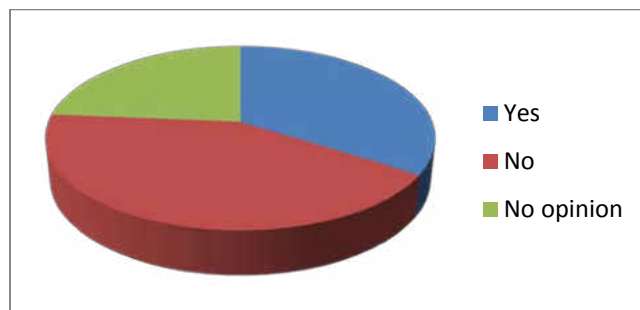


Figure 35. Respondents believing supplemental AOA systems contribute to more stabilized final turns and final approaches

When asked if general aviation pilots encountering an unstable approach were more likely to execute a go-around in aircraft equipped with supplemental AOA instrumentation than those without, 30 (30.93%) of the 97 pilots who responded said yes. Just over half (49 or 50.52%) said no, and 18 (18.56%) had no opinion or preferred not to answer (Figure 36).

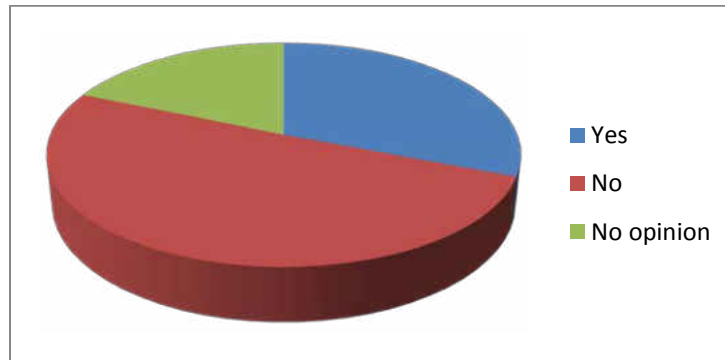


Figure 36. Respondents believing pilots encountering unstable approaches were more likely to execute a go-around when equipped with supplemental AOA instrumentation

When asked about the most positive aspects of having supplemental AOA systems installed on general aviation aircraft, 60 pilots responded. The dominant theme in these comments was increased situational awareness with regard to proximity to the stall angle of attack. One flight instructor said, “It’s another tool to enhance situational awareness for a pilot. It’s one more way for a pilot to help fly a stabilized approach.” A commercial pilot called AOA systems a “good back up for having to look down at airspeed, increases situational awareness.” A private pilot who had received ground and flight instruction with the instruments called AOA systems “an accurate look into the aircraft performance, as opposed to using hearing and buffeting to determine how close the aircraft is to a stall.” Lack of training in supplemental AOA systems was highlighted by another flight instructor. “I believe angle of attack instruments could help reduce the

amount of stall/spin accidents that occur inadvertently in general aviation. However, for this to occur the pilot needs to have proper training on the AOA system.”

Responses regarding the most negative aspects of having supplemental AOA systems installed on general aviation aircraft numbered 63. The overwhelming majority of comments addressed pilot distraction or potential over-reliance on instrumentation. Lack of training was mentioned in many cases and was evident from a misunderstanding of the systems displayed in some comments. One flight instructor said, “I find them to be a distraction. It’s one more thing inside the plane that pilots have to keep them from looking outside. When I flew with the AOA indicators I found myself several times just looking at it instead of outside at my aim point.” One student who reported receiving ground and flight instruction from an instructor explained, “I feel like it’s really not needed because people do without it all the time, it’s just another thing to look at and check to make sure it is not in a high angle of attack. The point of the flight instruments is to look at them and fly according to them, there is no need for another instrument.” Another flight instructor noted, “Turning base to final is not the time to be spending too much time with your head in the cockpit. Also no good if pilots are not trained on the proper use of the system.” An instructor who has not flown with AOA-modified aircraft said, “...adding yet another thing for beginning pilots to keep track of for their training. Because UND uses primarily G1000 equipped aircraft, it’s already difficult to keep some students focused outside the aircraft, which is essential for training...” A student pilot whose training was limited to self-study or discussion with other pilots was concerned AOA instrumentation “could take some of the pilot’s attention away from actually flying the aircraft or looking outside during critical phases of flight,” but added, “If they are

trained on how to use it though I believe it would be a positive addition to the aircraft.”

Finally, a commercial pilot with no training on AOA instrumentation said, “I’ve heard they are not helpful and too delayed to make any decisions off them. I don’t know if this is true.”

The safety survey’s final question asked for specific recommendations to improve training regarding supplemental AOA systems on general aviation aircraft and received 57 responses. Like the previous questions, respondents were quite divided in their opinions with answers covering the spectrum from “Get rid of them!” to “Equip the entire fleet!” Most answers, however, addressed the lack of formal training on supplemental AOA systems provided in the school environment up to now. One private pilot summed up the need for training.

Start teaching about them in ground schools. I’ve flown all three and at no point has anyone told me how to use it. I personally think it’s just one more gadget UND can put in their aircraft and it’s unnecessary. CFI, CFII, and MEIs should stress the importance of stalls in the traffic pattern, and this includes where it’s most likely to occur, also the correct place. They should also be stressing turn coordination more. I’ve flown on observation flights where the student didn’t make a single coordinated turn and nothing was said or corrected by the instructor. Safety deferred is safety denied, plain and simple.

Another private pilot added, “teaching about it in ground school, and explaining how it works and why it can be beneficial, students and instructors would utilize it much more often and it could be a great and efficient tool to increase situational awareness.”

Frustration was not limited to non-instructors. One CFI explained,

I have never received training on the AOA indicator. I have read some manuals, but don’t really know when to use it. Since we are doing training, we often have high AOA intentionally, so I just ignore the AOA indicator. If I receive proper training on how to use it, my opinion might change but for now I just don’t know when to use it.

Another CFI provided system-specific critiques and recommendations, while also concluding with a misunderstanding of the differences between airspeed and angle of attack and their relationship to stall.

Of the three that we have I feel as if two of them are fairly useless and one is excellent. The high-mid-low ones are not useful in my opinion but the one that shows varying segments as you approach critical angle of attack is actually really good. When we practice stalls in the airplane, during slow flight, that one just had a series of slow paced quiet beeps, and as we got to a buffet the AOA sensor was beeping louder and more rapidly as well as indicating a red downward arrow. I feel as if that could be a benefit to someone who is less experienced and might influence them to reduce AOA more urgently than a traditional stall horn. That to me is what a good angle of attack indicator should do as an enhancement to a stall horn. The other thing useful that it does is that on landing if a student or pilot were to flare high and airspeed is reduced significantly, they might be unaware of how close they are to stall, but the rapid beeping and downward pointed arrow just a degree or two away from critical AOA might influence a go-around, a positive outcome. Personally I have seen a student flare high in that airplane and with the AOA indicator beeping at its most urgent state, sure enough we dropped right onto the runway and it was a poor landing. I do not believe we should teach how to land at a specific AOA-an airspeed already achieves that.

CHAPTER IV

DISCUSSION

Over the course of 1,616 analyzed approaches flown between October 1, 2013 and December 31, 2014, the addition of supplemental angle of attack systems alone did not significantly increase the likelihood of University of North Dakota pilots flying a stabilized approach. The overall regression models for speed and height differential were significant, and although these are the two aspects of stabilized approaches where an effect due to AOA system installation would be most expected, no significant effect was observed. Likewise, checking each individual AOA system for influence on approach performance against the control group of unmodified aircraft yielded no significant regression models. In the case of height differential, the BendixKing KLR 10 AOA system by itself contributed significantly to the model with a very small correlation coefficient, but the overall regression model was not significant. As a result, none of the individual systems was considered to have predicted speed differential, height differential, or cross track error.

With regard to the presence of vertical guidance from an approach lighting system or radio signal from an instrument landing system, no significant effect was observed on speed differential or cross track error. However, perhaps as expected due to the increased amount of glide path information available to the pilot, presence of a vertical guidance system significantly lowered height differential, contributing to a more stable approach.

Day approaches significantly increased speed differential. Further research might be warranted in this area, but possible reasons for this relationship might include increased visual cues available in the daytime competing with instrument crosscheck and more attention paid to instruments for orientation at night. Daytime also generally results in more air traffic, so an increased speed differential might also be associated with speed adjustments accommodating that traffic. Time of day had no significant effect on height differential. While day approaches significantly reduced cross track error in the regression model, the overall model was not significant.

Outside air temperature did not significantly affect speed differential or cross track error. Interestingly, a higher outside air temperature was associated with a higher height differential. Summer conditions sometimes result in higher levels of convective turbulence than experienced during the winter, which might have an adverse effect on the pilot's ability to maintain a stable glide path. More research is warranted regarding seasonal effects on stabilized approaches.

Presence of an operating air traffic control tower resulted in significantly lower speed differential and height differential. ATC presence had no significant effect on cross track error. Possible reasons for these effects include busier and more regimented traffic patterns associated with tower controlled airports requiring pilots to focus more heavily on precise speed and glide path control to remain de-conflicted with other airplanes.

Runway characteristics of length and width are highly positively correlated for what might seem to be obvious reasons. Runways built for larger aircraft requiring longer takeoff or landing rolls also require wider surfaces to safely handle an increased

aircraft footprint. Increased runway length significantly resulted in higher speed differential but lower height differential. Runway length had no significant effect on cross track error. Both significant effects might be associated with small aircraft operations on larger runways. Smaller aircraft might tend to land longer on larger runways since landing distance is not as critical. Similarly, most instrument approaches are made to longer runways. Small aircraft tend to fly higher than final approach airspeeds during the instrument approach and slow to normal speeds when approaching the touchdown zone of the runway. Instrument approaches are also designed for a touchdown point farther from the approach end than might be used for a visual approach to a short runway. Pilots flying visual approaches or simulating short field approaches on long runways might aim short of the desired touchdown point, resulting in a lower height differential.

Given many years of favorable performance on military aircraft and the FAA's emphasis on making supplemental AOA systems more available to general aviation aircraft, an expectation was established that a positive relationship between installed AOA systems and improved elements of a stabilized approach would exist. A number of data collection limitations and a current lack of formalized training in AOA instrumentation may have contributed to finding no significant effects.

Historically, light general aviation aircraft have not been designed or equipped to collect flight data. As a result, few of these aircraft have any capability to record relevant flight parameters useful for safety research. Recently, some aircraft owners and flying schools have begun to install recording equipment on their airplanes to provide data useful for conducting safety analysis or providing playback of flight training. The

University of North Dakota's flight data monitoring system used in this study is able to capture many flight parameters from the Garmin G1000 avionics, but despite being much more capable than the majority of general aviation aircraft in this area, several real limitations still exist with regard to analyzing a dynamic approach environment.

Recording equipment is limited to a 1Hz update rate, meaning that the raw data is limited to "snapshots" of flight parameters once per second. While university staff have developed analysis tools for converting snapshot data to "pictures" of dynamic approaches, these pictures are still limited by data only being input to the model once each second. Also, the recording equipment is unable to measure some key parameters associated with landing approaches. Aircraft are not equipped with a radar altimeter, so altitude above the terrain must be calculated based on a combination of GPS position, the assumption of a correct altimeter setting, and computation of pressure altitude. Even with a correctly set pressure altimeter, allowable instrument error is +/- 75 feet.

The aircraft in question have fixed landing gear, so no weight on wheels sensors are available to tell the flight recorder when the airplane is on the ground. Likewise, flap position is not recorded, so even an educated guess about what the airplane is doing on or close to the ground is made more difficult.

Another data measurement limitation springs from the fact that all three of the installed AOA systems are hard-wired to the aircraft's electrical power system. Theoretically, if power is applied to the airplane, the instrument is operating. There is no way to tell from recordings if installed indicators were operating, were calibrated correctly, or had been muted or turned off by the pilots. Since all data was collected in a naturalistic environment where neither pilots nor maintenance personnel knew the AOA

instrumentation was being observed, there may be an unknown number of cases where the instrument was not powered or calibrated for proper use inflight.

Since the sample size for this study was quite large, the lack of significant effects due to AOA systems was not likely due to power limitations. Also, the pilot population was quite homogeneous in terms of approximate age (all participants in a university flight training program) and the flying environment in which they operate. At the same time, demographic information was necessarily limited due to privacy concerns and the true nature of pilot experience may not be evident. Training experience, social interaction, and resulting feelings about the addition of supplemental AOA instrumentation might tend to be more homogeneous with this sample than with the overall general aviation population.

Collecting data in a naturalistic environment where the pilots were unaware they were being observed is useful to limit the Hawthorne effect (tendency of individuals to adjust their behavior based on their awareness of being observed), but it also limits the researcher's ability to collect detailed debrief information which could have provided more details about the approaches flown and analyzed. For example, post-flight questionnaires or interviews might have yielded more information about instrument operation, details of maneuvers flown, and pilot inputs regarding specific use or non-use of AOA instrumentation on that specific flight.

Perhaps the largest limitation on this study was a distinct lack of formal training on angle of attack concepts and AOA instrumentation among the pilot sample surveyed. Pilots surveyed responded less than 90 days from the end of the flight data collection

period, so the assumption is made that many respondents to the safety survey were also pilots who flew during the flight data collection phase.

Of the 98 pilot participants in the safety survey, none responded that he or she had “extensive experience” flying with AOA instrumentation, yet many expressed strong opinions both pro and con. Over 82 percent of survey respondents reported either not having flown an AOA-modified aircraft or having ignored the instrument when they flew a modified aircraft. Only 17 pilots responding reported using the AOA instrumentation for supplemental information during approach and landing or throughout their flights. If what the pilots say about how they flew closely resembles how they actually did fly, this may be a major explanation for the lack of effect observed for AOA-modified aircraft on stabilized approaches. The instrumentation has gone largely unused.

This situation was reported to be largely due to a lack of formal training. When the three different AOA systems were installed in university aircraft, a conscious decision was made to install the instruments before formal training was offered. The reasoning reported was that these instruments were so intuitive that formal training would not be required. What was perhaps not anticipated was that pilots, particularly low time pilots, are often taught to develop habit patterns to keep them safe. Comments received in the safety survey often presented the theme of “I didn’t need it yesterday. Why do I need it today?” Others adopted an attitude often taught in other safety programs of not operating a system for which they had not received training.

The level of training in AOA instrumentation was self-reported in the safety survey. Over one quarter of the respondents (26.8 percent) reported having received no training at all regarding AOA instrumentation on their aircraft. Just over half (52.6

percent) reported learning what they knew about AOA instrumentation from “self-study or discussion with other pilots,” and the remaining quarter reported receiving some kind of ground and/or flight instruction on the systems from a flight instructor. “Self-study or discussion with other pilots” allows for a wide spectrum of interpretation, but pilots operating in a homogeneous training environment likely tend to discuss the topic with their classmates, and may tend toward similar opinions, whether or not they are based on technically correct information. In this study, those not in favor of using supplemental AOA systems on general aviation aircraft number approximately half the respondents and those in favor of using them or not wanting to express an opinion constitute the other half, yet three out of four had not received training beyond what they reported as self-study or discussion.

The low level of training, and resultant ignoring of the instrumentation, might be masking useful information about installed AOA systems which might not become evident until a trained pilot population is sampled. For example, at least one survey respondent had a definite opinion about which AOA system works best, but any potential effect it may have had on performance was lost among the high number of approaches flown where AOA equipment was ignored.

Investigating whether general aviation pilots who fly AOA-equipped aircraft are more likely to execute a go-around if they encounter an unstable approach than those flying aircraft not so equipped became nearly impossible due to a combination of data measurement technical limitations and lack of training among the survey respondents. The previously mentioned 1Hz update rate, lack of a radar altimeter, no weight-on-wheels sensor, and lack of information about flap position effectively mask detection of

low altitude go-arounds. Review of available data indicated a lack of reliability in differentiating late go-arounds from touch and go or full stop landings. Of 1,616 approaches analyzed, 310 or 19.2 percent, were labeled unstable by study criteria. By training policy, these approaches should have resulted in a go-around, but the actual number executed was not identifiable by the flight data.

Even in cases where a go-around appears to have occurred at a higher altitude (as illustrated by the 28 outlier cases eliminated from the approach analysis), no reliable method exists to differentiate among an intentional low approach, an ATC-directed go-around, or a go-around due to an unstable approach.

Survey responses do no better at predicting go-arounds due to unstable approaches. Respondents expressed their belief that pilots encountering unstable approaches were more likely to execute a go-around when equipped with supplemental AOA instrumentation at about the same rates they thought the systems were useful in general. With 97 pilots responding, 30.9 percent believe pilots would be more likely to execute a go-around from an unstable approach if equipped with AOA instrumentation. Just over half (50.5 percent) believed they would not, and the remaining 18.6 percent offered no opinion.

Only 57 pilots responded to questions about specific recommendations to improve training regarding supplemental AOA systems, and like the other responses to the safety survey, represented a wide variety of opinions. Even in responses not specifically recommending topics for training, misconceptions regarding airspeed versus AOA relationships were voiced, and indicated the need for better training in aerodynamic concepts. Many respondents agreed that AOA concepts and systems should be taught in

ground school in the same way other aircraft systems are taught. From there, flight training incorporating the concepts taught in ground school could be practiced. Some instructors expressed frustration with not knowing exactly how and when to use the instrumentation based on reading basic manuals provided by the manufacturers, and wanted more detailed information from knowledgeable sources.

Ultimately this study was about incorporating supplemental instrument displays into effective pilot decision making, but to accurately assess effect, the pilots must be trained to use the equipment and task being studied. To observe real differences between AOA-aided approaches and non-AOA approaches, future studies should examine groups of pilots who have and have not received formal training in AOA system use. While the Hawthorne effect may have a greater risk of being present, study participants should be volunteers willing to have their performance measured as well as willing to participate in more detailed debriefings of their flights. Supplemental AOA systems are worthy of more future study once adequate formal training has been provided, but until then, their demonstrated effectiveness must be considered inconclusive.

Recommendations for Further Study

Future research regarding supplemental AOA systems on light general aviation aircraft should focus on overcoming the three most restrictive limitations observed during this study: inclusion of formal training for subject pilots, developing a reliable ability to analyze approaches resulting in a go-around, and collection of pilot feedback immediately following flights using supplemental AOA systems. Research strengthened in each of these areas will provide more information needed to determine if supplemental AOA systems can truly potentially prevent loss of control accidents.

Formal training should be conducted in both ground and flight training settings prior to conducting future performance testing. This training should include aerodynamic theory related to angle of attack as well as how the specific instrument of interest operates. Subjects to fly data collection flights should be identified to participate as either trained pilots using supplemental AOA systems or non-trained pilots flying without AOA instrumentation. Pilots receiving training should also have the opportunity to train in flight with the AOA instrumentation before flying approaches for record. Comparisons can then be made between AOA-equipped flights and non-AOA-equipped flights.

Future research must address the issue of reliably identifying go-arounds at the conclusion of subject approaches. Several methods are available to address this problem. First, researchers can develop an additional analysis tool which could model various landing and go-around situations from the flight parameters collected. Second, with sufficient support made available, improved flight recording equipment could be used to more accurately represent the dynamic environment experienced during the approaches flown. Finally, should resources not be available to procure needed technological improvements, pilot observations could be manually recorded to overcome much of the uncertainty experienced in the naturalistic setting of this study. Observer pilots could be equipped with an event log to be carried on each subject flight, where relevant information regarding AOA system use and each approach could be recorded in writing.

Post-flight questionnaires and interviews should be used to determine types of approaches flown, flap settings, how the approach terminated, pilots' comments about relevant events, and other feedback needed by the researcher. This type of qualitative

data collection focuses on detailed event feedback based on training and actual performance rather than comment by random participants. Data collected in this manner might overcome some of the potential biases observed during this study which might have developed in members of a homogeneous pilot group before receiving formal training.

Including these improvements in future research procedures establishes more of an operational test environment than the naturalistic setting of the present study. While potential for the Hawthorne effect must be considered in this scenario, far greater potential to collect useful data more reliably identifying performance effects due to supplemental AOA systems should exist.

APPENDICES

Appendix A

List of Terms

AGL - feet above ground level

Angle of attack – the angle measured in degrees between the wing’s chord line and the relative wind or freestream velocity vector

Base – a short descending flight path at right angles to the approach end extended centerline of the landing runway

Chord line - a line drawn between the wing’s leading edge and its trailing edge

Critical Angle of Attack - that angle of attack at which the wing’s maximum lift is achieved, beyond which there is a significant loss of lift and increase in drag, where the wing “stalls”

Drag – the force that acts parallel to the relative wind

Electronic Flight Information System (EFIS) – an airplane instrument display system in which the display is electronic rather than electromechanical

Final – the last leg in an aircraft’s approach to the landing runway, where the aircraft is aligned with the runway and descending for landing

G loading (also load factor) – the dimensionless ratio of an aircraft’s lift to its weight expressed in terms of the *apparent* acceleration of gravity experienced by an observer on board the aircraft

Go-around (also rejected landing) -- abandoning a landing attempt from final approach

ILS – Instrument Landing System – a ground based instrument approach system designed to provide precision lateral and vertical guidance to an appropriately

equipped aircraft using a combination of radio signals, to allow a precision approach during instrument conditions. The lateral guidance is provided by a localizer signal, and the vertical guidance is provided by a glide slope signal.

KIAS - Knots Indicated Airspeed

Light-emitting Diode (LED) – a semiconductor which emits light when electrical current passes through it

Lift – the force acting perpendicular to the relative wind

NACA 2412 airfoil – airfoil shape categorized by the National Advisory Committee for Aeronautics commonly used in light general aviation airplane design

PAPI – Precision Approach Path Indicator – a lighting system serving as a visual aid to pilots acquiring and maintaining a proper glide path to the landing runway. It is installed on either side of the runway approximately 1,000 feet from the approach end and displays combinations of red and white lights to indicate an airplane's height in relation to the desired glide path.

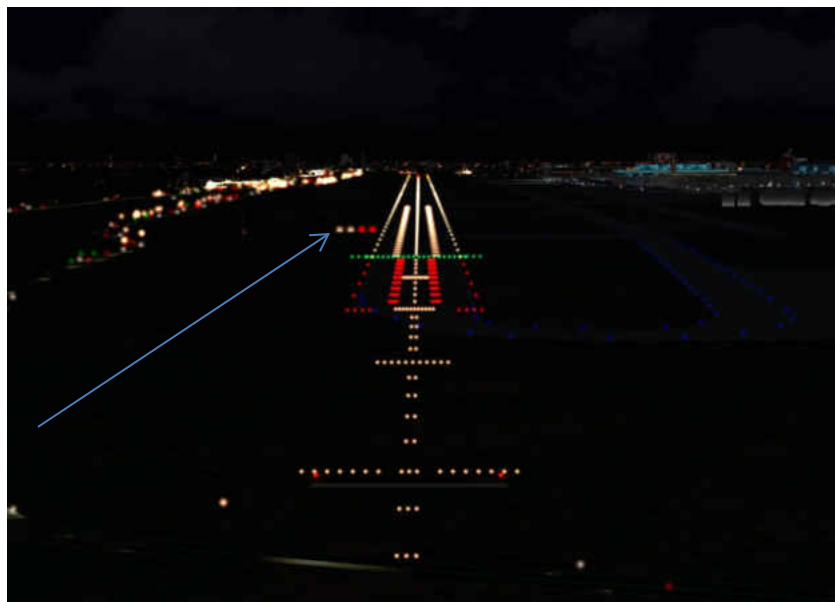


Figure 37. PAPI indicating on glide path

Pitot/static system – a system of pressure-sensitive instruments designed to determine
airspeed, altitude, and altitude trend

Relative wind - the direction at which a vehicle in flight meets the oncoming airstream

Secure Digital (SD) card – small flash memory card used to store large amounts of data
on a small device

Sideslip angle – rotation of the aircraft centerline from the relative wind, generally
referred to as positive when the relative wind approaches from right of the
nose and negative when the relative wind approaches from left of the nose

Stall – a condition where the wing drastically loses lift at an angle of attack greater than
the critical angle of attack

Spin – a stall resulting in autorotation about the vertical axis and descending in a shallow,
rotating path

Stall warning tab – a component of some light aircraft stall warning systems where a thin,
moveable, metal tab is mounted in an opening in the leading edge of a wing. The
tab is moved by air from the relative wind striking it. As airflow approaches the
critical angle of attack, the tab strikes a plate which activates a stall warning horn
audible to the pilot.

VASI – Vertical Approach Slope Indicator – a lighting system serving as a visual aid
to pilots acquiring and maintaining a proper glide path to the landing runway.
Light bars are installed at different distances from the approach end on the side of
the landing runway, so red or white lights are displayed depending on the
airplane's glide path angle. If on the desired glide path, the far bar will display
red while the near bar displays white. This is commonly referred to as “red over

white.” VASI has been replaced by the newer PAPI at many airports.

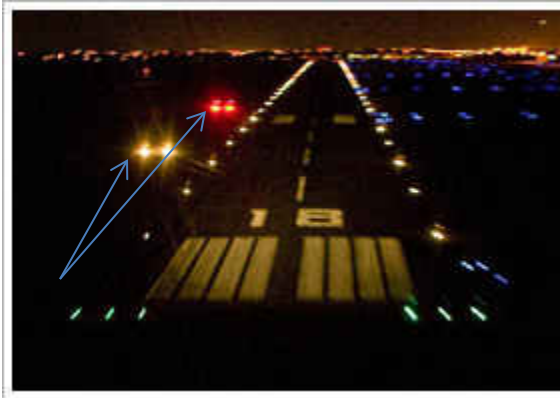


Figure 38. VASI indicating on glide path

Appendix B

Online Flying Safety Survey

Supplemental Angle of Attack Systems on General Aviation Aircraft

Welcome to our survey. Thank you for participating.

UNIVERSITY OF NORTH DAKOTA
Institutional Review Board
Informed Consent Statement

Title of Project: Enhancing General Aviation Aircraft Safety With Supplemental Angle of Attack Systems

Principal Investigator: David Kugler, (719) 277-7139, david.kugler@my.und.edu

Advisor: Dr. Thomas Petros, (701) 777-3260, thomas.petros@email.und.edu

Purpose of the Study:

The purpose of this research study is to investigate whether the number of stalls in the traffic pattern in light general aviation aircraft can be reduced when aircraft are equipped with supplemental angle of attack (AOA) instrumentation designed to provide the pilot continuous situational awareness regarding remaining lift available for the current aircraft configuration and flight conditions. This survey further investigates findings regarding AOA system contributions to flying stabilized approaches and aims to collect information useful to developing future training.

Procedures to be followed:

You will be asked 10 questions about your experiences with UND aircraft modified with AOA systems.

Risks:

There are no risks in participating in this research beyond those experienced in everyday life.

Benefits:

- You might learn more about supplemental angle of attack systems on general aviation aircraft.
- This research might provide a better understanding of how supplemental angle of attack systems might enhance safety on general aviation aircraft. Findings might contribute to future training and avionics design.

Duration:

It should take about 10 minutes to complete this survey.

Statement of Confidentiality:

The survey does not ask for any information that would identify whom the responses belong to. Therefore, your responses are recorded anonymously. If this research is published, no information that would identify you will be included since your name is in no way linked to your responses. All survey responses that we receive will be treated confidentially and stored on a secure server. However, given that the surveys can be completed from any computer (e.g., personal, work, school), we are unable to guarantee the security of the computer on which you choose to enter your responses. As a participant in our study, we want you to be aware that certain "key logging" software programs exist that can be used to track or capture data that you enter and/or websites that you visit.

Right to Ask Questions:

The researchers conducting this study are listed above. You may ask any questions you have during normal daytime business hours. If you later have questions, concerns, or complaints about the research, please contact the principal investigator or his advisor during the day.

If you have questions regarding your rights as a research subject, you may contact The University of North Dakota Institutional Review Board at (701) 777-4279. You may also call this number with problems, complaints, or concerns about the research. Please call this number if you cannot reach research staff, or you wish to talk with someone who is an informed individual who is independent of the research team.

Purpose of the Study:

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General information about being a research subject can be found on the Institutional Review Board website "Information for Research Participants" <http://und.edu/research/resources/human-subjects/research-participants.cfm>

Compensation:

You will not receive compensation for your participation.

Next

Powered by **SurveyMonkey**
Check out our [sample surveys](#) and create your own now!

Supplemental Angle of Attack Systems on General Aviation Aircraft

Welcome to our survey. Thank you for participating.

Voluntary Participation:

You do not have to participate in this research. You can stop your participation at any time. You may refuse to participate or choose to discontinue participation at any time without losing any benefits to which you are otherwise entitled.

You do not have to answer any questions you do not want to answer.

You must be 18 years of age older to consent to participate in this research study.

Completion and submission of the survey implies that you have read the information in this form and consent to participate in the research.

Please copy this form for your records or future reference.

[Prev](#) [Next](#)

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Check out our [sample surveys](#) and create your own now!

Supplemental Angle of Attack Systems on General Aviation Aircraft

1. Which of the following is the highest level FAA pilot certificate you hold?

- Student Pilot
- Private Pilot
- Commercial Pilot
- CFI or CFII or MEI

2. Please indicate the type(s) of training you've received regarding angle of attack (or reserve lift) instruments on general aviation aircraft (check all that apply).

- I've received no training on angle of attack instrumentation.
- I've learned about angle of attack instrumentation through self study or discussion with other pilots.
- I've received ground training on angle of attack instrumentation from a flight instructor.
- I've received flight training on angle of attack instrumentation from a flight instructor.

3. UND has installed various angle of attack instruments on three Cessna 172 aircraft in its fleet over the last year. Have you flown any of these aircraft with angle of attack instruments installed?

- Yes
- No
- Don't remember/Don't know

4. Which statement best describes your experience with angle of attack-modified aircraft at UND?

- I've not flown or do not remember flying a modified aircraft.
- I've flown a modified aircraft, but ignored the angle of attack instrumentation.
- I've flown a modified aircraft and used the angle of attack instrumentation for supplemental information during approach and landing.
- I've flown a modified aircraft and used the angle of attack instrumentation throughout the flight.
- I've flown modified aircraft many times and have used angle of attack instrumentation extensively.

5. Based on your training and experience with angle of attack instrumentation, which of the following do you feel are practical uses of the system (please check all that apply)?

- Avoiding departure stalls
- Avoiding stalls in the traffic pattern
- Avoiding stalls while maneuvering in flight
- Determining "best range" or "best endurance" conditions in flight
- I don't believe there are any practical uses of angle of attack instrumentation on light aircraft.
- Other (please specify)

6. In your opinion, are general aviation pilots more likely to fly a stabilized turn to final and final approach in aircraft equipped with supplemental angle of attack systems than in aircraft not so equipped?

- Yes
- No
- No opinion/Would rather not answer

7. In your opinion, are general aviation pilots who fly angle of attack-equipped aircraft more likely to execute a go-around if they encounter an unstable approach than those flying aircraft not so equipped?

- Yes
- No
- No opinion/Would rather not answer

8. In your opinion, what are the most *positive* aspects of having supplemental angle of attack instrumentation on general aviation aircraft?

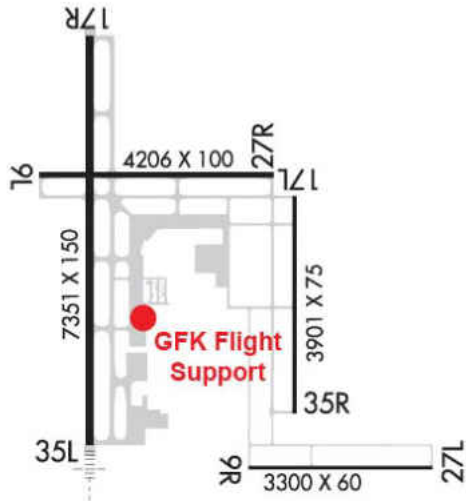
9. In your opinion, what are the most *negative* aspects of having supplemental angle of attack instrumentation on general aviation aircraft?

10. What recommendations would you make to improve training regarding supplemental angle of attack systems on general aviation aircraft? Please feel free to comment on any other aspect of using supplemental angle of attack instrumentation on general aviation aircraft.

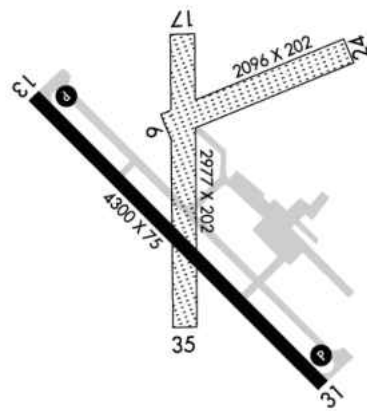
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Appendix C

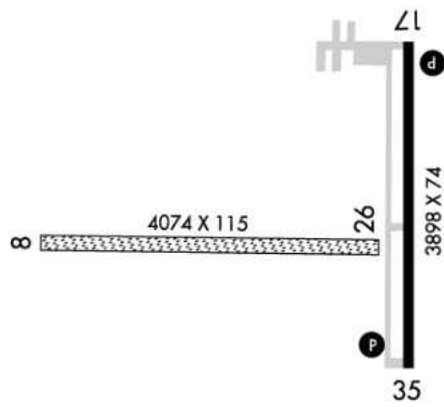
Airports and Runways Used for Approach Analysis



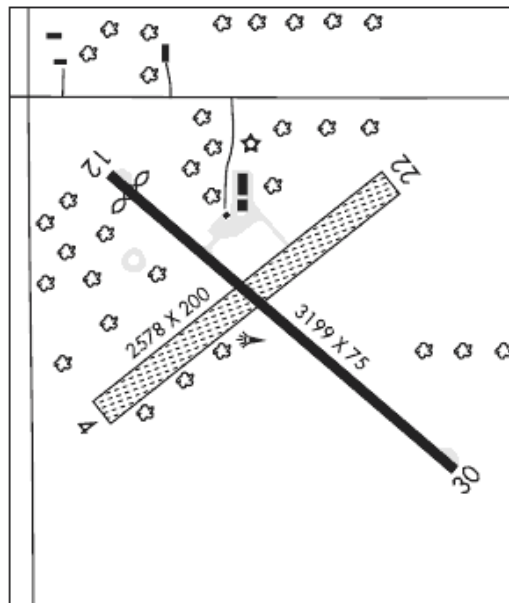
Grand Forks International Airport, Grand Forks, ND



Crookston Municipal Kirkwood Field, Crookston, MN



Hutson Field, Grafton, ND



Warren Municipal Airport, Warren, MN

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