Human Factors Flight Testing of an ADS-B Based Traffic Alerting System for General Aviation

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by

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Abstract

Mid-air collisions are a concern for general aviation. Current traffic alerting systems have limited usability in the airport environment where a majority of mid-air collisions occur. A Traffic Situation Awareness with Alerting Application (TSAA) has been developed which uses Automatic Dependent Surveillance – Broadcast (ADS-B), a Global Positioning System (GPS) based surveillance system, to provide reliable alerts in a condensed environment.

TSAA was designed to be compatible with general aviation operations. It was specifically designed to enhance traffic situation awareness and provide traffic alerting. The system does not include guidance or resolution advisories. In addition, the design was consistent with established standards, previous traffic alerting system precedents, as well as air traffic control precedent. Taking into account the potential financial burden associated with installation of a multi-function display (MFD), an audio based TSAA system was also designed to account for constrained cockpit space and the added cost of a MFD.

TSAA system performance and usability was tested by installing the system in an aircraft and having 21 general aviation pilots use the system in-flight. Pilots flew with the system during planned encounter testing as well as in typical high density traffic pattern environments in Daytona Beach, FL. Pilot's awareness of traffic awareness, out-the-window visual acquisition, and evasive action were recorded throughout the testing. A total of 109 encounters were analyzed comprising of 89 planned encounters and 20 targets of opportunity.

Overall, the system alerted as expected. The alert provided the first indication of an encounter in a majority of cases. In general, pilots considered alerts to be appropriate in both the planned encounter cases and the targets of opportunity. In most cases, pilots did not deem evasive action necessary during the high density flights, despite considering the alerts to be appropriate.

Out-the-window visual acquisition was made in 40.5% of cases for the planned encounters, and 81.0% of cases for the targets of opportunity. For the cases where visual acquisition was made in the planned encounters, pilots tended to make visual acquisition approximately 13 seconds (SD=21s) *after* an alert annunciated. In target of opportunity cases, pilots made visual acquisition approximately 8 seconds

(SD=32s) *before* an alert annunciated. The differences in visual acquisition could be due to the different geometries experienced with planned encounters as well as the different flight test regimes.

Pilots also indicated that the alert provided accurate information, and reported that they could trust the system. Pilots considered the alerts to be timely in 64% of encounters and too late in 36% of all encounters. In general subjective feedback suggested that the display symbology was effective, with some improvements desired in terms of font size and target vs obstacle discriminability. Overall the system was well received by pilots in the post-flight evaluation.

This research tested the pilot performance using the display system and the audio system. The findings of the studies will contribute to TSAA standards development for the FAA and design recommendations for avionics manufacturers.

Acknowledgements

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The authors would like to acknowledge the help of Avidyne in conducting the testing, in particular Mike Kiernan for his support during development of the test plan and flexibility during testing. Special thanks to Dean Ryan, Trevor Steffensen, Duane Ott, Pat Ryan, Joe Friel, Ed Sheasby, and the rest of the Avidyne team for their immense effort in prototype development. Also, thanks to Dave Schwarz for assisting as the intruder pilot during testing.

In addition, the authors appreciate the hospitality of Kim Brose and the entire Atlantic Jet Center team for providing a home base for the testing and helping advertise the experiment to local pilots. Also, thanks to the Melbourne Area Pilots Association and the Florida Institute of Technology for assisting in distributing the call for participants for the testing.

The authors would like to thank the pilots who volunteered to participate in the experiment as well as the pilots who offered to serve as test subjects during development.

Finally, the authors would like to acknowledge the valuable guidance and feedback provided by the entire TSAA team including: David Gray, Russell Gold, Robert Joslin, Gene Bollin, Jim Duke, Susan Minton, Colleen Donovan, Michelle Yeh, Kim Cardosi, Tracy Lennertz, Cathy Swider, Don Walker, Doug Arbuckle, Kara MacWilliams, Preston Barber, and Kirby Myers.

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Acronyms

AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-R	Automatic Dependent Surveillance – Rebroadcast
AGL	Above Ground Level
AIM	Aeronautical Information Manual
ATC	Air Traffic Control
ATP	Airline Transport Pilot
C182	Cessna 182
CAZ	Collision Airspace Zone
CDTI	Cockpit Display of Traffic Information
CFI	Certified Flight Instructor
CFII	Certified Flight Instructor – Instrument
COM	Communication
CPA	Closest Point of Approach
DT&E	Developmental Test and Evaluation
ES	Extended Squitter
FAA	Federal Aviation Administration
FT	Feet
GA	General Aviation
GPS	Global Positioning Service
HCR	High Closure Rate
HF	Human Factors

HITL	Human-In-The-Loop
IN	Inches
KDAB	Daytona Beach International Airport, Daytona Beach, FL
KMLB	Melbourne International Airport, Melbourne, FL
L	Left
LCR	Low Closure Rate
LTD	Limited
MEI	Multi-Engine Instructor
MHz	Mega-Hertz
MIN	Minute
MFD	Multi-Function Display
MOPS	Minimum Operational Performance Standards
MSL	Mean Sea Level
NextGen	Next Generation Air Transportation System
NM	Nautical Mile
NTSB	National Transportation and Safety Board
PAZ	Protected Airspace Zone
R	Right
SD	Standard Deviation
SM	Statute Mile
TAS	Traffic Advisory System
TCAS	Traffic Collision Avoidance System
TIS	Traffic Information Service
TSAA	Traffic Situation Awareness with Alerting Application
UAT	Universal Access Transceiver
VMC	Visual Meteorological Conditions
?	Unknown Direction

Chapter 1

Introduction

A Traffic Situation Awareness with Alerting Application (TSAA) has been developed using the emerging ADS-B technology to reduce the occurrence of mid-air collisions. Effective human interaction is critical to the functionality and usability of the system in the cockpit.

1.1 Motivation

Mid-air collisions are a concern for general aviation (GA). Between 2004 and 2010, the mid-air collision rate involving general aviation aircraft averaged 10 per year. Approximately one-half of those collisions resulted in fatalities [1]. An MIT study analyzed 112 NTSB mid-air collisions involving general aviation aircraft between 2001 and 2010. Figure 1.1 shows that 59% of collisions occurred in the airport environment [2]. There is a gap between the capabilities of current traffic alerting systems and the environment where most collisions occur.

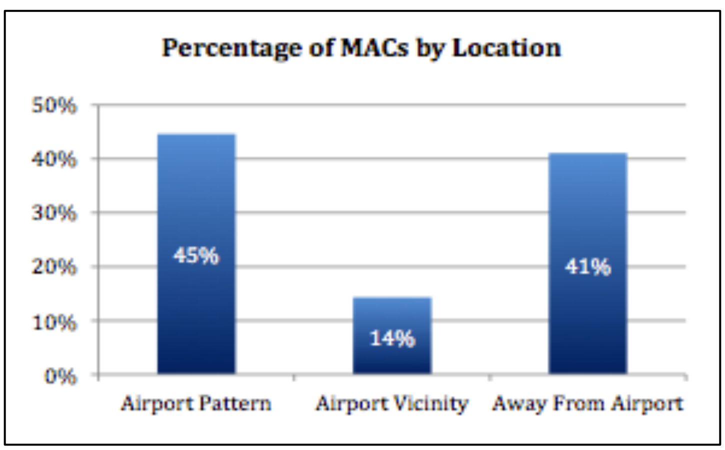

Figure 1-1. Percentage of NTSB Mid-Air Collisions [2]

Current State-of-the-Art Traffic Systems

Traffic alerting systems have been developed for general aviation aircraft such as Traffic Information Systems (TIS) and Traffic Advisory Systems (TAS). TIS is a ground-based service that transmits radar data to aircraft equipped with a Mode S transponder. The TIS service uplinks information on radar traffic to the aircraft, and the position and trend information is presented to the pilots on a dedicated display or a multi-function display (MFD). TIS is limited to radar coverage and radar update rates so the information provided by TIS only updates every 4-12 seconds. TAS actively interrogates aircraft in a given proximity through transponder range interrogation, displays the location and trend information on a MFD, and provides aural alerts to help pilots locate conflicting traffic. Traffic Collision Avoidance System II (TCAS II) is a system primarily used in commercial aviation where flight crews receive both traffic alerts and resolution advisories, which provide guidance on the evasive maneuver required. Neither TAS, TIS, nor TCAS I, are designed to provide resolution guidance. Though all existing systems contribute to traffic situation awareness in the cockpit, because of the quality of the surveillance and the challenging environment, it is difficult for TAS, TIS, and TCAS, to operate in close proximity to other aircraft and alert reliably on maneuvering targets; therefore, these systems are often less effective in the airport environment.

Traffic Situation Awareness with Alerting Application (TSAA)

Using the enhanced information provided by Automatic Dependent Surveillance – Broadcast (ADS-B), a Traffic Situation Awareness with Alerting Application (TSAA) was developed with the purpose of providing reliable prediction capabilities in the general aviation environment. ADS-B offers the potential for more reliable alerting in a dynamic airport environment by providing more precision than radar and a faster update rate (1 second) [3]. When augmented by ADS-R, ADS-B is not limited by horizontal line of sight reception between aircraft. It can also be used at altitudes lower than traditional radar-based systems. Additionally, the enhanced update rate of ADS-B allows a prediction to be developed that better accounts for maneuvering flight, which is a capability the current state-of-the-art technology does not provide.

ADS-B Out has been mandated by the Federal Aviation Administration (FAA) in support of the Next Generation Air Transportation System (NextGen) implementation. Additionally, the benefits of TSAA may compel some users to install ADS-B equipment in their aircraft prior to the FAA mandate [4].

As can be seen in Figure 1-2, the three key elements of TSAA are ADS-B surveillance, alerting logic, and human interface. The focus of this research was the design of the interface and human interaction with the system. The goal of this research is to develop an interface for the TSAA system and evaluate the TSAA interface through a series of simulations and flight testing involving general aviation pilots. The final step of development included testing the system in an operational environment, and the results of flight testing are presented in this document. Overall objectives for TSAA flight testing included demonstrating functionality of TSAA and addressing any operational issues which may arise during prototype development.

The specific objectives of human factors flight testing for TSAA included testing basic usability and functionality of the system in an operational environment with subjective feedback from general aviation pilots, evaluating pilot traffic awareness & response to alerts in an operational environment, and investigating subjective criteria for nuisance alerts. The outcomes of human factors testing provided feedback for algorithm tuning as well as provided feedback to decision-makers regarding the pilot acceptability and usability of the system.

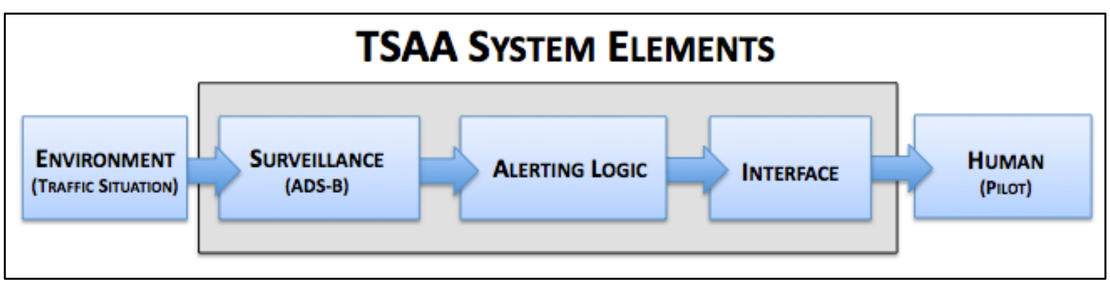

Figure 1-2. TSAA System Elements

Chapter 2

System Design

2.1 Design Philosophy

TSAA was designed to provide reliable and valid alerts in the general aviation environment with the following three objectives:

1. The TSAA system was designed to enhance traffic situation awareness and provide traffic alerting. In order to minimize the cost associated with development and certification, the TSAA system was not designed to provide guidance or resolution of conflicts.
2. The TSAA system was designed to be compatible with high density general aviation operations. This includes cruising flight, maneuvering, and close proximity operations such as flight training or traffic pattern training. The TSAA system must also be flexible to account for constrained cockpit space in typical GA aircraft and potential cost sensitivity of GA aircraft owners.
3. The TSAA system was designed to be consistent with established standards, as well as precedents set by existing traffic systems or air traffic control (ATC) procedures. The Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications Systems (DO-317) defines the standards for TSAA [5]. In addition to a number of system requirements, this document provides guidance on display symbology and functionality. FAA Advisory Circular 20-165A, Airworthiness Approval for ADS-B Out Systems and Applications, also provides guidance on display development [6]. Where requirements were subject to interpretation, the system was designed to be consistent with existing traffic systems such as TAS and TCAS in order to minimize any confusion when transitioning between the current state-of-the-

art systems and TSAA. Consistency with air traffic control phraseology was also considered [7].

2.2 TSAA Overall Design

With the above objectives in mind, the TSAA system was developed with two interface versions detailed in Table 2.1. The primary version is referred to as TSAA Class II where the system includes both audio alerts as well as a cockpit display of traffic information (CDTI). Cockpit space could be limited in many aircraft or helicopters. In addition, the overall cost of the TSAA system could be prohibitive for users who do not currently have a multi function display, MFD, installed in their aircraft. These two considerations contributed to the design requirement for a version of the TSAA system that does not include the cockpit display of traffic information. TSAA Class I version refers to an audio alert system which also includes a visual cue (e.g. Crew Alerting System message or labeled lamp) to indicate when an alert is active. TSAA Class I equipment does not include a cockpit display of traffic information [8].

TSAA Version	Aural Traffic Alert	Cockpit Display of Traffic Information	Visual Indicator Light
Class I (Audio System)	√		√
Class II (Display System)	√	√	

Table 2-1. TSAA Class I and II Interface Versions

2.2.1 TSAA Alerting Criteria

As shown in Figure 2-1, in order to understand the development of the human interface, it is necessary to describe the established alerting criteria for TSAA. The alerting logic presented below was the logic used during the human factors flight testing, however the final algorithm parameters were finalized after testing was completed.

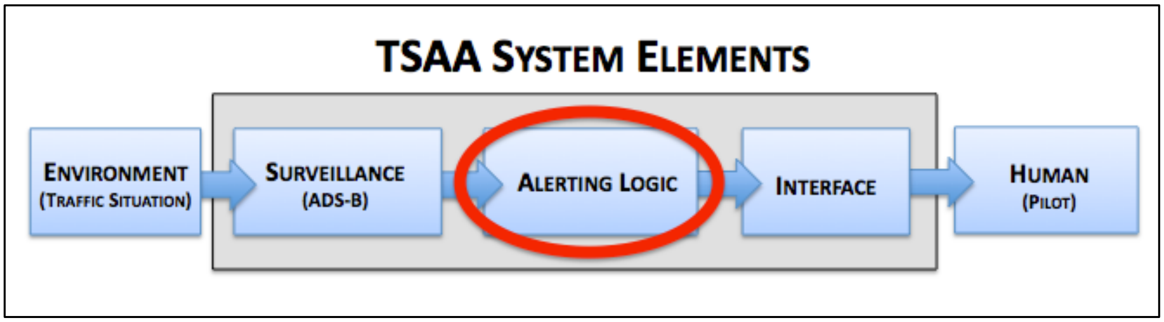

Figure 2-1. TSAA System Elements (Highlighting Alerting Logic)

The alerting system inputs information from ownship and target surveillance to determine whether a collision threat exists between ownship and other aircraft. The system inputs ADS-B position and velocity and propagates the trajectory of each aircraft within range of the ownship. Two airspace zones were defined to characterize the threat level of an aircraft. As can be seen in Figure 2-2, two cylinders are calculated around a target aircraft. The protected airspace zone (PAZ) is a variable sized cylinder surrounding the target aircraft (depicted in yellow in Figure 2-2). The size of the PAZ is scaled based on the closure rate of the traffic; when a threat has a high closure rate, the PAZ increases in size and when the threat has a low closure rate, the PAZ shrinks. The minimum size of the PAZ is 750 feet in radius, and +/- 450 feet in altitude, so that it is always larger than the Collision Airspace Zone (CAZ). The CAZ is a fixed size cylinder around the target (depicted in red in Figure 2-2). The radius of the CAZ is 500 feet and the altitude spans +/- 200 feet.

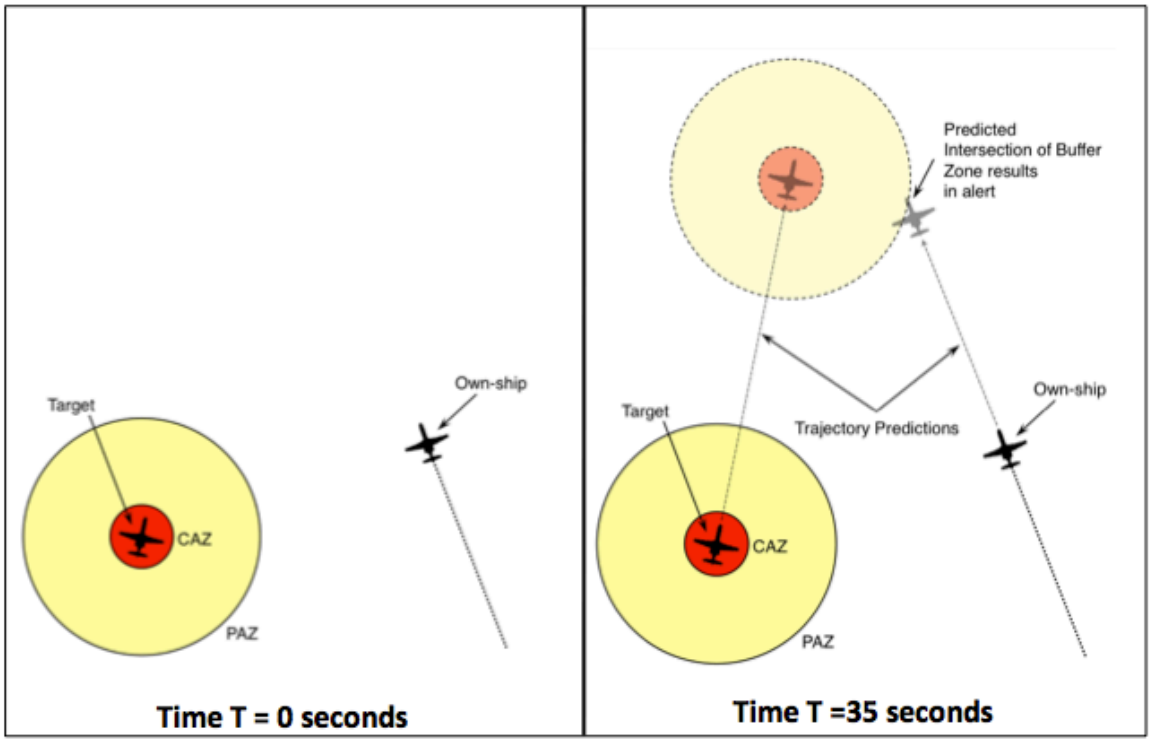

Figure 2-2. Sample Conflict Describing Alerting Criteria

The system propagates target and ownship position 35 seconds into the future as is shown on the right side of Figure 2-2. If at any point in that time period, the ownship penetrates either the CAZ or PAZ, an alert is issued. If penetration of the PAZ is predicted, a *Traffic Caution Alert* is annunciated. If penetration of the CAZ is predicted, a *Traffic Caution Alert* is re-annunciated with updated information.

ADS-B data is subject to various inherent errors in position, velocity, update rate, and latency. These could originate from GPS error or processing time delays. In addition to ADS-B targets, the TSAA system processes information from radar targets. These targets' data is subject to the type of radar as well as the information update rate. The TSAA system is designed to perform using a minimum data quality, however there is the possibility where data quality is so poor, a reliable alert cannot be provided.

2.2.2 TSAA Human Interface

Through a series of design reviews with FAA and industry reviewers, potential human factors concerns were identified. Reviewers consisted of members from the FAA ADS-B Program Office, FAA Aircraft Certification, FAA Flight Standards Service, FAA Human Factors Division, Department of Transportation Volpe Center, and the Avidyne Corporation. The baseline design was refined through a series of eight design reviews, and the residual issues identified were probed through a series of three human factors simulations where pilots were presented with traffic encounter scenarios and expected to respond to traffic [9]. The interface used during flight testing was the recommended design based on these simulations and expert review.

The TSAA interface consists of an audio component and a visual component.

Audio Interface

The audio interface is present in both the Class I and II TSAA systems. The aural alerts are annunciated for the *Traffic Caution Alert* and includes azimuth, range, relative altitude, and vertical trend information (e.g. "Traffic, 3 o'clock, high, 2 miles, descending"). Multiple aural alerts are queued and an aural alert would complete before another alert annunciated, thus alerts are not interrupted mid-sentence. The tonal elements (volume, cadence, intonation) of the aural annunciation are expected to follow best practices in industry.

Display Interface - Baseline CDTI Symbology

The TSAA Class II system includes a CDTI. Examples of the CDTI are shown in Figure 2-3 and 2-4. Figure 2-3 shows a situation on a black background that does not include terrain information; Figure 2-4 shows the same situation on a map background option that includes terrain and other information.

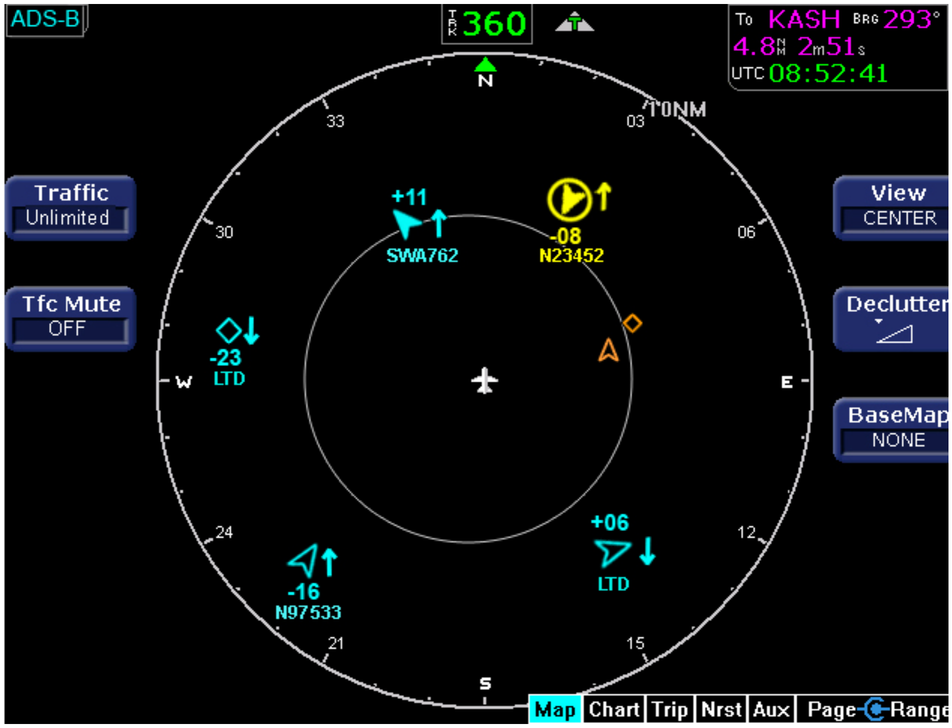

Figure 2-3. Sample Scenario on MFD Black Background (without Terrain Information)

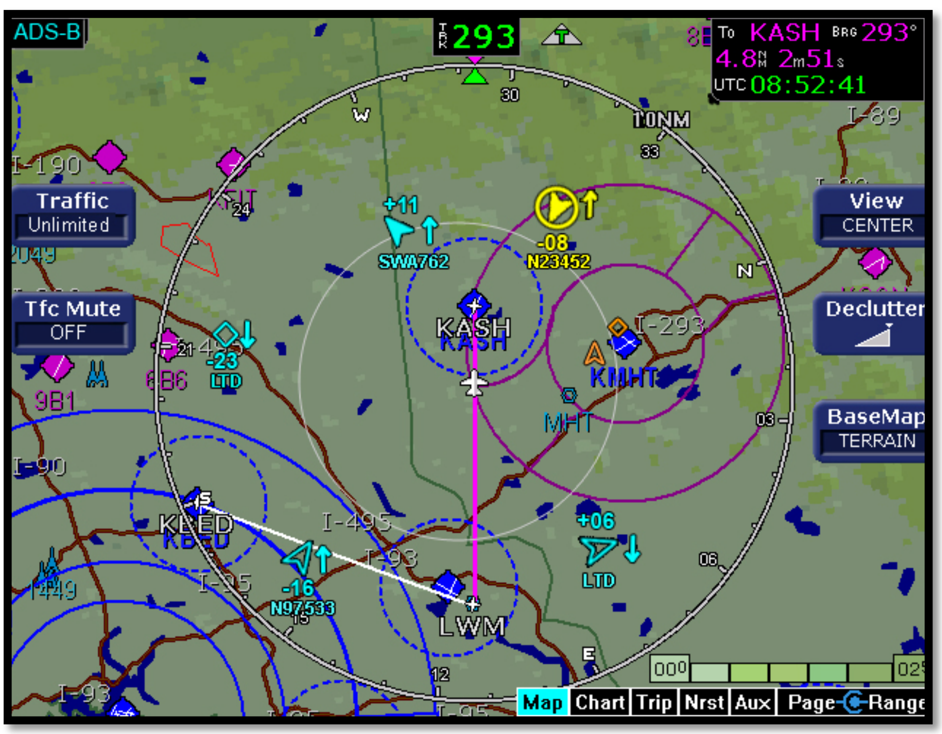

Figure 2-4. Sample Scenario on MFD Map Background (with Terrain Information)

Display symbology for the TSAA system was based on FAA standards for traffic with ADS-B information [5]. Data tags for TSAA include relative altitude in hundreds of feet, vertical trend information, call sign, and data quality (if applicable). Any instance where altitude, vertical trend, and call sign are valid, they are displayed on the data tag.

ADS-B provides directional information; thus, targets are displayed with a directional symbol (Figure 2-5) whenever directional information is valid.

Figure 2-5. Directional Target

Non-directional targets are shown with a diamond (Figure 2-6) whenever directional information is not valid.

Figure 2-6. Non-Directional Target

As can be seen in Figure 2-7, ground targets are depicted in brown/tan either shown with a directional symbol or diamond, based on the validity of the directionality on the target. The TSAA system is an airborne system, thus no conflicts on the surface are alerted. In order to avoid alerting on ground targets, they must be distinguished from airborne targets, which was the assumption used for flight testing. This could be defined using a system similar to "weight on wheels," airspeed, or altitude [6].

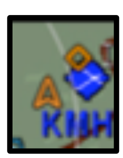

Figure 2-7. Ground Targets

Nearby airborne (proximate) traffic is a convention standard in existing traffic alerting systems where aircraft within 6 nm horizontally and 1,200 feet vertically would be shown with a filled symbol (Figure 2-8).

Figure 2-8. Proximate Target

In some cases, data quality may not be sufficient to issue a reliable alert. A provision was put into the design to display these targets with a "LTD" in the call sign field (Figure 2-9). For the flight testing TSAA prototype, non-qualified targets did not exist because a criteria for sufficient quality had not been determined by the time testing began.

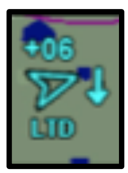

Figure 2-9. Non-Qualified Target

Display Interface - Alert CDTI Symbology

The *Traffic Caution Alert* for directional targets is depicted using the caution symbol shown in Figure 2.10. These targets are depicted in yellow because the alert is caution level. The alert symbol also includes a circle surrounding the directional target in order to allow discrimination by colorblind pilots.

Figure 2-10. Directional Alert Target (On-scale)

Non-directional targets which alerted were displayed using current TAS symbology shown in Figure 2-11, and were depicted as a filled yellow circle in the prototype.

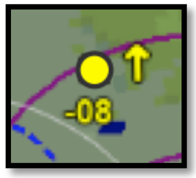

Figure 2-11. Non-Directional Alert Target (On-scale)

No current guidance exists regarding display of alert traffic that is outside the current MFD range setting. As can be seen in Figure 2-12, in order to maintain consistency with previous TAS systems, off-scale alert traffic are depicted in TSAA by a half-symbol on the compass rose located at the relative bearing to traffic.

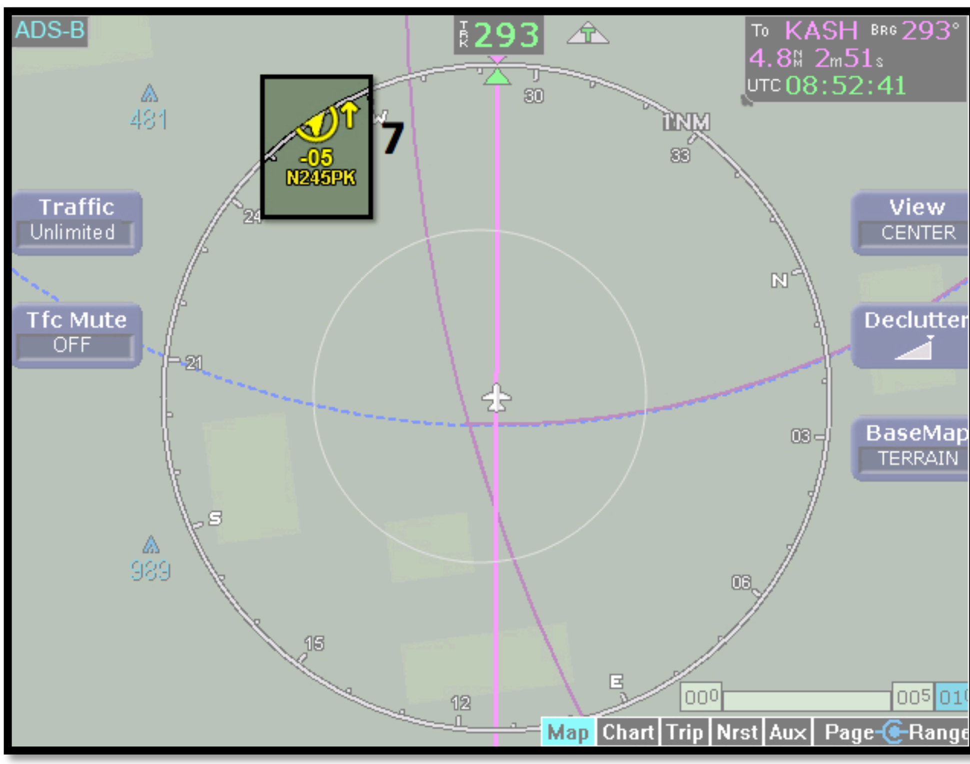

Figure 2-12. Off-Scale Alert Symbol

Chapter 3

Flight Test Design

3.1 TSAA Flight Test Program

The TSAA flight test program was the final segment of TSAA development. The program's overall flight test goals included development of the TSAA prototype and evaluating performance of the algorithm in an operational environment. As is shown in Figure 3-1, the TSAA flight test program had 3 distinct phases, Developmental Test and Evaluation (DT&E), Algorithm Performance, and Human Factors. The DT&E phase had the purpose of verifying that hardware and software implementation was satisfactory. The Algorithm Performance phase was designed to test the system in a variety of encounters varying in closure rate, geometry, and data quality in order to identify adequate algorithm performance in the environments the system was designed to operate. The final phase, Human Factors, was designed to gather pilot input on the human interface and overall functionality of the system. The Human Factors flight testing is the focus of this report.

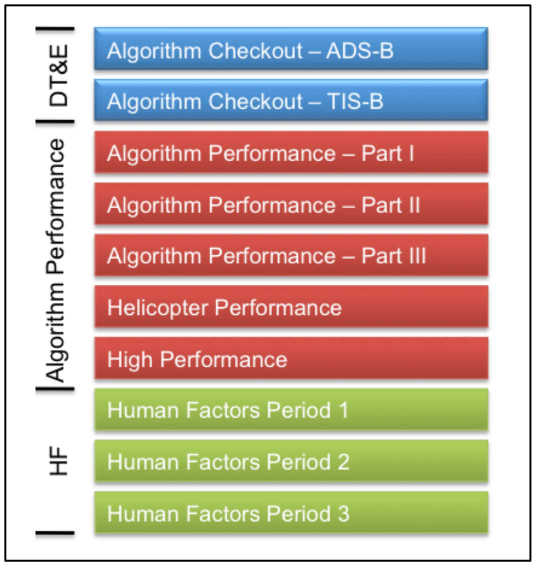

Figure 3-1. TSAA Flight Test Program Overview

3.2 Human Factors Flight Testing

Because TSAA was designed to provide reliable alerting in a typical general aviation environment, it was necessary to assess usability and functionality of the system in an actual flight environment. Considering a major limitation of the current state of the art traffic alerting systems (TIS, TAS, and TCAS) is perceived nuisance alerting in the traffic pattern, it was important to gauge pilot perception of TSAA nuisance alerting in the airport environment.

In summary, the objectives of flight testing for TSAA included:

- testing basic usability and functionality of the system in an operational environment
- evaluating pilot traffic awareness & response to alerts in an operational environment.
- and, investigating subjective criteria for nuisance alerts.

In order to evaluate the TSAA system in a representative environment, two types of flights were conducted. Planned encounter flights were used to expose pilots to a variety of encounter scenarios; high density flights were used to expose pilots to use of the system in typical enroute and traffic pattern environments using targets of opportunity.

3.2.1 Planned Encounter Flights

Planned encounter flights were conducted to expose pilots to a variety of enroute and pattern encounter scenarios, which were representative of historical accidents or tested the performance limits of the system. Pilots actively controlled the ownship and were presented with flight profiles to fly. A coordinated intruder aircraft then forced pre-planned encounters with the ownship to a predefined minimum separation at which an encounter was broken off[1]. Following each encounter, a post-event questionnaire was presented to the subject pilot verbally. Once the flight was complete, subject pilots were presented with an online post-evaluation questionnaire regarding their overall perception of the system.

Planned encounter flights originated at Melbourne Airport (KMLB). Most enroute encounters took place around a rectangular lake located 20 nm south of KMLB shown in Figure 3-2. Pattern encounters took place 10 nm southwest of KMLB where an east-west dirt road was used as a simulated runway for pilots and is shown in Figure 3-3.

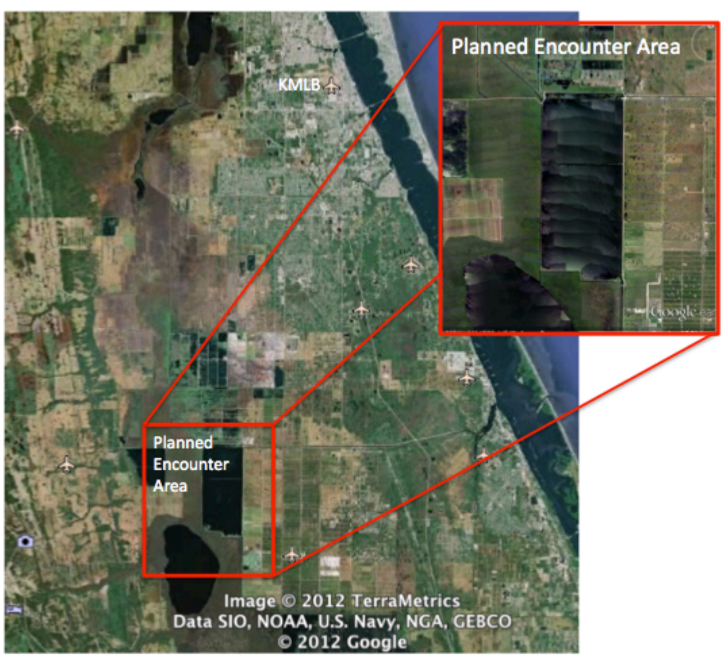

Figure 3-2. Planned Encounter Area for Enroute Encounters

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[1] The flight profile and procedures underwent an FAA safety review process and was approved by the FAA Safety Review Management Team [10].

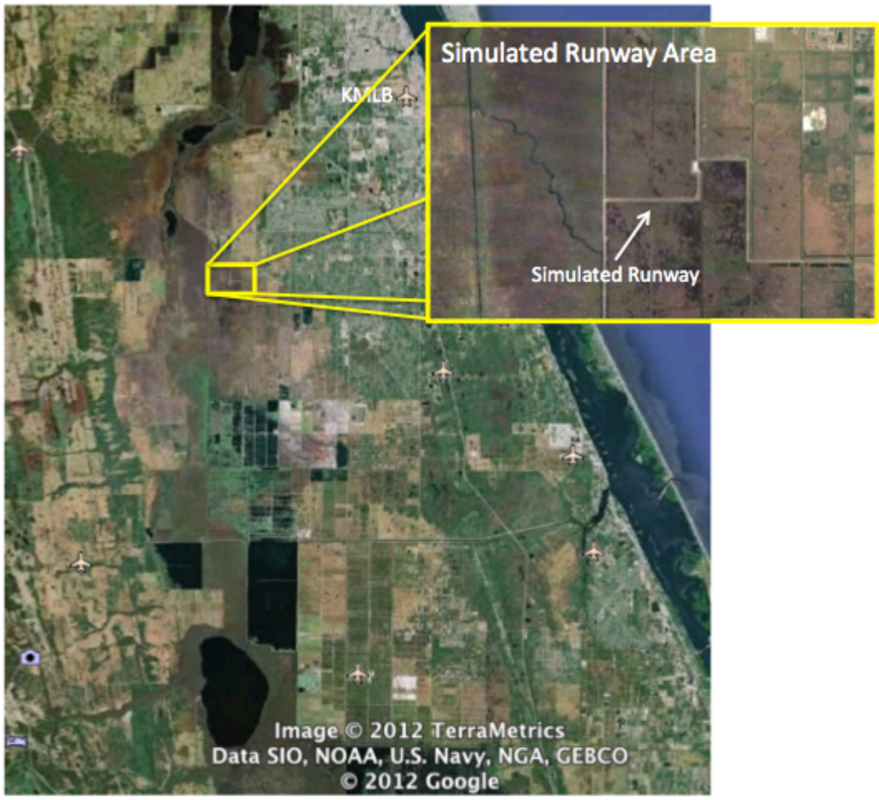

Figure 3-3. Simulated Runway Area for Traffic Pattern Encounters

Table 3-1 shows the 5 encounters that pilots experienced during planned encounter testing. The subset of encounters were chosen to 1) test the system in a variety of closure speeds and geometries, and 2) test human performance in more "difficult" cases identified by the previously conducted simulator testing of TSAA. The test card for each encounter can be found in Appendix C.

Encounter 1	Horizontal Low Closure Overtake
Encounter 2	Vertical High Closure Rate
Encounter 3	Head-On
Encounter 4	Overtaking on Final
Encounter 5	Entry vs. Downwind

Table 3-1. Scenarios Used in Planned Encounter Testing

1. *Horizontal Low Closure Rate Overtake Scenario* ***(Encounter 1)***

   The intruder in this scenario flew at the same altitude as the ownship and approached from behind the ownship with a 15-30 knot closure. Following the alert, the intruder continued his approach to overtake the ownship on the right so that the subject pilot could visually acquire the traffic.

2. *Vertical High Closure Rate Scenario* ***(Encounter 2)***

   The intruder in this scenario was 1,000 feet above, paralleling the ownship course, and slightly converging from the left. At a given time, the intruder began a steep descent (1000 ft/min or more) in order to trigger a predicted collision from above.

3. *Head-On Scenario* ***(Encounter 3)***

   During this encounter, the intruder approached from directly ahead. For safety reasons, the aircraft were spaced 200 feet vertically and 0.25 nm horizontally. The ownship and intruder flew different sides of the lake edge in order to maintain horizontal separation. The ownship flew speeds between 100 and 115 knots and the intruder flew speeds between 130 and 150 knots for closure speeds ranging from 230 to 265 knots for this encounter.

4. *Overtaking on Final Scenario* ***(Encounter 4)***

   The intruder in this encounter was simulating a jet on extended final. The scenario was designed to occur once the ownship turned final and the high closure rate intruder approached from behind. The conflict point in this situation was the threshold of the runway.

5. *Entry vs. Downwind Scenario* ***(Encounter 5)***

   The intruder in this scenario was on a 45-degree entry to midfield downwind and the ownship was in the pattern established on downwind.

Pilots departed KMLB and were vectored to a 189 radial toward the planned encounter area. As is shown in Figure 3-4, the first encounter (Horizontal Low Closure Rate Overtake) occurred in transit to the planned encounter area. The intruder departed Melbourne following the ownship and began the encounter approach when the ownship had leveled off at the enroute altitude.

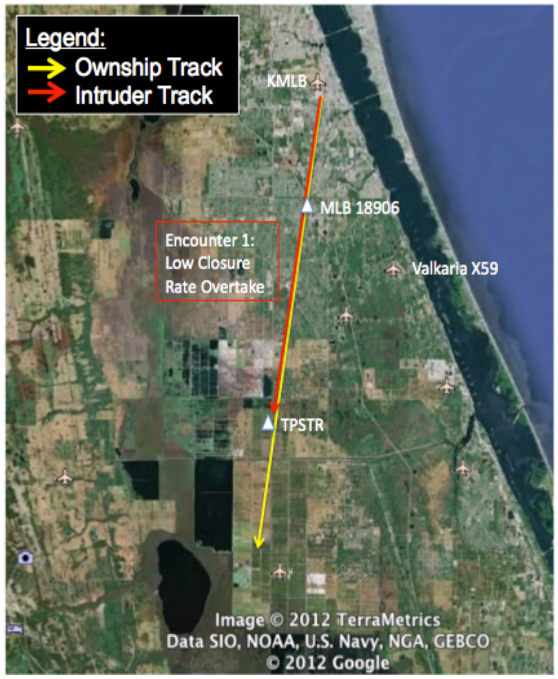

Figure 3-4. Encounter 1 and Transit to Planned Encounter Area

Following the first encounter the post-event questionnaire was completed. Once completed, the subject pilot was then instructed to fly to the northeast corner of the lake and fly left hand circuits around the lake.

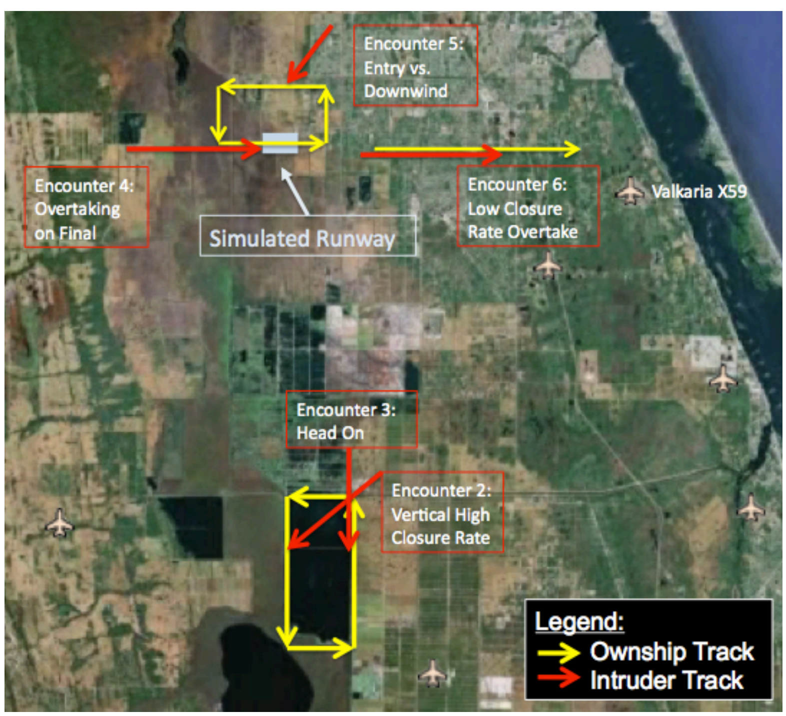

Figure 3-5. Encounters 2-6

As is seen in Figure 3-5, the 2nd encounter (Vertical High Closure Rate) typically occurred on the southbound leg of the circuit. Following this encounter, the HF Specialist would inform the subject pilot of the proximity of the intruder in the case that the subject did not visually acquire traffic. Once the subject understood the scenario, the post-event questionnaire was conducted.

The 3rd encounter (Head-On) occurred on the northbound leg of the circuit. The subject was told to maintain a course over the right side of the lake edge. The intruder also maintained a course to the right of the lake edge in order to maintain horizontal separation. This scenario continued until the intruder passed off the left side of the ownship. Following the encounter, the post-event questionnaire was conducted.

Following the enroute encounters, the subject was vectored toward the simulated runway area and told to descend to a pre-determined pattern altitude. Once the simulated runway was in sight, the safety pilot instructed the subject pilot to overfly the field, enter left downwind for the simulated runway, and fly a wide pattern for the runway. Visual landmarks were used for pattern legs and a floor of 300 feet MSL (approximately 280 ft AGL) was used for the approach.

The 4th encounter (Overtaking on Final) occurred on the final approach leg of the pattern. Following the encounter, control of the aircraft was transferred to the safety pilot, and the test conductor informed the subject pilot of the proximity of the other aircraft. Once the subject understood the scenario, the post-event questionnaire was conducted.

The 5th encounter (Entry vs. Downwind) occurred on the downwind leg of the traffic pattern. Following the encounter, the HF Specialist visually pointed out the traffic to the subject (in the case he did not acquire it on his own) or informed the pilot of the proximity of the target. Once the subject understood the scenario, the post-event questionnaire was conducted.

The subject was then instructed to fly east-bound toward the beach in order to approach KMLB from the south. Encounter 6, the Low Closure Horizontal Overtake encounter, was then repeated on the way to the beach. Following the post-event questionnaire for this encounter, the safety pilot maintained control of the aircraft for the rest of the flight.

3.2.2 High Density Flights

In order to test TSAA in a challenging environment, testing was conducted in a high density general aviation traffic pattern. Daytona Beach, FL (KDAB) was used as the high density pattern due to the high number of training flights conducted at the airport. In 2012, aircraft operations totaled 782 per day at KDAB, and 29% of those operations consisted of local general aviation [11].

The flights originated at Melbourne Airport (KMLB), a lower traffic density airport south of KDAB. Pilots flew the intra-coastal waterway route to KDAB as is shown in Figure 3-6. At KDAB, the pilots remained in the pattern for 7L/25R for approximately 30 minutes doing low approaches before returning to KMLB. The airport diagram for KDAB is shown in Figure 3-7. Following each alert scenario with a target of opportunity, control was handed to the safety pilot, and a post-event interview was conducted. Upon return to KMLB, a post-flight evaluation was conducted.

Figure 3-6. Flight Profile for High Density Flights

During the post-event interview, subject pilots did not have control of the aircraft, nor could they hear the alerts. Thus, the data collected for the targets of opportunity can be classified as 1) encounters that the subject pilot experienced, and 2) encounters that the safety pilot experienced. For the purpose of the human factors testing, only the encounters that the subject pilot experienced were analyzed.

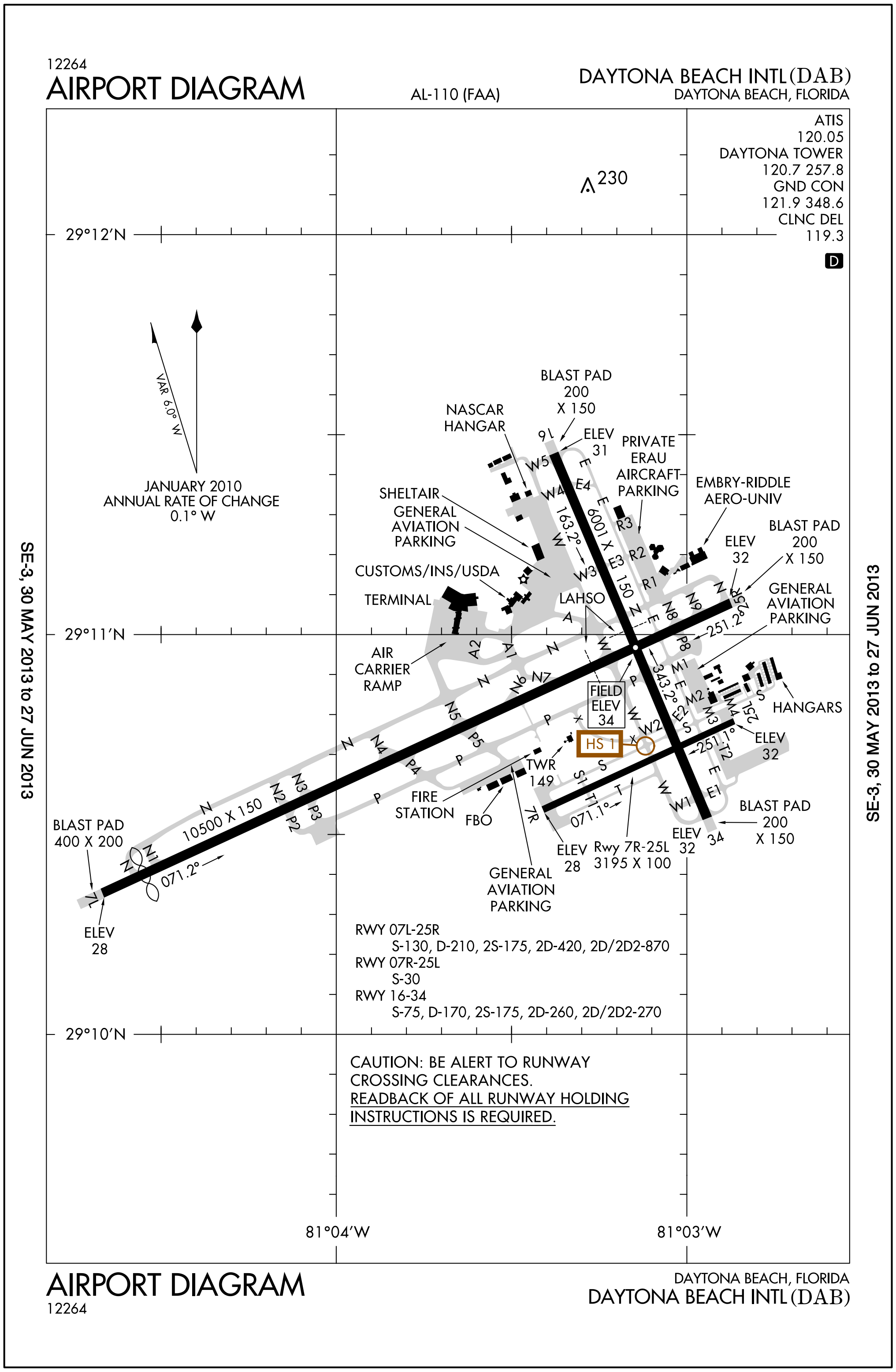

Figure 3-7. Airport Diagram for KDAB [12]

Chapter 4

Test Equipment and Experimental Protocol

4.1 Aircraft

The ownship used was a Cessna 182 aircraft with conventional instruments and is pictured in Figure 4-1. The TSAA system was presented on an EX600 MFD, located in the middle of the instrument panel seen in Figure 4-2. Using the top of the instrument panel in the left seat position as a normal line of sight reference for subjects, the location of the MFD was approximately 12 degrees right, and approximately 30 degrees below the pilot reference. The individual viewing angles were dependent on the height of the pilot as well as the distance he was positioned from the instrument panel. The EX600 has a viewable size of 4.6 in. width by 3.48 in. height and a resolution of 640x480 pixels [13].

The audio-only version of TSAA was simulated by shielding the MFD from the subject pilot. A mute/repeat button was also installed in the aircraft, the location of which is shown in Figure 4-2. In order to mute the current call, pilots could press the button once. In order to get an aural information update on the latest traffic threat, pilots could press the button twice in quick succession. Also shown in Figure 4-2 is the visual indicator light that would illuminate whenever an alert state was active. The light and mute button were located to the directly to the left of the attitude indicator (approximately 12 degrees below the top of instrument panel reference).

The aural annunciations were generated by concatenating statements from Avidyne's repository of human recorded speech. All aural alerts were annunciated through the headsets as well as through the aircraft speakers.

Figure 4-1. Cessna 182Q – Ownship for TSAA Testing

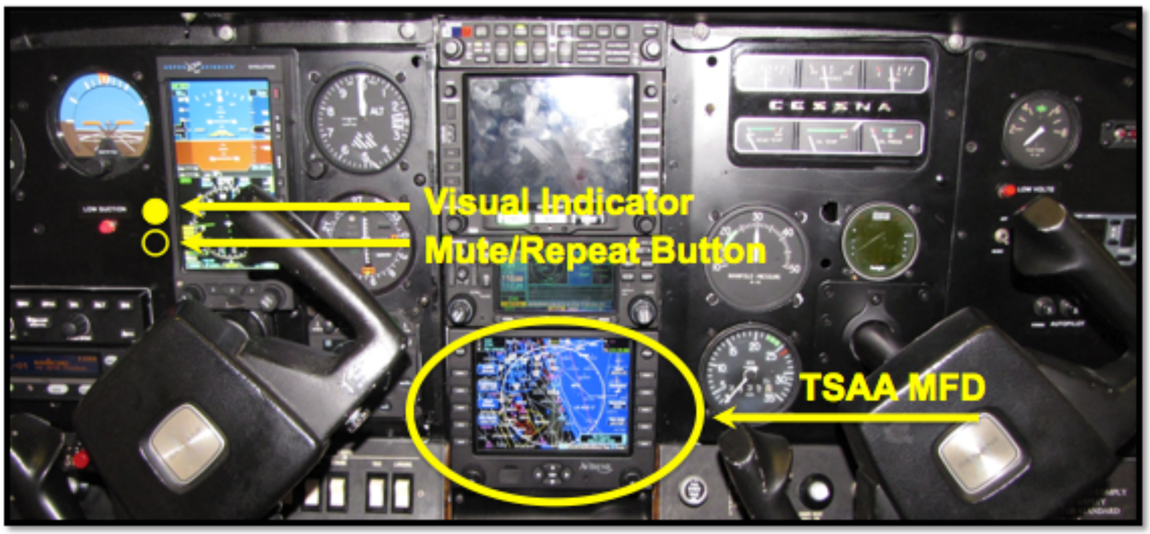

Figure 4-2. TSAA Interface in Ownship Cockpit

The intruder aircraft used was a Cirrus SR22 pictured below in Figure 4-3. This aircraft was chosen for its maneuverability and range of speed profiles which enabled reliable execution of the planned encounters.

Figure 4-3. Cirrus SR22 – Intruder for TSAA Testing

4.2 Flight Test Personnel

There were four occupants in the ownship. A visualization of the ownship personnel is presented in Figure 4-4 viewing the aircraft from the rear looking forward. The subject pilot flew the aircraft from the left seat. A safety pilot served as pilot in command from the right seat of the aircraft. The safety pilot conducted all takeoffs and landings and handed control of the aircraft over to the subject pilot at approximately 500 ft MSL.

Two human factors specialists sat in the back seat. Human Factors (HF) Specialist 1 was in charge of collecting verbal data as well as conducting the post-event questionnaire. HF Specialist 2 held test conductor responsibilities. A list of responsibilities of each person in the aircraft is provided in Figure 4-5.

Figure 4-4. Ownship Flight Test Personnel

Safety Pilot (PIC)	Human Factors Specialists	Subject Pilot
• Instructing subject pilot during simulated pattern (speeds, glide path) • Monitoring subject pilot performance during flight and intervening if necessary • Managing encounter • Responsible for appropriate breakaway • Safety of flight • Preflight inspection • Fuel / W&B • Checklists • Communications • Taxi/Takeoff/Landing	• Test conductor responsibilities • Conducting post-event questionnaire • Recording verbal data and alert times	• Flying aircraft when instructed to • Verbalizing scans, visual acquisition, and proposed evasive action • Answering post event questionnaire

Figure 4-5. Ownship Personnel Responsibilities

The intruder test pilot was typically the sole occupant of the SR22. Occasionally an observer rode along in the backseat of the intruder aircraft.

4.3 Data Acquisition Equipment

A variety of equipment was used to collect data for the test flights. A schematic of the equipment and where they were located in the aircraft is presented in Figure 4-6.

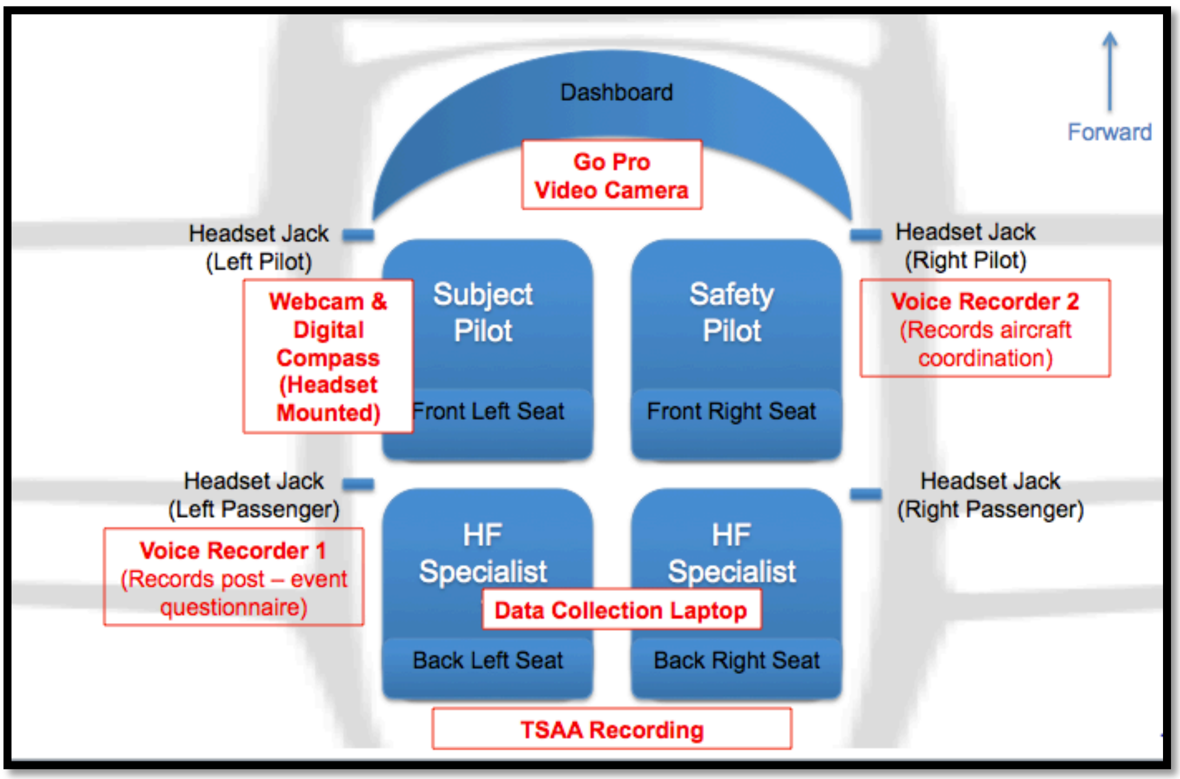

Figure 4-6. Test Equipment Location in Ownship

Figure 4-7 shows the GoPro video camera that was used to capture footage of the Multi-Function Display during flight. It was mounted off of the glare shield above the instrument panel and adjusted to capture the MFD without interfering with subject view of the MFD.

Figure 4-7. Go Pro Mounted on Glare Shield of Ownship

Figure 4-8 depicts the head mounted camera and digital compass that were used to capture scan patterns of the subject pilot. The camera and compass were attached to the top of the pilot headset.

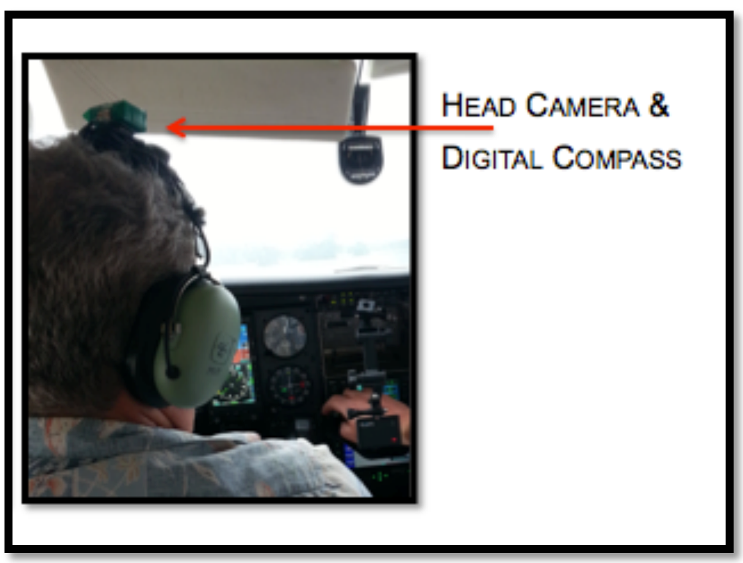

Figure 4-8. Head Camera and Digital Compass Mounted on Subject Pilot Headset

Two voice recorders were used to capture cockpit audio. Both recorders were installed using a PatchCord Cockpit Voice Recorder cable. The first recorder was connected to the subject pilot's audio stream in order to record exactly what the subject heard as well as to capture the post-event interview. The second recorder was connected to the safety pilot's audio stream in order to record the coordination between the ownship safety pilot and the intruder pilot as well as to record the coordination between the safety pilot and test conductor.

The data collection laptop was used by HF Specialist 1 to record various data: verbal protocol data, post-event questionnaire answers, head-cam and digital compass data, and time syncs between the computer, MFD, and TSAA.

The TSAA equipment was also recording state vector, alert status, and system status data for the TSAA system. The TSAA equipment was located in the tail cone storage area of the C182.

It was necessary to synchronize the time between the voice recorders, laptop, MFD, and TSAA recording equipment in order to get proper timing data of the parameters of interest. This time sync was conducted prior to takeoff on each flight using the following two procedures.

Procedure A: Time Sync of MFD, Voice Recorders, and Laptop

1. HF Specialist 1 typed in a future time displayed MFD (30 seconds in to the future) into the laptop interface.
2. HF Specialist 1 began a verbal count down to the future time within 10 seconds
3. Once the countdown reached zero, the HF Specialist would click to save the time in the laptop capturing the MFD time and the laptop time at the time of synchronization.

Procedure B: Time Sync of TSAA Recording and Voice Recorders

1. The safety pilot requested a volume test of the TSAA system.
2. The time of the volume test request was logged in the TSAA log files.
3. During post processing, HF Specialists synchronized the time of volume test request in the log file with the time of the aural volume test heard on the voice recorders.

All of the above acquisition equipment was used in the C182, ownship. The intruder aircraft only had the TSAA data recording equipment on board, and it was located in the front right seat of the SR22.

4.4 TSAA Prototype System

The aircraft equipment included a Trig TT31 transponder which complied with DO-260B ADS-B Out standards, with the aircraft operating in experimental category. The TSAA prototype system was based on rule compliant Version B ADS-B with a single channel 1090ES receiver. Thus, any ADS-B equipped aircraft transmitting 978UAT were received by the ownship as an ADS-R target.

Due to schedule considerations, Human Factors testing was conducted during system development; thus, a number of prototype issues were identified during human factors testing that were addressed during the test period. The major issues included:

- TSAA Stability – The TSAA system software occasionally crashed during the flights. The problem was isolated to the ownship and was resolved in the second week of data collection.
- Ground Alerting – Initially, targets were alerting when the conflict was projected to occur on the ground. This issue was temporarily resolved by implementing an altitude filter following the first week of data collection.
- Dropouts – There were also occasional dropouts of target tracks that resulted in late alerts. The problem was tracked to improper antenna location and resolved following the first week of data collection.
- Lack of Alerting when Coasting – Late alerts were observed when the system was coasting target position. This problem was tracked to a software bug which inhibited alerting when coasting. The issue was resolved during the first week of data collection.
- Traffic Lamp Inoperative – The traffic lamp was not illuminating during alerts at the beginning of the test period. The issue was resolved in the first week of data collection. Audio only system tests were deferred until the issue was resolved.

Figure 4-9 highlights the major issues encountered throughout the human factors test period. The major issues were resolved, however there were a few minor residual issues that remained.

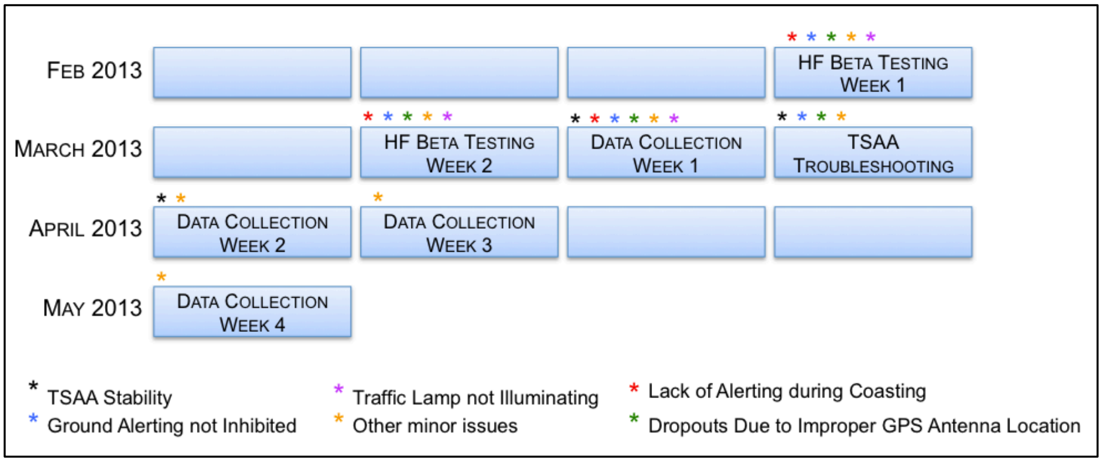

Figure 4-9. Prototype Issues during Human Factors Testing

4.4 Communications Protocol

A specific communications protocol was developed in order to accomplish the following goals.

1. The subject pilot, safety pilot, and human factors specialists must adequately hear the aural alerts.
2. The subject pilot and HF Specialist 1 must be isolated during the post-event interview in order to minimize distraction of the safety pilot (flying pilot).
3. There must be a protocol where the test conductor and safety pilot could communicate freely in the case that coordination must be made without the subject pilot hearing.
4. The ownship safety pilot must be able to freely communicate with the intruder pilot without the subject pilot hearing the coordination.

In order to assure sufficient volume of alerts in the back seats of the aircraft, it was necessary to feed the front seat headset input into both the front and back seats to accomplish Goal 1 above, as is seen in Figure 4-10. This was accomplished using a splitter cord.

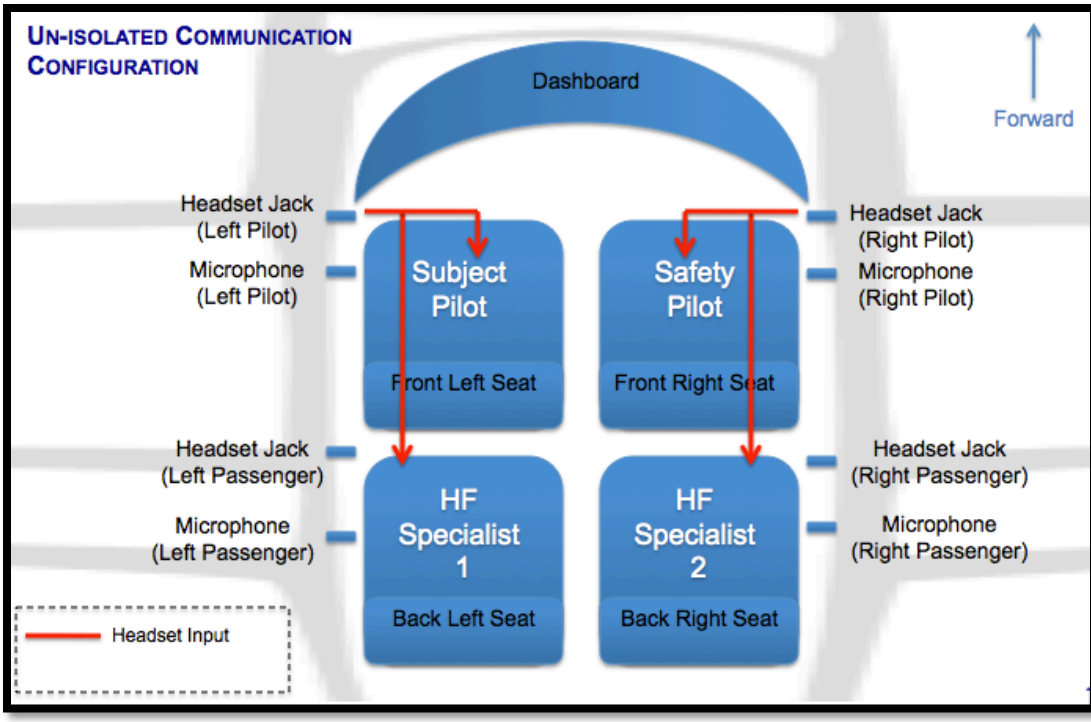

Figure 4-10. Splitting of Front Seat Audio to Feed Front and Back Seats In Ownship

In order to facilitate Goals 2 and 3 above, the "Crew Isolate" button was used on the avionics panel shown in Figure 4-11. This button isolates the front seat headset inputs and front seat microphone inputs. However, in order to isolate the safety pilot and HF Specialist 2, HF Specialist 2 was connected to the front left microphone output. Also, in order to isolate the subject pilot and HF Specialist 1 during the post-event interview, the subject pilot was connected to the back seat microphone output. Thus, the HF Specialist 2 and Subject Pilot microphone outputs were swapped, which can be seen in Figure 4-12.

Figure 4-11. Crew Isolate Button on Avionics Panel

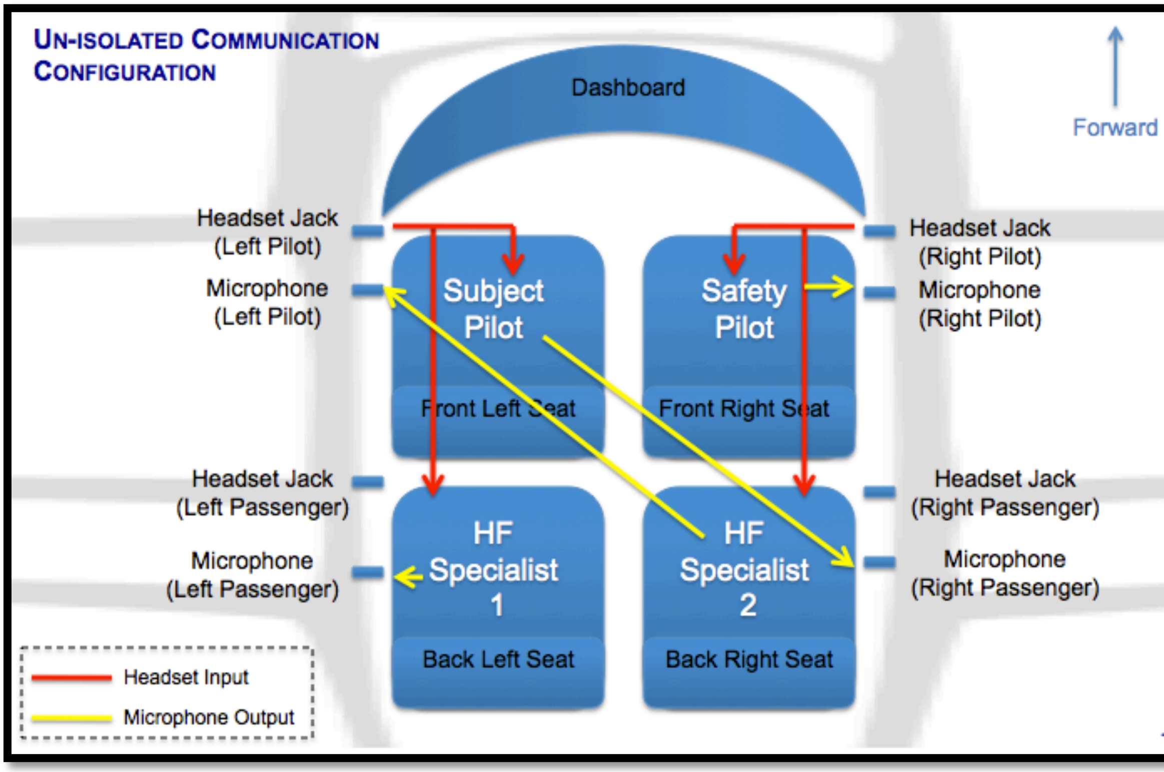

Figure 4-12. Swapping of Left Pilot and Right Passenger Microphone Outputs

In order to completely isolate the subject pilot, the subject pilot's headset input was connected to a backseat headset input. Thus, HF Specialist 1 manually swapped the subject pilot's headset input from front to back whenever the subject was to be isolated. The schematic of the fully isolated configuration is shown in Figure 4-13.

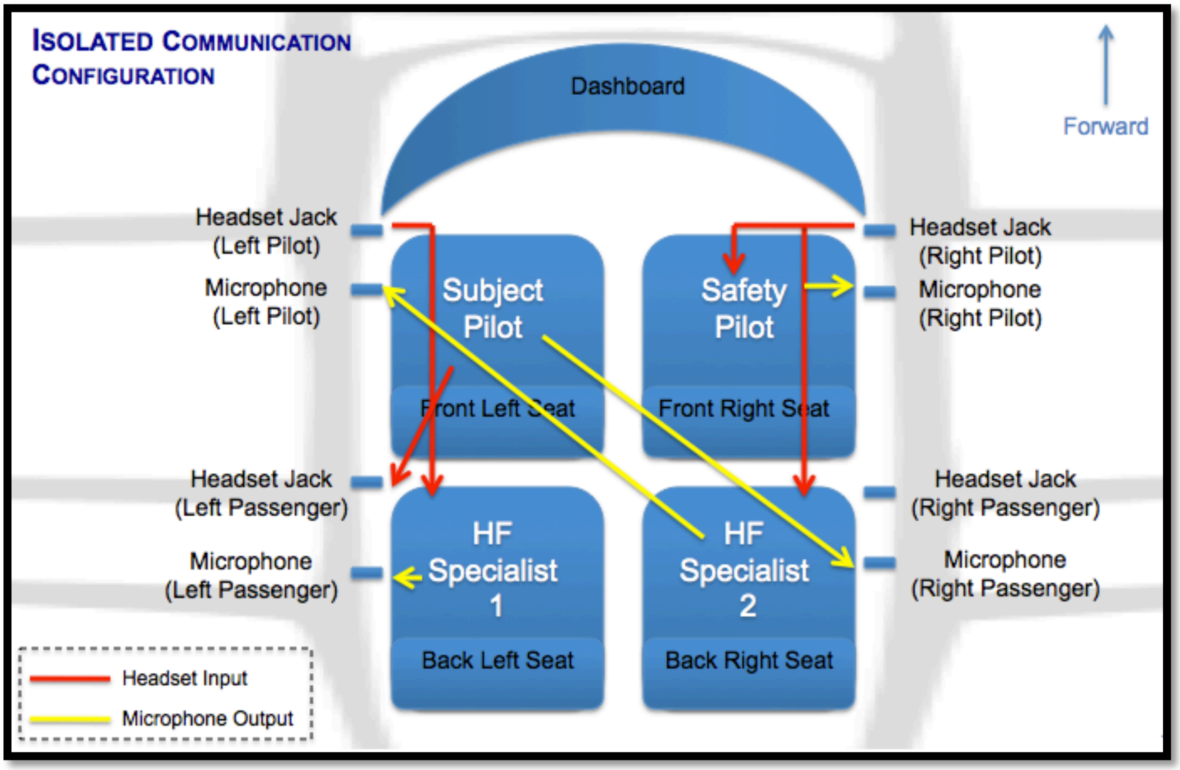

Figure 4-13. Fully Isolated Communication Configuration

In summary, two configurations were used during testing. The un-isolated configuration is shown in Figure 4-10, which is the configuration pilots would fly during the encounters. The isolated configuration, shown in Figure 4-13, was activated by two actions. First, the safety pilot would press "Crew Isolate" on the instrument panel. Second, HF Specialist 1 would manually swap the subject pilot headset input from front seat to back seat. The isolated configuration was used during the post-event interview as well when the safety pilot and test conductor wished to communicate without the subject pilot in the loop.

The last goal was accomplished using a split communication protocol. Using the "Split 1/2" button on the instrument panel highlighted in Figure 4-14, the left front seat and left back seat listen to the COM1 frequency, and the right front and right back seat would listen and communicate on the COM2 frequency. The COM1 frequency was set to an innocuous frequency of 121.5 MHz or the Melbourne Airport Ground frequency. The COM2 frequency was set to a common coordination frequency for the ownship and intruder. When split communication was active, the subject pilot could not hear the coordination between the safety pilot and the intruder pilot.

Figure 4-14. Split Communication Button on Avionics Panel

4.6 Experimental Protocol

When subject pilots arrived for their flight, they were given a brief overview about the TSAA project motivation. The test conductor then reviewed the consent form and the subjects were given the form to read and sign. Following the consent form, an overview of the experiment (pre-brief, training, flight, post-brief) was highlighted.

Subject pilots were provided background information regarding the study and TSAA system via email prior to the flight. The test conductor reviewed this material with the subject pilots during the pre-flight briefing.

Following the review of background information, display-system subjects were given the symbology pretest. Once completed, the test conductor reviewed any answers missed with the subject.

Pilots were then presented with the instructions for the experiment detailing the verbal protocol. Pilots were asked to verbalize anytime they were looking for traffic on the display (for display system subjects) or scanning out of the window. They were also asked to report traffic in sight and verbalize when they would take evasive action. Planned encounter subjects were asked not to actually take evasive action in order to maintain safety separation minimums.

The final step of the pre-briefing consisted of training with the system. The goals of the training period were to 1) introduce pilots to the TSAA system in a dynamic environment prior to experiencing it in the airplane, and 2) have pilots practice the verbal protocol and give feedback to pilots regarding their verbalization. A computer was set up with film loops of two scenarios, one enroute and one in the traffic pattern. The first scenario was a head on encounter, and the second scenario was a base vs. final encounter in the traffic pattern where the target was on extended final to the runway and the ownship was flying on base leg of the traffic pattern.

Figure 4-15 shows how display systems subjects received views of the MFD as well as a cockpit view. Figure 4-16 shows how audio system subjects received the cockpit view and a visual indication of the alert. Both systems received aural annunciations of traffic. Following the training, pilots were escorted to the airplane where the safety pilot reviewed the safety procedures with the subject pilot.

Figure 4-15. Screenshot of Training Film for Subjects who Flew with the TSAA Display System

Figure 4-16. Screenshot of Training Film for Subjects who Flew with the TSAA Audio System

Following the flight, subject pilots completed a post-evaluation questionnaire on their overall perception of the TSAA system. All supplemental material for the study is provided in Appendix A.

All flights took place in day – Visual Meteorological Conditions (VMC) conditions and with cloud ceilings greater than 1500 ft. Ceiling conditions varied for all subjects from overcast to clear. Visibility varied between subjects from 5 SM to approximately 25 SM. Turbulence conditions varied from calm to moderate throughout the test period. The tests were not performed in precipitation.

Dependent Variables – Objective Data

Data was being recorded by voice recorders, TSAA equipment, video recorders, and manually using a laptop. The time of awareness was taken by the first awareness the subject had regarding the impending encounter (via the display, out-the-window visual acquisition, or alert). The time of visual acquisition was taken by the initiation of the "traffic" call when participants stated "traffic in sight." The time of visual acquisition was only used when subjects acquired traffic without test conductor or safety pilot point out. The time of evasive response was determined as the time the pilot verbalized that he would take evasive action.

Dependent Variables – Subjective Data

Subjective evaluations were also collected from the participants. Background questionnaires were completed prior to data collection and consisted of questions regarding pilot experience, access to aircraft, and experience with traffic alerting systems.

A post-event questionnaire was used to collect data regarding perception of the system for each encounter. This questionnaire probed perception of appropriateness of the alert, timeliness, accuracy, as well as whether the pilot would have taken evasive action and what action would have been taken. The full questionnaire is provided in Appendix A. The post-event questionnaire was presented as a verbal interview by HF Specialist 1.

The post-evaluation questionnaire was conducted at the end of the experiment probing general usability, clutter, display issues, perception of the best and worst features of the TSAA system, trust, as well as perceived value of the system. The questionnaire was presented to subjects on a computer.

Chapter 5

System Performance

The TSAA design was evaluated in both the audio only (Class I) and the display based (Class II) systems. The system was evaluated using planned encounter flights as well as high density flights.

Encounters that were affected by the prototype issues detailed in Chapter 4 were segregated out of the analysis. In most cases, encounters were repeated in the case that a prototype issue prevented the encounter from being successful. Thus, a complete set of encounters exists for a majority of the subjects. Discounting prototype issue encounters, a total of 109 usable encounters remained for analysis. 89 of these were planned encounter (50 display-system, 39 audio-system), and 20 encounters involved targets of opportunity (17 in traffic pattern, 3 enroute).

Twenty one general aviation pilots experienced the TSAA system. Thirteen participants flew with the display based system, while eight participants flew with the audio based system. The post-event data presented in this chapter reflects the 19 participants where a full set of usable data was available.[2] The post evaluation results presented include all 21 participants. Pilots were chosen to reflect a range of experience levels as well as a range of experience types from recreational to professional. Pilots were recruited from local flight schools and pilot associations in the greater Melbourne, Florida area.

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[2] For one *Planned Encounter – Audio* subject and one *High Density – Display* subject, detailed analysis could not be conducted due to data recording problems.

	TOTAL	Planned Encounter – Display	Planned Encounter – Audio	High Density – Display
Total Number of Pilots	21	10	8	3
Mean Total Time (hours)	4629	7904	1514	2017
Mean Hours (Past 90 days)	27	25	25	37
Mean Hours (Previous 12 months)	183	176	138	327
Private	5	2	3	0
Private/Instrument	3	2	1	0
Commercial/Instrument	8	2	4	2
ATP	5	4	0	1
CFI(I)/MEI	4	2	1	1

Table 5-1. Experience for the 21 Pilots Who Participated in Flight Testing

As is shown in Table 5-1, pilots experienced one of the following configurations.

a. TSAA Class II (Display – System) in the planned encounter environment
b. TSAA Class I (Audio – System) in the planned encounter environment
c. TSAA Class II (Display – System) in the high density target of opportunity environment

Because subjects experienced only one of the configurations, the results displayed in this section are displayed in aggregate, however the details can be distinguished using colors in the plots shown in Figure 5.1.

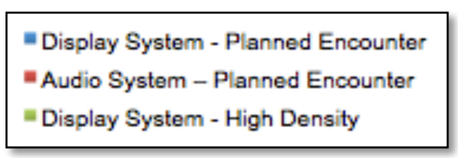

Figure 5-1. Legend for Subject Configurations

5.1 General Post-Flight Subjective Response

Subjectively, the system was well received by the pilots in the post-flight evaluation. Figure 5-2 shows that all pilots considered the TSAA to be a valuable safety system.

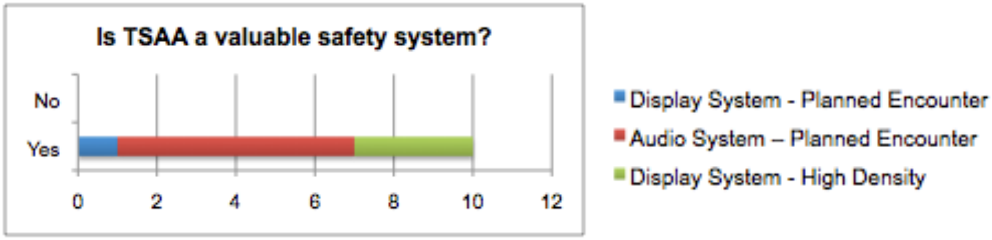

Figure 5-2. Perception of Value of TSAA[3]

5.1.1 Trust in TSAA

Figure 5-3 shows that trust in TSAA was high overall.

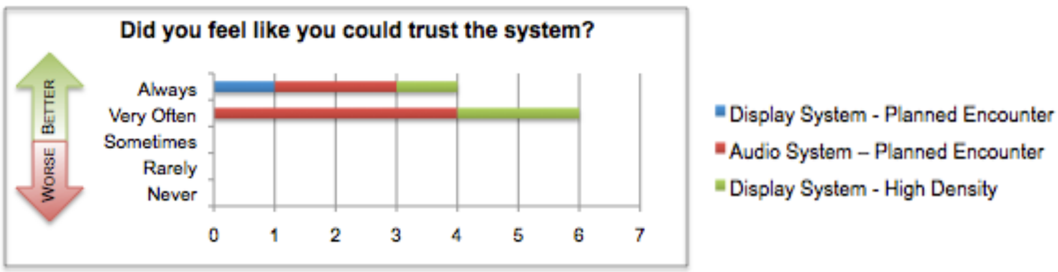

Figure 5-3. Trust in TSAA[4]

When pilots were directly probed whether TSAA missed genuine threats, most replied with rarely or never, however some pilots did indicate that it sometimes missed genuine threats as is shown in Figure 5-4. When asked to explain the cases where it missed threats, the feedback reflected 1) pilots noticing aircraft that were not displayed on the MFD, 2) pilots noticing targets drop on and off the display, and 3) pilots preferring alerts earlier.

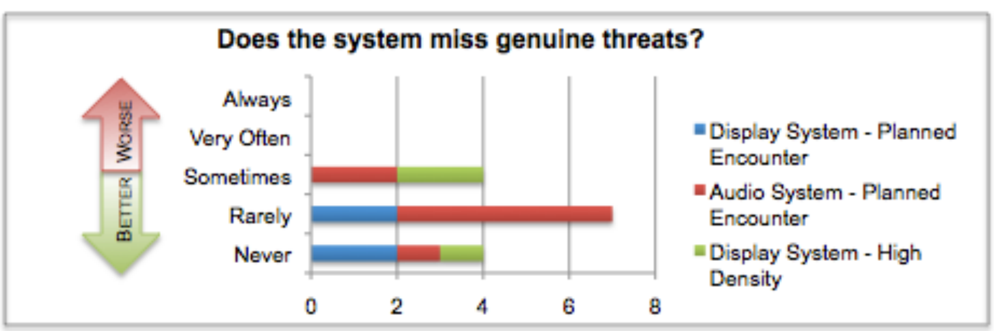

Figure 5-4. Perceived Missed Alerts in TSAA[5]

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[3] Data presented for subjects run following the stability, ground alerting, and dropout resolutions
[4] Data presented for subjects run following the stability, ground alerting, and dropout resolutions

5.1.2 Perception of Alerts

In addition to the post-event analysis, pilots were also probed during the post-flight questionnaire whether the number of alerts was appropriate. Figure 5-5 shows the results of this question for the subjects who experienced a system following resolution of the major prototype issues. A majority of pilots consider the system to alert on an appropriate amount of traffic. Detailed comments can be found in Appendix D,

Figure 5-5. Perception of Appropriateness of Alerts[6]

Pilots were also probed as to whether the alert provided enough information to be useful. The results presented in Figure 5-6, show that the majority of pilots considered the alert to provide the right amount of information.

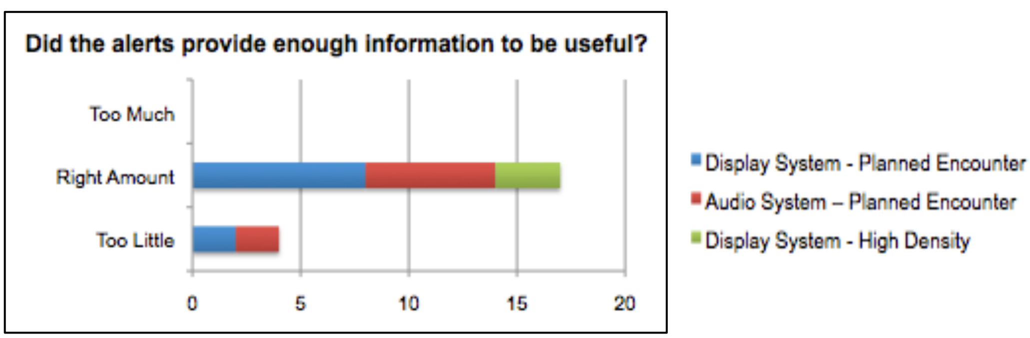

Figure 5-6. Alert Information Results

[5] Data presented for subjects run following dropout problem resolution
[6] Data presented for subjects run following the stability, ground alerting, and dropout resolutions

In addition to whether the alerts provided information, pilots were asked whether they would have preferred more constant updates on an encounter. Figure 5-7 shows that most pilots would have preferred more constant updates in some cases.

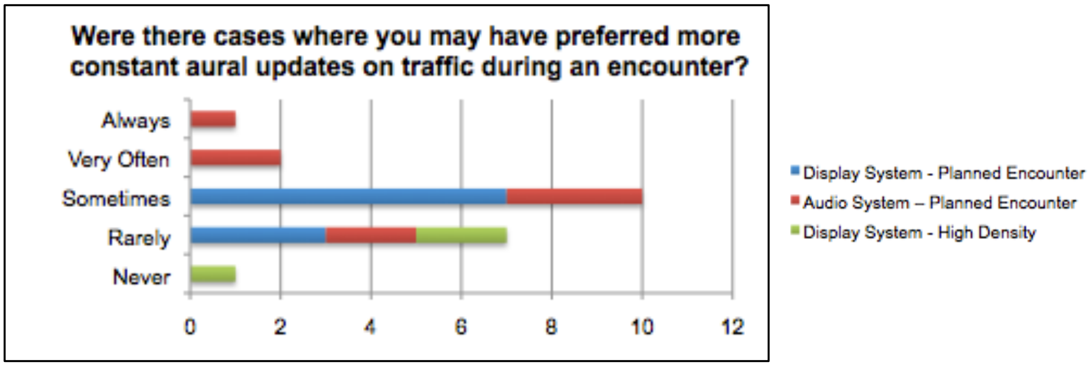

Figure 5-7. Preference for More Constant Updates on Alerts

Aural alert clarity was also probed. A majority of pilots considered the alerts to be easy to understand.

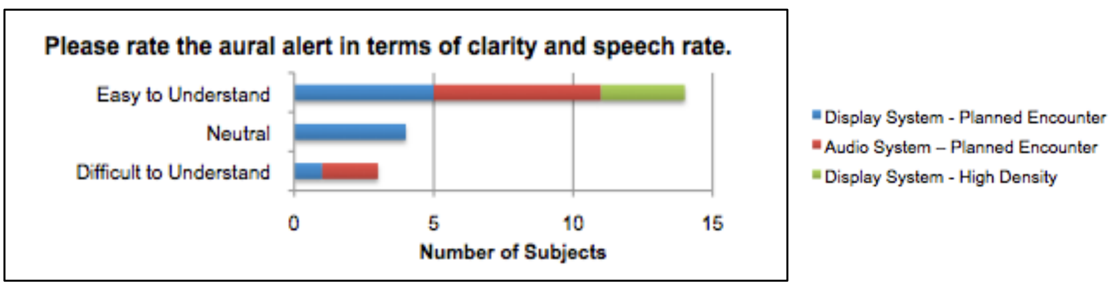

Figure 5-8. Aural Alert Clarity

5.1.3 Readability

There were no reported issues regarding display clutter. However, there were a few interface issues identified.

1. Symbol size was too small.
2. Font size on relative altitude, call sign, and vertical trend arrow was too small.

3. Misinterpretation between obstacle and target symbol – similar shape and color (Figure 5-9)[7].
4. Background map color interfered with cyan target symbol.

Pilots also complained that the CDTI was mounted too low in the cockpit, which could have contributed to some of the size issues listed above.

Figure 5-9. Target-Obstacle Interference

5.1.4 Design Features

Proximate traffic, vertical trend information, mute functionality, repeat functionality, and call sign were probed for usefulness.

Pilots who experienced the display system rated proximate traffic positively as can be seen in Table 5-2. All of the subjects indicated that it always or sometimes helped them identify threats.

[7] Subjects experienced a system with a declutter setting set to 2 out of 4 which prioritized obstacles at a given range and altitude [13]. Participants were not given control over the declutter setting. Thus, the issue presented reflects the test personnel observations.

How useful did you find the indication of proximate traffic on the display?

	Display System - Planned Encounter	Display System - High Density
Always helped me identify the threat	4	2
Sometimes helped me identify the threat	6	1
Did not help nor hinder me in identifying the threat.	0	0
Sometimes made it more difficult to identify the threat.	0	0
Always made it more difficult to identify the threat.	0	0

Table 5-2. Usefulness of Proximate Traffic

The inclusion of vertical trend in the aural alert was also rated positively by pilots who experienced the audio system shown in Table 5-3.

How useful did you find the indication of vertical trend (climbing, level, descending) in the aural call out of traffic?

	Audio System - Planned Encounter
Never used it	1
Sometimes useful	1
Always useful	6

Table 5-3. Usefulness of Vertical Trend in Aural Alert

Mute functionality was not generally used during the planned encounter testing by the subjects who experienced the audio system. Note that the audio system was not tested in the high density target of opportunity environment.

How useful did you find the mute functionality of the system?

	Audio System - Planned Encounter
Never used it	7
Sometimes useful	1
Always useful	0

Table 5-4. Usefulness of Mute Functionality

Repeat functionality was found to be more useful than mute functionality by pilots who experienced the audio system during planned encounters.

How useful did you find the repeat functionality of the system?

	Audio System - Planned Encounter
Never used it	4
Sometimes useful	2
Always useful	2

Table 5-5. Usefulness of Repeat Functionality

Call sign was found to be occasionally useful by some subjects, however most did not use the information during the planned encounter testing or the high density testing. It is possible that some of the readability issues and location of the display in the cockpit may have contributed to the usefulness of the call sign information.

How useful did you find the call sign information on the display?

	Display System - Planned Encounter	Display System - High Density
Never used it	6	2
Sometimes useful	3	1
Always useful	1	0

Table 5-6. Usefulness of Call Sign Information

5.1.5 Interference

Pilots were asked whether the TSAA system interfered with ATC communication or other crew tasks. Note that planned encounter subjects were not given ATC as a resource during the flights. The high density subjects indicated that the system rarely to never interfered with ATC as is shown in Figure 5-10.

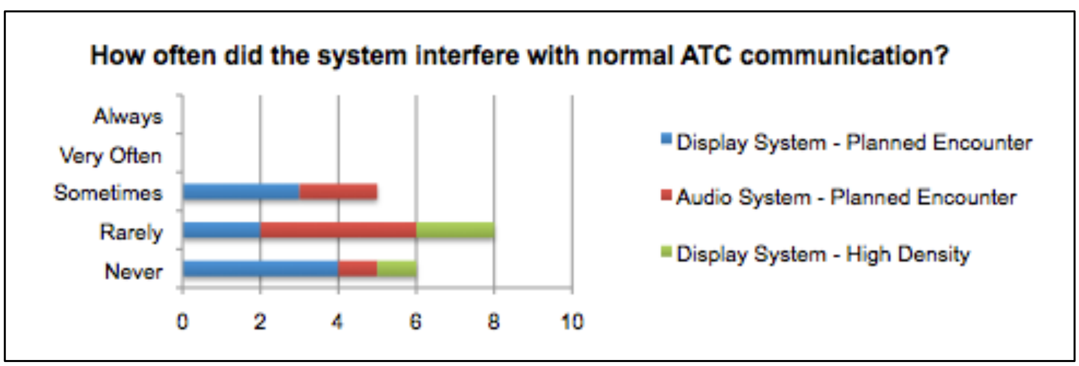

Figure 5-10. Interference with ATC Communication

The majority of subjects indicated that the system rarely or never interfered with other crew tasks as is seen in Figure 5-11. In general, they acknowledged that the system was a tool for visual scanning.

Other pilots did indicate that the system sometimes interfered with other crew tasks. When probed, the prototype issues experienced earlier in the testing contributed to their perception of the system. In addition to prototype issues, pilot perception was influenced by their understanding of the encounter. Some pilots did not believe pattern alerts (during planned encounters) were real threats unless they made visual acquisition of the traffic. Thus, some indicated that the system interfered with flying tasks in the pattern. Note that the high density subjects did not indicate major interference with other crew tasks.

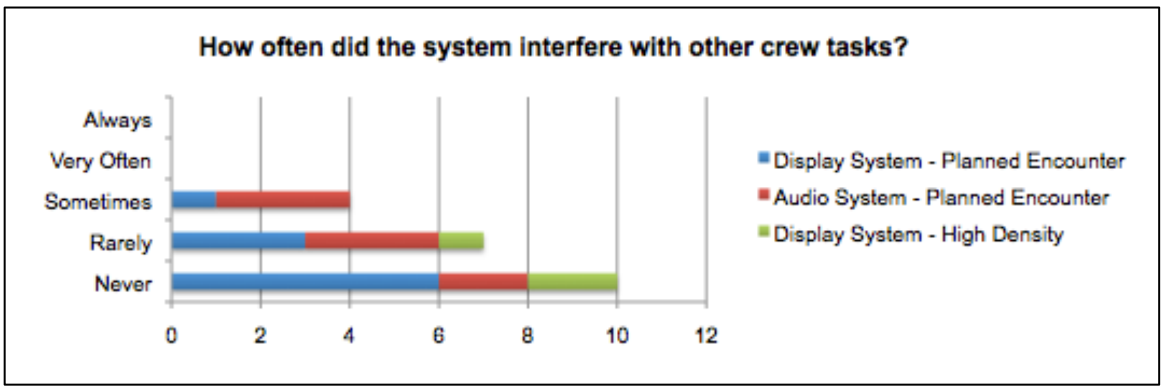

Figure 5-11. Interference with Other Crew Tasks

5.1.6 Summary

Subjectively, the system was well received by the pilots in the post-flight evaluation, and trust was rated highly. Non-displayed aircraft and dropouts of targets on and off the display negatively influenced perception of the system. In general, the number of alerts were considered appropriate and aural alerts were rated as easy to understand. Pilots in general preferred more constant updates on an encounter. The mute functionality and call sign information were not widely used by pilots, however the repeat functionality in the audio system was valued by some pilots. Pilots were generally accepting of the system and did not indicate major interference of the system with normal pilot operations or radio communications.

5.2 In-flight Performance and Subjective Response

5.2.1 First Indication of Encounter

Experimenters recorded the time whenever the following occurred.

1. Traffic was referred to on the display (in the case that a display was available)
2. Traffic was visually acquired
3. Traffic was called out by Air Traffic Control (ATC) via a direct communication with the ownship or through party line communication with other aircraft.

For each encounter, the first indication that an encounter was imminent was recorded. The first indication could come from any of the following sources.

1. Participant received an alert on the target.
2. Participant noticed the target on the display.
3. Participant acquired target visually.
4. Participant received information over the radio regarding the traffic target.

The results for the first indication of encounter are presented below for the planned encounter environment (display and audio systems) as well as the targets of opportunity, both enroute and in the pattern.

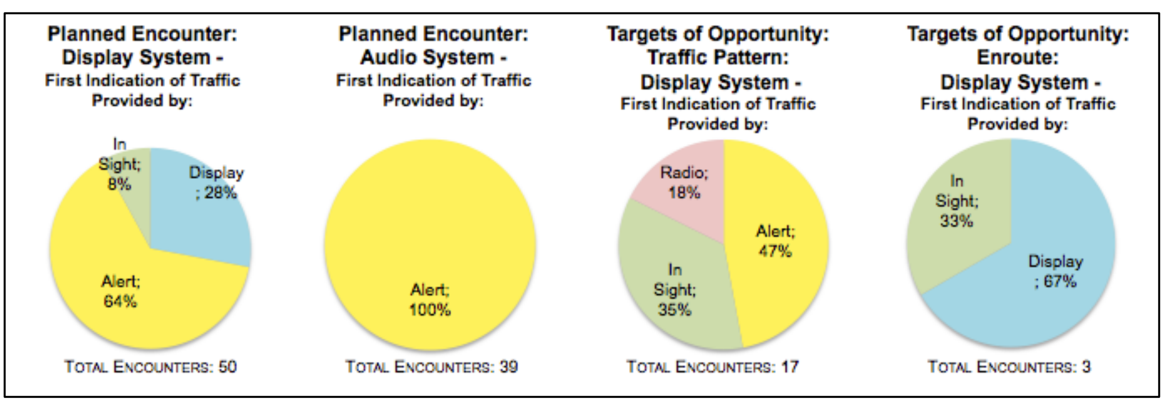

Figure 5-12. First Indication of Alert Results

Overall, the alert provided the first indication of an encounter in a majority of cases. In the audio system, the alert provided the first indication in all of the 39 encounters. For encounters with targets of opportunity in the traffic pattern, a higher percentage of encounters were first identified visually. This is expected due to the primarily visual flight regime of the traffic pattern. Also in the pattern, pilots did receive information about traffic from radio communications. Note that radio communication was not given to pilots as a resource during the planned encounter testing.

5.2.2 First Look Direction Following Alert

It was desired to understand where pilots first scanned when an alert was provided. In addition to the head-cam data, experimenters actively recorded the first look scan as the alert annunciated. The first look was determined by either the head-cam data, or the experimenter observation, whichever was more reliable. The results presented below reflect the experimenter observations of pilot first look for the 52 planned encounter flights where a display was available.

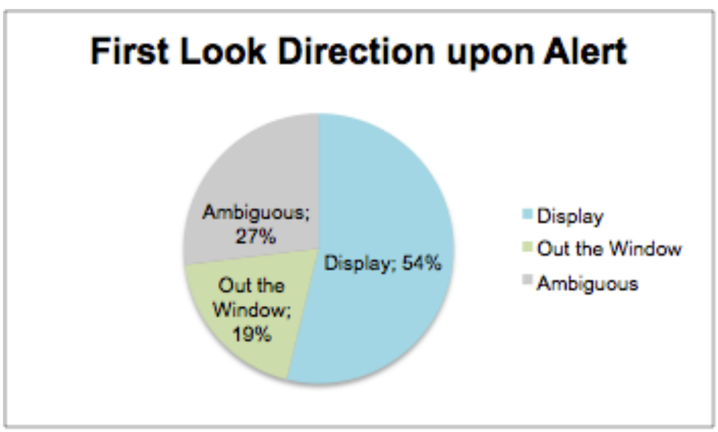

Figure 5-13. First Look Direction Upon Alert for All Display System Encounters

As is shown in Figure 5-13, pilots referred to the display first in 54% of encounters. In 19% of cases, pilots first looked outside when an alert annunciated. In the remaining 27% of cases, the direction of first look was unclear to the experimenter. In most cases, pilots searched for traffic visually, even if their first look was at the display. The exception reflected cases where the target was directly behind the ownship and the subject did not believe he would be able to visually acquire the target.

5.2.3 Planned Encounter Flights

5.2.3.1 Perception of Nuisance Alerts – Planned Encounter Flights

Pilots were probed regarding their perception of whether a given alert was appropriate or nuisance in the post-event interview following each encounter. For the planned encounters, shown in Table 5-7, pilots considered the alerts to be appropriate in 91.7% of cases for the display system and 94.6% of cases for the audio system. In all 6 cases where pilots considered the alert a nuisance, the target was never visually acquired.

	Display Based System		Audio Based System	
Scenario	**Appropriate**	**Nuisance**	**Appropriate**	**Nuisance**
LCR Overtake	16	0	12	1
High VCR	8	1	5	1
Head On	7	0	7	0
Overtaking Final	5	2	6	0
Entry vs. Downwind	8	1	5	0
Total Percentage	**91.7%**	**8.3%**	**94.6%**	**5.4%**

Table 5-7. Perception of Nuisance Alerts for the Planned Encounter Flights

5.2.3.2 Perception of Timeliness of Alerts – Planned Encounter Flights

Pilots rated timeliness of the alert during the post-event questionnaire. They rated the alert as too early, timely, or too late. Overall, pilots tended to perceive the alerts as timely or too late with no cases of the alert being too early.

The timeliness results for planned encounters is presented in Table 5-8. In the display based system, pilots considered the alerts to be timely in 53.1% of cases and too late in 46.9% of cases. In the audio system, pilots considered the alerts as timely in 73.5% of cases and late in 26.5% of cases.

	Display Based System			Audio Based System		
Scenario	Too Early	Timely	Too Late	Too Early	Timely	Too Late
LCR Overtake	0	8	8	0	7	4
High VCR	0	4	5	0	4	1
Head On	0	5	2	0	6	1
Overtaking Final	0	5	2	0	5	1
Entry vs. Downwind	0	4	6	0	3	2
Total Percentage	**0.0%**	**53.1%**	**46.9%**	**0.0%**	**73.5%**	**26.5%**

Table 5-8. Perception of Timeliness of Alerts for the Planned Encounter Flights

5.2.3.3 Perception of Accuracy of Alerts – Planned Encounter Flights

Pilots rated accuracy of the alert during the post-event questionnaire. Pilots were asked whether they considered the location (clock position) and distance of the traffic called out in the aural alert to be accurate or inaccurate. In the case that the subjects considered the information inaccurate, they were probed about why they considered it inaccurate.

Table 5-9 shows the perceived accuracy of alerts during the planned encounter flights. Overall, accuracy was rated as good when the traffic was visually acquired. In the display system, pilots rated the position and distance as accurate in 83.3% of cases where visual acquisition was made. In the audio system, pilots rated the information as accurate in 88.9% of cases. The inaccurate cases for both the display and audio cases were dependent on when the pilot made visual acquisition with the target. In 4 out of the 6 inaccurate cases, pilots reported that the target looked closer than what was reported in the alert. In another inaccurate case, the pilot reported that he found the target closer to 12 o'clock when the alert annunciated 11 o'clock. The final inaccurate case was due to the pilot observing the target on the breakaway maneuver following the encounter.

	Display Based System			Audio Based System		
Scenario	Not Acquired	Inaccurate	Accurate	Not Acquired	Inaccurate	Accurate
LCR Overtake	11	1	4	9	0	5
High VCR	4	2	3	4	0	2
Head On	0	1	6	1	2	2
Overtaking Final	7	0	1	4	0	3
Entry vs. Downwind	4	0	6	1	0	4
Total Percentage	**52.0%**	**8.0%**	**40.0%**	**51.4%**	**5.4%**	**43.2%**
If Acquired Percentage		**16.7%**	**83.3%**		**11.1%**	**88.9%**

Table 5-9. Perception of Accuracy of Alerts for the Planned Encounter Flights

5.2.3.4 Visual Acquisition of Traffic – Planned Encounter Flights

The HF Specialists actively recorded when pilots reported traffic in sight in real time which was verified by the time on the voice recorders. The time corresponded to the beginning of the "traffic in sight" call. The reader should note that for later subjects (12 and later), the aircraft was pointed out to the subject in the Low Closure Rate (Scenario 1), Head On (Scenario 3), and Entry vs. Downwind (Scenario 5) encounters in the case the scenario developed close to the closest point of approach (CPA) without the subject getting visual acquisition. The reason was to provide subjects with the understanding of the threat level of the traffic. These traffic point outs are not considered in the analysis in this section. They are highlighted with the symbol (*) each time a point out was given.

As is shown in Table 5-10, for planned encounters, visual contact was made in 40.5% of all encounters. During the Low Closure Overtake (Scenario 1) and the Overtaking on Final (Scenario 4) encounters, the traffic approached from 6 o'clock and it would have been difficult to visually acquire the targets given the geometry. For the remaining three encounters, Vertical High Closure Rate (Scenario 2), Head On (Scenario 3), and Entry vs. Downwind (Scenario 5), visual contact was made 58% of the time in the case that the pilot had a marginal chance of visually acquiring traffic.

	Positive Visual Acquisition	No Visual Acquisition During Scenario
LCR Overtake	7 (25%)	21(75%) ******
Vertical HCR	7 (50%)	7 (50%)
Head On	9 (64%)	5 (36) ****
Overtaking on Final	2 (15%)	11 (85%)
Entry vs. Downwind	9 (60%)	6 (40%) *
TOTAL %	**40.5%**	**59.5%**

Table 5-10. Visual Acquisition during Planned Encounter Flights[8]

Table 5-11 provides details on how soon before or after the alert pilots visually acquired traffic. Pilots visually acquired traffic before the alert annunciated in 3 out

[8] There were 6 point outs of traffic in the Low Closure Overtake scenario, 4 point outs of traffic in the Head On scenario, and 1 point out of traffic in the Entry vs. Downwind scenario.

of the 33 total cases where pilots visually acquired traffic. The remaining 30 cases consisted of visual acquisition being made following the alert annunciation. In aggregate, a weighted average can be calculated for time before and time after alert that visual acquisition was made. Pilots made visual acquisition on average 13 s (SD=21s) after the alert annunciated when considering all 5 scenarios. When discounting the scenarios where traffic approached from 6 o'clock and visual acquisition was not expected, pilots made visual acquisition on average 14 s (SD=19s) after the alert annunciated in the remaining scenarios.

	Visual Acquisition *Before* Alert		Visual Acquisition *After* Alert	
	Number	**Seconds (Before)**	**Number**	**Seconds (After)**
LCR Overtake	0	-	7	19 (SD =15)
Vertical HCR	0	-	7	17 (SD =11)
Head On	0	-	9	26 (SD =9)
Overtaking on Final	1	50 (SD =NA)	1	9 (SD =NA)
Entry vs. Downwind	2	33 (SD =22)	7	9 (SD =7)

Table 5-11. Time of Visual Acquisition during Planned Encounter Flights

Analysis can also be done regarding the difference in visual acquisition between the TSAA display system and the TSAA audio system. Table 5-12 shows the results split between the display and audio systems. 43% of traffic was visually acquired when the display system was in use. 36% of traffic was visually acquired when the audio system was in use. When discounting the scenarios where traffic approached from 6 o'clock and visual acquisition was not expected, pilots made visual acquisition in 62% of cases when using the display system, and in 52% of cases when using the audio system in the remaining scenarios (Vertical HCR, Head On, Entry vs Downwind).

	Display System		Audio System	
	Positive Visual Acquisition	No Visual Acquisition During Scenario	Positive Visual Acquisition	No Visual Acquisition During Scenario
LCR Overtake	4	12	3	9
Vertical HCR	5	4	2	3
Head On	6	1	3	4
Overtaking on Final	1	5	1	6
Entry vs. Downwind	5	5	4	1
TOTAL %	**43.7%**	**56.3%**	**36.1%**	**63.9%**

Table 5-12. Visual Acquisition for Display vs Audio Systems during Planned Encounter Flights

Table 5-13 shows the time before and after the alert, visual acquisition was made for pilots the display system only. Of the pilots who made visual acquisition, they did so, on average 13 seconds (SD=25s) after the alert annunciated. When discounting the scenarios where traffic approached from 6 o'clock and visual acquisition was not expected, pilots visually acquired traffic on average 14 seconds (SD=22s) after the alert annunciated in the remaining scenarios.

	Visual Acquisition *Before* Alert		Visual Acquisition *After* Alert	
	Number	Seconds (Before)	Number	Seconds (After)
LCR Overtake	0	-	4	23 (SD =16)
Vertical HCR	0	-	5	20 (SD =12)
Head On	0	-	6	26 (SD =11)
Overtaking on Final	1	50 (SD =NA)	0	-
Entry vs. Downwind	2	33 (SD =22)	3	12 (SD =10)

Table 5-13. Time of Visual Acquisition for the Display System Encounters during Planned Encounter Flights

Table 5-14 shows the time before and after the alert, visual acquisition was made for pilots the audio system only. Of the pilots who made visual acquisition, they did so, on average 15 seconds (SD=11s) after the alert annunciated. When discounting the scenarios where traffic approached from 6 o'clock and visual acquisition was not expected, pilots visually acquired traffic on average 14 seconds (SD=11s) after the alert annunciated in the remaining scenarios. Notice that no pilots made visual acquisition before the alert annunciated in the audio system tests.

	Visual Acquisition *Before* Alert		Visual Acquisition *After* Alert	
	Number	Seconds (Before)	Number	Seconds (After)
LCR Overtake	0	-	3	14 (SD =16)
Vertical HCR	0	-	2	10 (SD =7)
Head On	0	-	3	28 (SD =5)
Overtaking on Final	0	-	1	9 (SD =NA)
Entry vs. Downwind	0	-	4	7 (SD =1)

Table 5-14. Time of Visual Acquisition for the Audio System Encounters during Planned Encounter Flights

5.2.3.5 Evasive Action – Planned Encounter Flights

Pilots were asked to verbally indicate when they would maneuver for traffic during flight. They were also probed during the post-event interview whether they would have maneuvered and how they would have maneuvered. Pilots however, found it difficult to actively report when they would have taken evasive action during the encounter. Thus, the results presented below reflect the post-event interview data.

Table 5-15 shows the evasive action results for the planned encounters. For the display system, pilots reported that they would have taken evasive action in 70.0% of cases. In the audio system, pilots reported that they would have taken evasive action in 64.1% of cases. It was observed that the decision not to take evasive action was influenced by when the pilots made visual acquisition with the target. In some cases, the pilots made visual acquisition during the breakaway maneuver, so an opening rate would have already been established in those cases.

	Display Based System		Audio Based System	
Scenario	**Yes**	**No**	**Yes**	**No**
LCR Overtake	11	5	10	4
High VCR	7	2	2	4
Head On	6	1	4	3
Overtaking Final	4	4	4	3
Entry vs. Downwind	7	3	5	0
Total Percentage	70.0%	30.0%	64.1%	35.9%

Table 5-15. Evasive Action for the Planned Encounter Flights

Details regarding the action pilots specified they would take for traffic is provided in Table 5-16 for each scenario. For the horizontal low closure encounter, in 12 out of

17 cases, pilots stated they would have turned left and maintained altitude. For the high vertical closure rate encounter, 5 out of 9 pilots reported that they would have turned right and maintained altitude in response to traffic. For the head on, 6 out of 10 pilots reported that they would have turned right and maintained altitude. For the overtaking final case, 6 out of 8 pilots reported that they would have performed a go around in the situation. For the entry vs. downwind scenario, 9 pilots reported that they would have turned left and 5 of those pilots would have also initiated a descent in response to traffic.

	Turn & Maintain Altitude			Turn & Descend			Turn & Climb			Climb & Maintain Course	Descend & Maintain Course	Go Around	Unknown
Scenario	L	R	?	L	R	?	L	R	?				
LCR Overtake	12	1	1	3	1	1					1		1
High VCR	1	5		1	2								
Head On	1	6			1			1		1			
Overtaking Final			1								1	6	
Entry vs. Downwind	4			5			1				1		1

Table 5-16. Type of Evasive Action Reported for Planned Encounter Flights

5.2.4 High Density Flights

Following high density testing, analysis was conducted on each alert. There were a total of 27 alerts received during the high density pattern flights. Ten out of a total of 27 alert encounters were received by the safety pilot, while the subject pilot was offline being interviewed. These 10 alerts were segregated out of the analysis, and the remaining 17 encounters were analyzed for human factors response in the traffic pattern. Each encounter was reconstructed using the logged state vector data. From these reconstructions, it was possible to categorize the traffic pattern alerts into 4 different encounter categories.

1. Turning Alerts – Turning alerts occurred mostly due to wrap around (of constant turn rate prediction) of the aircraft trajectory during turns. Graphical examples of the geometry of turning alerts observed are shown in Figure 5.14. 10 out of the 17 alerts analyzed in the pattern were turning alerts.

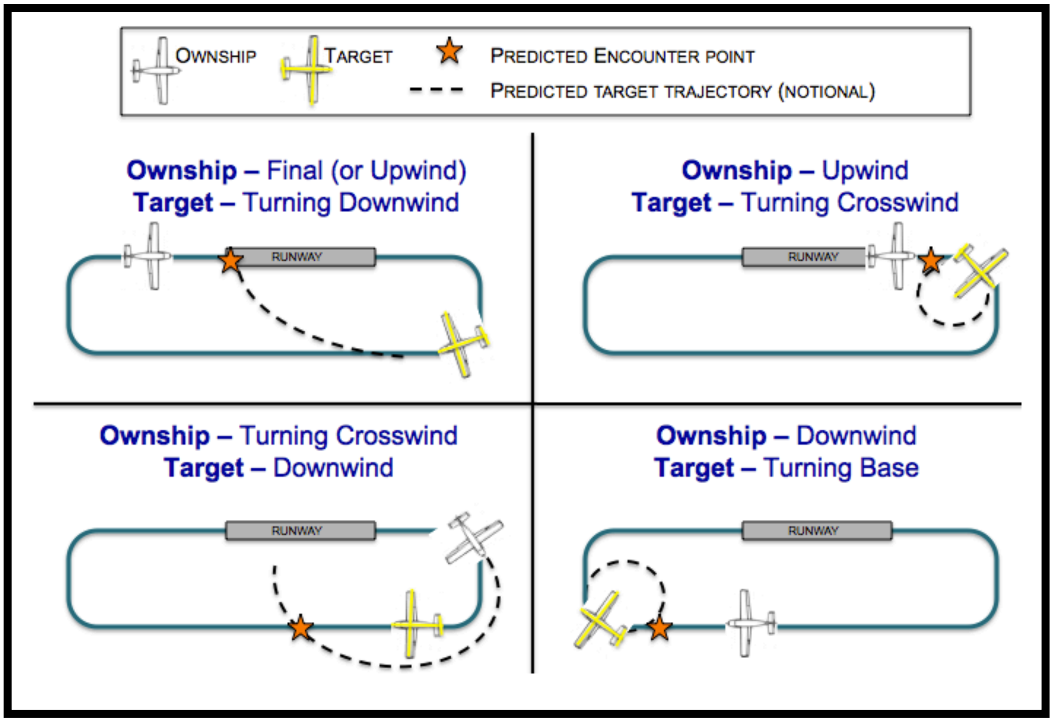

Figure 5-14. Typical Turning Alert Geometry

2. Parallel Runway Alerts – Parallel runway alerts occurred due to the interaction with the parallel runway. Figure 5-15 shows the notional geometries observed for the parallel runway alerts. 4 out of the 17 encounters analyzed in the pattern were classified as parallel runway alerts.

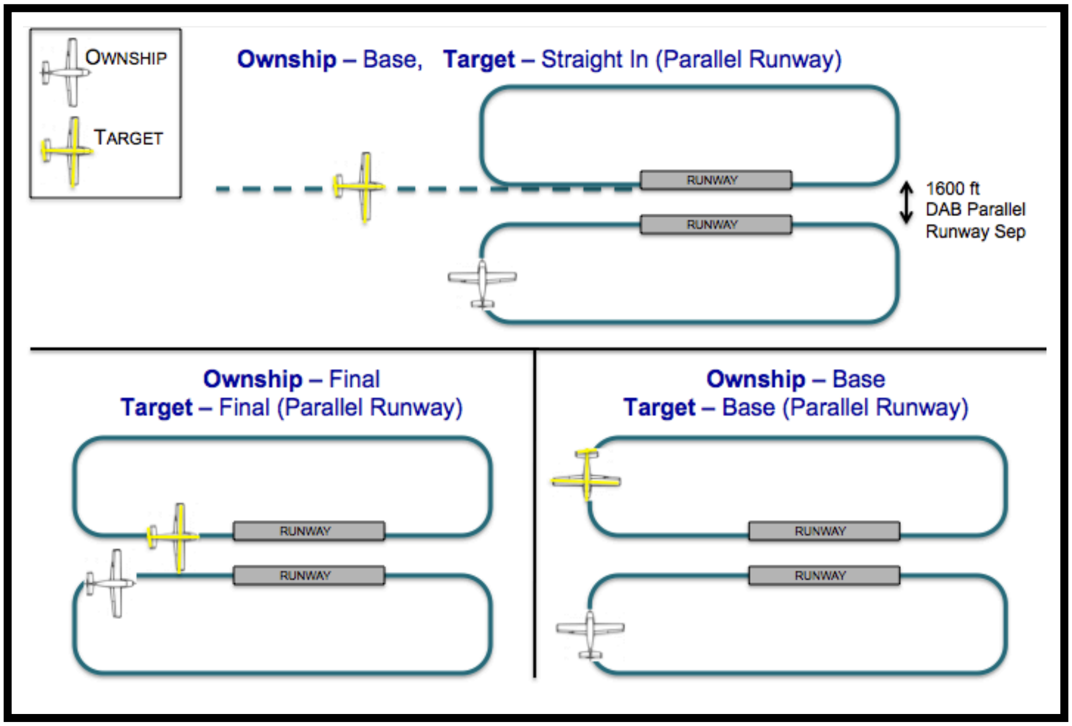

Figure 5-15. Typical Parallel Runway Alert Geometry

3. Overtake Alerts – Overtake alerts occurred due to close sequencing in the pattern and the higher speed the ownship flew compared to the other aircraft in the pattern. Figure 5-16 shows the typical geometry of the overtake alerts. 2 out of the 17 encounters in the pattern can be classified as overtake alerts.

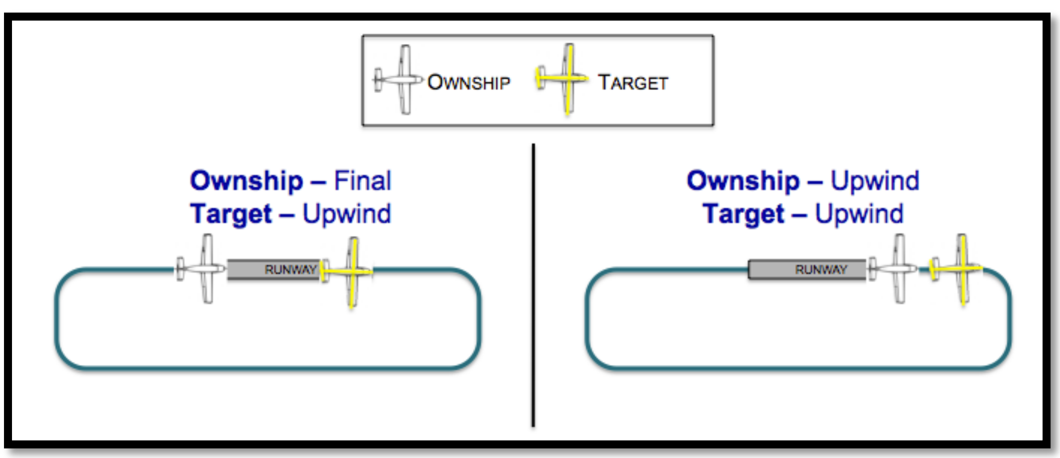

Figure 5-16. Typical Overtake Alert Geometry

4. Other Alerts – The one alert that falls into this category occurred when the ownship was turning crosswind and an alert annunciated on traffic entering the downwind on a 45 degree entry.

In addition to the taxonomy presented above for traffic pattern encounters, 3 encounters with targets of opportunity were also observed enroute between KMLB and KDAB. The results presented below include the traffic pattern targets of opportunity as well as the enroute targets of opportunity.

5.2.4.1 Perception of Nuisance Alerts – High Density Flights

As is seen in Table 5-17, in 80% of cases, pilots considered the alerts on targets of opportunity to be valid. There were four alerts that were considered as nuisance alerts by the participants. The overtake case was considered nuisance because it occurred on short final. The "other pattern" case was an alert on traffic entering downwind while the ownship was turning crosswind, and was considered nuisance because the pilot had visually acquired the traffic prior to the alert. The 2 turning alerts that were considered nuisance occurred during a time that the display experienced difficulty. Alerts for two separate aircraft were received during this time, and the evaluation of the alerts as nuisance may have been influenced by the hardware problem.

		Display Based System	
	Scenario	Appropriate	Nuisance
PATTERN	Turning Alerts	9	2*
PATTERN	Parallel Runway Alerts	3	0
PATTERN	Overtakes	1	1
PATTERN	Other Pattern	0	1
	Enroute	3	0
	Total Percentage	**80%**	**20%**

Table 5-17. Perception of Nuisance Alerts for the High Density Flights (* The two nuisance turning alerts occurred during a display anomaly)

5.2.4.2 Perception of Timeliness of Alerts – High Density Flights

Pilots rated timeliness of the alert during the post-event questionnaire. They rated the alert as too early, timely, or too late. Overall, pilots tended to perceive the alerts as timely or too late with no cases of the alert being too early.

The timeliness results for the targets of opportunity is presented in Table 5-18. In the display based system, pilots considered the alerts to be timely in 76.5% of cases and too late in 23.5% of cases. During all of the reported cases, the system was functioning as designed.

		Display Based System		
	Scenario	Too Early	Timely	Too Late
PATTERN	Turning Alerts	0	7	2
PATTERN	Parallel Runway Alerts	0	2	1
PATTERN	Overtakes	0	1	0
PATTERN	Other Pattern	0	1	0
	Enroute	0	2	1
	Total Percentage	**0.0%**	**76.5%**	**23.5%**

Table 5-18. Perception of Timeliness of Alerts for the High Density Flights

5.2.4.3 Perception of Accuracy of Alerts – High Density Flights

Pilots rated accuracy of the alert during the post-event questionnaire. Pilots were asked whether they considered the location (clock position) and distance of the traffic called out in the aural alert to be accurate or inaccurate. In the case that the subjects considered the information inaccurate, they were probed about why they considered it inaccurate.

Table 5-19 shows the perceived accuracy of alerts during the target of opportunity flights. Again, accuracy was rated as good when the traffic was visually acquired. Pilots rated the position and distance as accurate in 84.2% of cases where visual acquisition was made. The 3 cases where alert was rated inaccurate, the pilot rated it as such because he understood the “less than one mile” annunciation to indicate that the traffic was to the left. It is possible to consider other options to relay distance information such as "within one mile" or "inside one mile," however they were not tested in these studies. It may be candid to study possible other options as further research.

		Display Based System		
	Scenario	Not Acquired	Inaccurate	Accurate
PATTERN	Turning Alerts	0	2	9
PATTERN	Parallel Runway Alerts	0	0	3
PATTERN	Overtakes	0	0	1
PATTERN	Other Pattern	0	1	0
	Enroute	0	0	3
	Total Percentage	**0.0%**	**15.8%**	**84.2%**
	If Acquired Percentage		**15.8%**	**84.2%**

Table 5-19. Perception of Accuracy of Alerts for the High Density Flights

Overall however, pilots considered the location and distance information provided in the alert to be accurate.

5.2.4.4 Visual Acquisition of Traffic – High Density Flights

For the high density flights, the definition of visual acquisition time remained the same as with the planned encounter flights. The time corresponded to the beginning of the "traffic in sight" call. Because the pattern is a consistently visual environment, a definition was required to determine when an encounter began and ended.

- The beginning of an encounter was defined as the end of a previous post-event interview.
- The end of an encounter was defined as the beginning of the next post-event interview.

The test conductor actively determined when the post-event interview should be conducted in each encounter which was influenced by the flight safety of the environment that the encounter occurred in. For example, if an encounter occurred when the ownship was on short final, the post-event interview would be postponed until the go around when a safe transfer of controls from the subject pilot to the safety pilot could be conducted.

The time of visual acquisition is influenced by the definition of the encounter since a single aircraft could be in sight continuously and participate in multiple encounters. Thus, the visual acquisition times reported in the following section refer to the time that the subject reported the traffic in sight during each encounter.

Table 5-20 shows that visual acquisition was made in 81% of cases for the targets of opportunity.

	Positive Visual Acquisition	No Visual Acquisition During Scenario
Turning Alerts	9 (82%)	2 (18%)
Parallel Runway Alerts	3 (75%)	1 (25%)
Overtakes	1 (50%)	1 (50%)
Other Pattern	1 (100%)	0 (0%)
Enroute	3 (100%)	0 (0%)
TOTAL %	**81.0%**	**19.0%**

Table 5-20. Visual Acquisition during High Density Flights

Table 5-21 shows the time before and after an alert that visual acquisition was made. Notice that in the target of opportunity flights, visual contact was made prior to the alert annunciation in 53% of cases where visual contact was made. Of the pilots who made visual contact during the scenario, they visually acquired the traffic on average 8 seconds (SD=32s) *before* the alert annunciated.

	Visual Acquisition *Before* Alert		Visual Acquisition *After* Alert	
	Number	Seconds (Before)	Number	Seconds (After)
Turning Alerts	5	48 (SD =43)	4	21 (SD=28)
Parallel Runway Alerts	0	-	3	12 (SD =16)
Overtakes	1	22 (SD =NA)	0	-
Other Pattern	1	45 (SD =NA)	0	-
Enroute	2	37 (SD =49)	1	6 (SD =NA)

Table 5-21. Time of Visual Acquisition during High Density Flights

5.2.4.5 Evasive Action – High Density Flights

During the high density flights, pilots were allowed to maneuver for traffic. As can be seen in Table 5-22, in 2 cases, one in the pattern and one enroute, pilots took evasive action in this environment. The pattern case was an overtake geometry where the ownship side stepped to the right in order to maintain sight of the target in front of him. The enroute case was for a target maneuvering at low altitude. Once the target turned toward the ownship and the alert annunciated, the pilot chose to turn approximately 20 degrees to the right in this case. Note that pilots in general considered the alerts as appropriate even if they did not consider evasive action necessary.

		Display Based System	
	Scenario	**Yes**	**No**
PATTERN	Turning Alerts	0	11
PATTERN	Parallel Runway Alerts	0	3
PATTERN	Overtakes	1	1
PATTERN	Other Pattern	0	1
	Enroute	1	2
	Total Percentage	**10%**	**90%**

Table 5-22. Evasive Action for the High Density Flights

5.3 Summary

Overall, the system alerted as expected. The alert provided the first indication of an encounter in a majority of cases. In general, pilots considered alerts to be appropriate in both the planned encounter cases and the targets of opportunity. In most cases, pilots did not deem evasive action necessary during high density flights, despite considering the alerts to be appropriate.

Visual acquisition was made in 40.5% of cases for the planned encounters, and 81.0% of cases for the targets of opportunity. For the cases where visual acquisition was made in the planned encounters, pilots tended to make visual acquisition approximately 13 seconds *after* an alert annunciated. In target of opportunity cases, pilots made visual acquisition approximately 15 seconds *before* an alert annunciated in the target of opportunity cases. The differences in visual acquisition could be due to the different geometries encountered with planned encounters as well as the different flight regimes.

Pilots also indicated that the alert provided accurate information, and reported that they could trust the system. Pilots considered the alerts to be timely in 64% of all encounters and too late in 36% of all encounters. In general subjective feedback suggested that the display symbology was effective, with some improvements desired in terms of font size and target vs obstacle discriminability. Overall the system was well received by the pilots in the post-flight evaluation.

Chapter 6

Summary and Conclusions

A Traffic Situation Awareness with Alerting Application (TSAA) was developed which uses ADS-B, a GPS based surveillance system, to provide reliable alerts in a condensed environment.

TSAA system performance and usability was tested by installing the system in an aircraft and having 21 general aviation pilots use the system in-flight. Pilots flew with the system during planned encounter testing as well as in typical high density traffic pattern environments in Daytona Beach, FL. Pilot's awareness of traffic, visual acquisition, and evasive action were recorded throughout the testing. A total of 109 encounters were analyzed comprising of 89 planned encounters and 20 targets of opportunity.

Overall, the system alerted as expected. The alert provided the first indication of an encounter in a majority of cases. In general, pilots considered alerts to be appropriate in both the planned encounter cases and the targets of opportunity. In most cases, pilots did not deem evasive action necessary during high density flights, despite considering the alerts to be appropriate.

Visual acquisition was made in 40.5% of cases for the planned encounters, and 81.0% of cases for the targets of opportunity. For the cases where visual acquisition was made in the planned encounters, pilots tended to make visual acquisition approximately 13 seconds (SD=21s) *after* an alert annunciated. In target of opportunity cases, pilots made visual acquisition approximately 8 seconds (SD=32s) *before* an alert annunciated. The differences in visual acquisition could be due to the different geometries encountered with planned encounters as well as the different flight regimes.

Pilots also indicated that the alert provided accurate information, and reported that they could trust the system. Pilots considered the alerts to be timely in 64% of encounters and too late in 36% of all encounters. In general subjective feedback suggested that the display symbology was effective, with some improvements desired in terms of font size and target vs obstacle discriminability. Overall the system was well received by the pilots in the post-flight evaluation.

This research tested the pilot performance using the display system and the audio system. The findings of the studies will contribute to TSAA standards development for the FAA and design recommendations for avionics manufacturers.

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Appendix A:

Flight Testing Supplementary Material

Appendix A1: Participant Consent Form

CONSENT TO PARTICIPATE IN NON-BIOMEDICAL RESEARCH

ADS-B Display Configurations with Alerting: Flight Testing

You are asked to participate in a research study conducted by R. John Hansman, T. Wilson Professor of Aeronautics and Astronautics and Sathya S. Silva, S.M., from the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology (M.I.T.). You were selected as a possible participant in this study because the study requires private pilots to properly evaluate the test equipment. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

- **PARTICIPATION AND WITHDRAWAL**

Your participation in this study is completely voluntary and you are free to choose whether to be in it or not. If you choose to be in this study, you may subsequently withdraw from it at any time without penalty or consequences of any kind. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

- **PURPOSE OF THE STUDY**

The purpose of this project is to examine designs of a traffic awareness system that uses Automatic Dependent Surveillance Broadcast (ADS-B) information to alert pilots of traffic situations. Using an aircraft, we will perform a basic usability test of two main Traffic Situation Awareness with Alerting (TSAA) configurations, In particular, our focus is the target symbology for the Cockpit Display of Traffic Information (CDTI) to establish a preferred generic display. Additionally, we will examine ways to differentiate levels of avoidance zones in aircraft separation and how to depict degraded targets.

- **PROCEDURES**

If you volunteer to participate in this study, we would ask you to do the following things:

You will be instructed to fly a flight profile in an aircraft equipped with TSAA, indicate any traffic issues, and respond appropriately. The flight tasks will examine flights in the traffic pattern and en route. The study will take approximately 3 hours to complete and will include post-experiment feedback. Please feel free to ask any questions throughout the study.

- **POTENTIAL RISKS AND DISCOMFORTS**

The risks involved in your participation include aircraft operating in a close proximity and a risk of smoke in the cockpit. These are the two risks that are higher than what you would experience flying an aircraft typically. There are a number of mitigations to reduce this risk, and an experienced pilot will assume safety of flight responsibilities and also serve as pilot in command for the flight.

- **POTENTIAL BENEFITS**

Participation in this study provides an opportunity to aid in the evaluation of various displays for reducing mid-air collisions.

- **PAYMENT FOR PARTICIPATION**

We are not currently offering compensation for participation in this study.

- **CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. All audio and video recordings will be de-identified and MIT will have control over any audio/visual data collected for the human factors testing. All data will be disposed of following the completion of the study.

Your participation in this study is completely voluntary. Your participation is strictly confidential, and no individual names or identities will be recorded with any data or released in any reports. Only arbitrary numbers are used to identify pilots who provide data. You may terminate your participation in the study at any time.

- **IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about the research, please feel free to contact John Hansman at rjhans@mit.edu or call 617-253-3371 or contact Sathya Silva at ssilva@mit.edu.

- **EMERGENCY CARE AND COMPENSATION FOR INJURY**

If you feel you have suffered an injury, which may include emotional trauma, as a result of participating in this study, please contact the person in charge of the study as soon as possible.

In the event you suffer such an injury, M.I.T. may provide itself, or arrange for the provision of, emergency transport or medical treatment, including emergency treatment and follow-up care, as needed, or reimbursement for such medical services. M.I.T. does not provide any other form of compensation for injury. In any case, neither the offer to provide medical assistance, nor the actual provision of medical services shall be considered an admission of fault or acceptance of liability. Questions regarding this policy may be directed to MIT's Insurance Office, (617) 253-2823. Your insurance carrier may be billed for the cost of emergency transport or medical treatment, if such services are determined not to be directly related to your participation in this study.

- **RIGHTS OF RESEARCH SUBJECTS**

You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you feel you have been treated unfairly, or you have questions regarding your rights as a research subject, you may contact the Chairman of the Committee on the Use of Humans as Experimental Subjects, M.I.T., Room E25-143B, 77 Massachusetts Ave, Cambridge, MA 02139, phone 1-617-253 6787.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

____
Name of Subject

____
Name of Legal Representative (if applicable)

______________________________________ _____________
Signature of Subject or Legal Representative Date

SIGNATURE OF INVESTIGATOR

In my judgment the subject is voluntarily and knowingly giving informed consent and possesses the legal capacity to give informed consent to participate in this research study.

______________________________________ _____________
Signature of Investigator Date

Appendix A2: Background Questionnaire (Administered online)

Participant ID: ______

Background Questionnaire

Total flight hours (approximate):	
Total hours flown in previous 90 days (approximate):	
Total hours flown in previous 12 months (approximate):	
Total hours flown in Cessna 182	

Please list all of the certificates and ratings you hold.

Within the past year, what aircraft type do you have the most time in?

How much of your fixed wing flight experience was conducted in high wing versus low wing aircraft?

- All of my experience is in high wing aircraft
- I have some experience in low wing aircraft, but most of my experience is in high wing aircraft
- I have about equal experience in high wing and low wing aircraft
- I have some experience in high wing aircraft, but most of my experience is in low wing aircraft
- All of my experience is in low wing aircraft

How do you typically gain access to aircraft? (Check all that apply)

- Own
- Rent
- Fly Professionally (Please Specify)
- Other (Please Specify)

How often do you fly with Avidyne displays? (EX 500/600, EX 5000, Entegra, etc...)

- Never
- Rarely
- Occasionally
- Always

How often do you fly with TCAS (Traffic Collision and Alerting System)?

Note: TCAS provides traffic alerts *and resolution advisories* to pilots. TCAS is typically more often found in commercial aircraft.

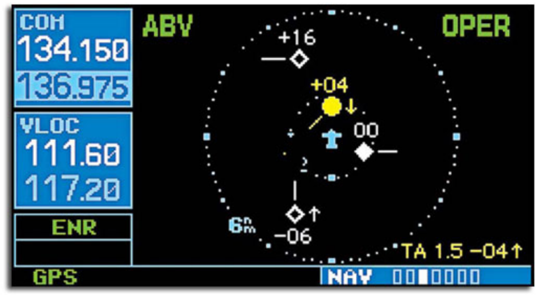
Example TCAS Display:

- Never
- Rarely
- Occasionally
- Always

How often do you fly with TAS (Traffic Advisory System)?

Note: TAS provides traffic alerts to pilots only (no resolution advisories). These systems are becoming more common on general aviation aircraft.

Example TAS Display:

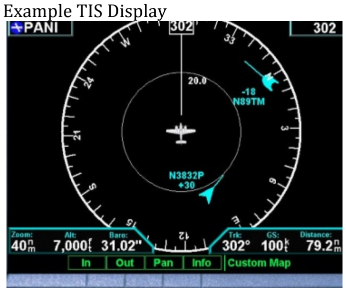


○ Never
○ Rarely
○ Occasionally
○ Always

How often do you fly with TIS (Traffic Information System)?

Note: TIS provides only traffic information. TIS does not provide traffic alerting or resolution advisories. These systems are common in general aviation aircraft.

Example TIS Display



○ Never
○ Rarely
○ Occasionally
○ Always

How often do you fly an ADS-B traffic display?

- Never
- Rarely
- Occasionally
- Always

Have you flown with any other traffic display? If so, please specify what other display and how often you fly with it.

Please use the following links to advise us when you would be available to participate. If you are able to participate in either Melbourne or Daytona Beach, please fill out both schedule links. Thank you.

Melbourne, FL http://doodle.com/3cbsudayz6cirhzt
Daytona Beach, FL http://doodle.com/ec5ymqnyatuifsd4

Please select the following choices, once you have filled out the link(s).

- **I have completed one or both of the schedule links above.**
- **I no longer wish to participate in the study**

Appendix A3: Background Information Provided to Participants

Thank you for participating in the ADS-B Traffic Alerting Display Human Factors Flight Testing conducted by the Massachusetts Institute of Technology.

Background:

Automatic Dependent Surveillance Broadcast (ADS-B) is a GPS based surveillance system that will be replacing radar as the primary surveillance method for air traffic control. This study examines the display design for a traffic situation awareness with alerts (TSAA) system based on ADS-B.

Overview:

During the experiment, you will be presented with scenarios in a C182 and instructed to fly a flight profile. You will be asked to verbalize any traffic concerns, scan for traffic and verbalize how you would respond when you deem it appropriate.

Throughout the flight, we will ask you various questions regarding your situation and response. At the end of the flight, you will be given a post-experiment questionnaire to provide feedback on the experiment. The experiment is expected to take about 3 hours.

During this experiment you may experience a display based system or an audio only system. You will be notified upon arrival at the experiment site which system you will be flying with. An overview of display symbology is provided below in the case you experience the display based system.

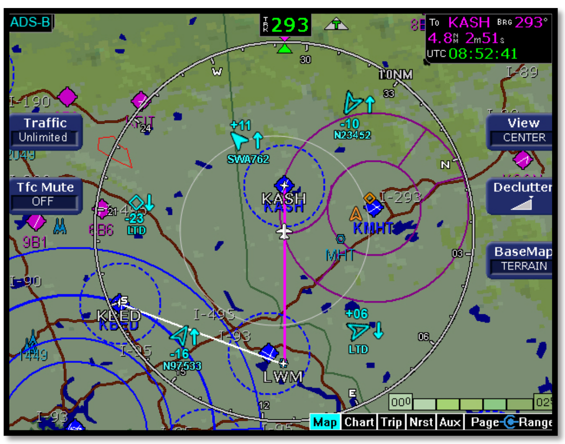


Figure 1. Example situation on Multi – Function Display with map background

The Alerting System:

The alerting system uses ADS-B to determine if a collision threat exists with another aircraft. To determine if a collision threat exists, the system calculates the range, altitude, bearing, and closure rate of all aircraft within range. Figure 2 illustrates a top down view of a sample conflict described below.

The Traffic Caution Alert is based on penetration of a variable sized cylinder around the target (depicted in yellow in Figure 2). The size is scaled based on closure rate. (i.e. when a threat has a high closure rate, the radius and altitude range is large and when the threat has a low closure rate, the radius and altitude range of the protected cylinder is small). Upon annunciation of the Traffic Caution Alert, penetration of the protected area is predicted to occur in 30 seconds or less.

A repeat of the Traffic Caution Alert is annunciated based on predicted penetration of a fixed size cylinder around the target (depicted in red in Figure 2). The radius of the protected cylinder is 500 feet and the altitude ranges +/- 200 feet.

The Traffic Caution Alert will be depicted with a caution symbol on the display. (Area 1 in Figure 3) Aural alerts will also annunciate for the alert voicing azimuth, range, and altitude, and vertical trend information (e.g. "Traffic, 3 o'clock, 2 miles, high, descending"). For the audio only system, a light will illuminate in your forward field of view whenever an alert is active.

In addition, the display differentiates nearby airborne traffic who are within 6nm, +/- 1,200 feet of your position with a filled symbol (Area 5 in Figure 3)

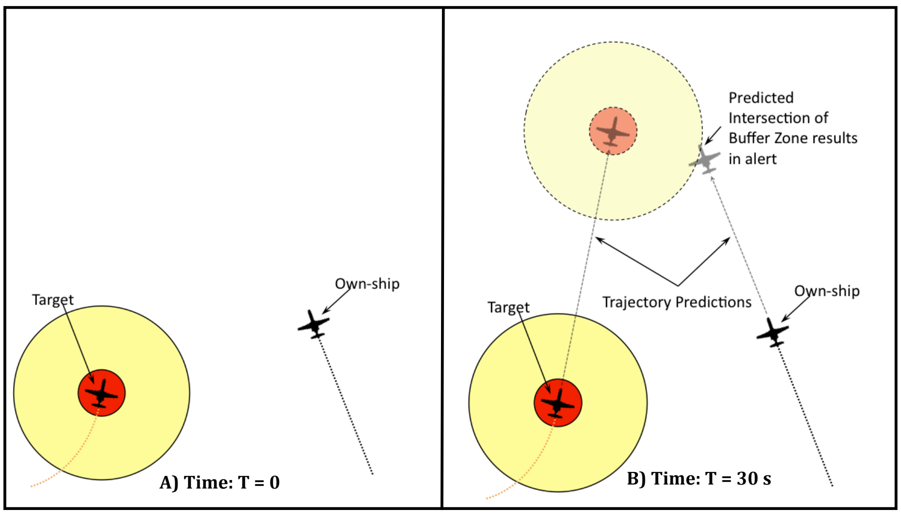


Figure 2. Alert Illustration

Non-Qualified Targets

There may be some aircraft where there is information available, however it is not good enough to provide an alert. These targets are referred to as non-qualified targets. These targets are differentiated on the display with a LTD designator on the data-tag.

Display Symbology

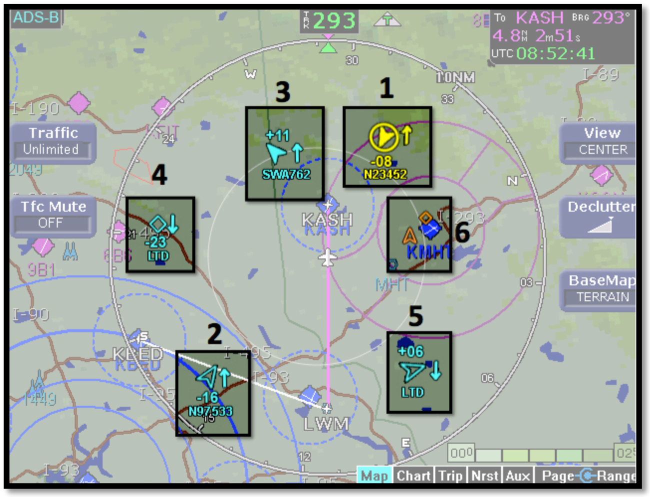


Figure 3. Display Symbology

Whenever the system has the appropriate valid information, it will display relative altitude (in hundreds of feet), vertical trend, and call sign. For example, Area 1 in Figure 3 shows an aircraft, N23452, that is 800 feet below you and climbing. Area 2 in Figure 3 shows an aircraft, N97533, that is 1600 feet below you and climbing.

1. (N23452) is **alert traffic**. Notice the symbol change compared to the depiction in Figure 1. This symbol change will be accompanied by an aural alert "Traffic, 1 o'clock, 6 miles, low. climbing" This specific traffic is 800 feet below you and climbing.
2. (N97533) is depicted as **non-alert traffic with directionality**. This specific traffic is shown 1,600 feet below you and climbing.
3. (SWA762) is **directional nearby airborne traffic**. The nearby airborne traffic symbology is designed to be consistent with TCAS; thus, the fill in a symbol designates that the target is within 6nm and +/- 1,200 feet of you. This specific traffic is shown 1,100 feet above you and climbing.
4. **Non-directional target** where directional information is not available. This specific traffic is shown 2,300 feet below you and descending. Note that this target is also non-qualified signified by the LTD in the call sign field.
5. **Non-qualified directional target**. This specific traffic is 600 feet above you and descending. As you can see with the LTD designator, you will not get an alert on this traffic.
6. **Ground targets**. One of the targets shows directionality while the other one does not and is represented with a non-directional diamond. You will not get alerts on ground targets.
7. (N245PK) is an **off scale alert target**. (Figure 4) In this case, the traffic on which an alert was given is outside of your current range. The symbol is placed at the relative bearing to the traffic along the compass rose.

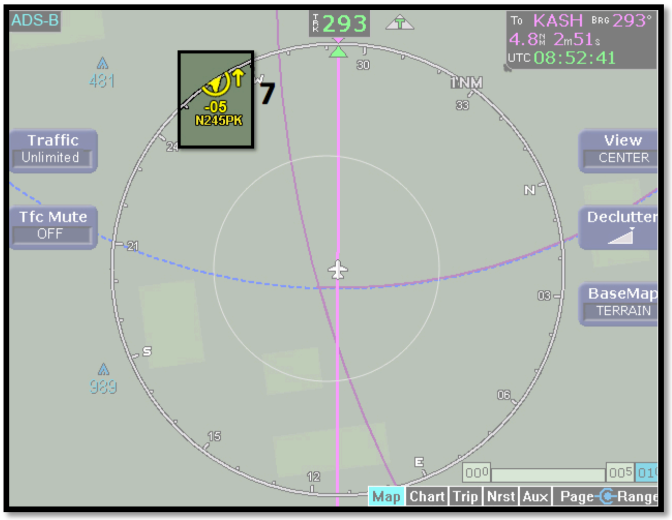


Figure 4. Off-Scale Traffic

4

Appendix A4: Instructions for Participants

Instructions to Participants

You will be instructed to fly specific flight profiles in a C182 for this experiment. You will be held to private pilot practical test standards for heading, altitude and airspeed.

The safety pilot (PIC) is responsible for safety of flight at all times and is the ultimate authority in the aircraft. Any exchange of controls, will be conducted using positive exchange of control procedures.

"You have the flight controls"
"I have the flight controls"
"You have the flight controls"

You are expected to:

- Verbalize any traffic concerns
- Verbalize when Scanning for Traffic
  - Say "**LOOKING for traffic"** plus the **bearing** . Example. "Looking for traffic at 10 o'clock"
  - Turn to look in the direction where you would scan
- Verbalize Visual Acquisition
  - State **"Traffic in Sight"** when traffic is acquired
- Verbalize that you would maneuver for traffic by stating, "Escape" whenever you would maneuver
  - Do NOT take evasive action, unless instructed to do so by the safety pilot

Throughout the flight, a human factors specialist will ask you various questions regarding the situation and your response.

Note: If you have any questions regarding aircraft handling, please ask your safety pilot.

Appendix A5. Subjective Evaluations

Appendix A5.1: Post-event Evaluation (Administered via in-flight interview)

Participant ID: ______

Post Event Questionnaire

Would you consider the alert to be a nuisance alert or appropriate alert?

◯ Nuisance	◯ Appropriate

Comments:

Would you have taken evasive action in this case? (Y/N) If so, how would you have maneuvered?

◯ Yes	◯ No

Comments:

Was the alert timely?

◯ Too Early	◯ Timely	◯ Too Late

Comments

(If traffic visually acquired) Please rate the accuracy of the location (clock position) and distance of the intruder provided in the alert.

◯ Not visually acquired	◯ Inaccurate	◯ Accurate

Comments

Appendix A5.2: Post-flight Evaluation (For Participants who Experienced Display System) (Administered online)

Participant ID# ______

Post Evaluation Questionnaire

1. Did you experience any problems using the system? If so, please explain.

○ YES	○ NO

Explain:

2. Were there any problems reading the traffic symbology on the map background? If so, please explain.

○ YES	○ NO

Explain:

3. Was display clutter a problem? If so, please explain.

○ YES	○ NO

Explain:

4. Please rate the aural alert in terms of clarity and speech rate.

○ Difficult to Understand	○ Neutral	○ Easy to Understand

Explain:

1

5. Did the alerts provide enough information to be useful?

○ Too little information	○ Right amount	○ Too much information
Explain:		

6. Did you feel like you could trust the alerts?

○ 1 Never	○ 2 Rarely	○ 3 Sometimes	○ 4 Very Often	○ 5 Always
Explain:				

7. Were there cases where the TSAA System missed genuine conflicts/risks?

○ 1 Never	○ 2 Rarely	○ 3 Sometimes	○ 4 Very Often	○ 5 Always
Explain:				

8. How appropriate did you find the alerts given?

○ Too Few (the system should have alerted on more traffic)	○ Just the right amount (the system alerted on the traffic which I considered as a threat and did not alert on traffic I did not consider as a threat)	○ Too many (the system should have alerted on less traffic)
Explain:		

2

9. Were there cases where you would have preferred more constant updates during an encounter?

○	○	○	○	○
1	2	3	4	5
Never	Rarely	Sometimes	Very Often	Always
If there were cases where you would have preferred more constant updates, please describe those cases:				

10. How useful did you find the indication of nearby airborne (filled in) traffic?

○	○	○	○	○
1	2	3	4	5
Always helped me identify the threat	Sometimes helped me identify the threat	Did not help **nor** hinder me in identifying the threat	Sometimes made it more difficult to identify the threat	Always made it more difficult to identify the threat

11. How useful did you find the indication of call sign information?

○	○	○
1	2	3
Always useful	Sometimes useful	Never used it

12. How often did the system interfere with normal ATC communications?

○	○	○	○	○
1	2	3	4	5
Never	Rarely	Sometimes	Very Often	Always
Explain:				

3

13. How often did the system interfere with other crew tasks?

○	○	○	○	○
1	2	3	4	5
Never	Rarely	Sometimes	Very Often	Always

Explain:

14. What was the best feature of the TSAA System?

15. What was the worst feature of the TSAA System?

16. What recommendations would you make for improving the design of the TSAA System?

17. Is TSAA a valuable safety system?

○ YES ○ NO

Explain:

18. If you own an aircraft, please answer question 18A (1 &2).
If you typically rent an aircraft, please answer question 18B (1 & 2).

A1. How much would you pay to install an MFD and ADS-B alerting system like this on your airplane?

- ◯ Less than $1,000
- ◯ $1,000 - $1,999
- ◯ $2,000 - $4,999
- ◯ $5,000 - $9,999
- ◯ $10,000 - $14,999
- ◯ $15,000 - $19,999
- ◯ More than $20,000
- ◯ Would Not Buy
- ◯ No Opinion

A2. How much would you pay to add the ADS-B traffic alerting onto an existing Multi-Function Display for your airplane?

- ◯ Less than $1,000
- ◯ $1,000 - $1,999
- ◯ $2,000 - $4,999
- ◯ $5,000 - $9,999
- ◯ $10,000 - $14,999
- ◯ $15,000 - $19,999
- ◯ More than $20,000
- ◯ Would Not Buy
- ◯ No Opinion

B1. If you rent, how much more would you pay per hour to have an MFD and ADS-B alerting system like this installed on the airplane you fly?

- ◯ $0
- ◯ $1 - $4
- ◯ $5 - $9
- ◯ $10 - $19
- ◯ $20 - $29
- ◯ $30- $49
- ◯ More than $50
- ◯ No Opinion

B2. If you rent, how much more would you pay per hour to have an ADS-B alerting system like this added to an existing Multi-Function Display on an airplane you fly?

- ◯ $0
- ◯ $1 - $4
- ◯ $5 - $9
- ◯ $10 - $19
- ◯ $20 - $29
- ◯ $30- $49
- ◯ More than $50
- ◯ No Opinion

19. Do you have any feedback regarding the experiment?

20. Additional Comments:

6

Appendix A5.3: Post-flight Evaluation (For Participants who Experienced Audio Based System) (Administered online)

Participant ID# ______

Post Evaluation Questionnaire

1. Did you experience any problems using the system? If so, please explain.

○ YES	○ NO

Explain:

2. Please rate the aural alert in terms of clarity and speech rate.

○ Difficult to Understand	○ Neutral	○ Easy to Understand
Explain:		

3. Did the alerts provide enough information to be useful?

○ Too little information	○ Right amount	○ Too much information
Explain:		

4. Did you feel like you could trust the alerts?

○ 1 Never	○ 2 Rarely	○ 3 Sometimes	○ 4 Very Often	○ 5 Always
Explain:				

1

5. Were there cases where the TSAA System missed genuine conflicts/risks?

○ 1 Never	○ 2 Rarely	○ 3 Sometimes	○ 4 Very Often	○ 5 Always
Explain:				

6. How appropriate did you find the alerts given?

○ Too Few (the system should have alerted on more traffic)	○ Just the right amount (the system alerted on the traffic which I considered as a threat and did not alert on traffic I did not consider as a threat)	○ Too many (the system should have alerted on less traffic)
Explain:		

7. Were there cases where you would have preferred more constant updates during an encounter?

○ 1 Never	○ 2 Rarely	○ 3 Sometimes	○ 4 Very Often	○ 5 Always
If there were cases where you would have preferred more constant updates, please describe those cases:				

8. How often did the system interfere with normal ATC communications?

○ 1 Never	○ 2 Rarely	○ 3 Sometimes	○ 4 Very Often	○ 5 Always
Explain:				

9. How often did the system interfere with other crew tasks?

○	○	○	○	○
1	2	3	4	5
Never	Rarely	Sometimes	Very Often	Always
Explain:				

10. How useful did you find the indication of vertical trend (climbing, descending, level) in the aural alert?

○	○	○
1	2	3
Always useful	Sometimes useful	Never used it
Explain:		

11. How useful did you find the alert repeat button?

○	○	○
1	2	3
Always useful	Sometimes useful	Never used it
Explain:		

12. How useful did you find the mute capability for the alert?

○	○	○
1	2	3
Always useful	Sometimes useful	Never used it
Explain:		

13. What was the best feature of the TSAA System?

3

14. What was the worst feature of the TSAA System?

15. What recommendations would you make for improving the design of the TSAA System?

16. Is TSAA a valuable safety system?

○ YES ○ NO

Explain:

17. If you own an aircraft, please answer question 17A .
If you typically rent an aircraft, please answer question 17B .

A1. How much would you pay to install an ADS-B alerting system like this on your airplane?

○ Less than $1,000
○ $1,000 - $1,999
○ $2,000 - $4,999
○ $5,000 - $9,999
○ $10,000 - $14,999
○ $15,000 - $19,999
○ More than $20,000
○ Would Not Buy
○ No Opinion

B1. If you rent, how much more would you pay per hour to have an ADS-B alerting system like this installed on the airplane you fly?

- ◯ $0
- ◯ $1 - $4
- ◯ $5 - $9
- ◯ $10 - $19
- ◯ $20 - $29
- ◯ $30- $49
- ◯ More than $50
- ◯ No Opinion

18. Do you have any feedback regarding the experiment?

19. Additional Comments:

Appendix A6: Symbology Pre-test (Administered online)

1. (Select the best answer) The following symbol represents:

a) Alert traffic that is directional and on-scale
b) Alert traffic that is directional and off-scale
c) Non-alert traffic that is directional
d) Non-alert traffic that is *not* directional
e) Nearby airborne traffic
f) On-Ground Traffic

2. (Select the best answer) The following symbol represents:

a) Alert traffic that is directional and on-scale
b) Alert traffic that is directional and off-scale
c) Non-alert traffic that is directional
d) Non-alert traffic that is *not* directional
e) Nearby airborne traffic
f) On-Ground Traffic

3. (Select the best answer) The following symbol represents:

a) Alert traffic that is directional and on-scale
b) Alert traffic that is directional and off-scale
c) Non-alert traffic that is directional
d) Non-alert traffic that is *not* directional
e) Nearby airborne traffic
f) On-Ground Traffic

4. (Select the best answer) The fill in the following symbol represents:

a) Alert traffic that is directional and on-scale
b) Alert traffic that is directional and off-scale
c) Non-alert traffic that is directional
d) Non-alert traffic that is *not* directional
e) Nearby airborne traffic
f) On-Ground Traffic

5. (Select the best answer) The following symbol represents:

a) Alert traffic that is directional and on-scale
b) Alert traffic that is directional and off-scale
c) Non-alert traffic that is directional
d) Non-alert traffic that is *not* directional
e) Nearby airborne traffic
f) On-Ground Traffic

6. (Select the best answer) The following symbol represents:

a) Alert traffic that is directional and on-scale
b) Alert traffic that is directional and off-scale
c) Non-alert traffic that is directional
d) Non-alert traffic that is *not* directional
e) Nearby airborne traffic
f) On-Ground Traffic

Question 2 of 7

Which of the traffic below will not get an alert even if it penetrates your protected areas? (Select all that apply)

☐ 

☐ 

☐ 

☐ 

☐ 

Appendix B

Human Factors Study Protocols

Appendix B1: Planned Encounter Flight Protocol

Human Factors Flight Testing Protocol – Planned Encounter Flight Testing

	Human Factors Specialist	Safety Pilot (Ownship)	Subject Pilot	Safety Pilot (Intruder)
PREFLIGHT	• Perform introductions • Review background information with participant • Administer symbology pre-test (if subject experiencing display system) • Conduct training **<u>Preflight Checks:</u>** Verify that the following are in the aircraft. ___ Voice recorders (2) ___ Patchcord cables (3) ___ Laptop (>half battery) ___ Headset with webcam and digital compass ___ USB Extender ___ AAA batteries ___ Clipboards (2) ___ Headsets (4 total) ___ Go Pro & mounts ___ Check charge on voice recorders (if flashing, replace batteries) ___ Verify fuel quantity ___ Record METAR/TAF	• Perform introductions • Perform preflight inspection • Record hobbs time	• Perform introductions • Sign Consent Form • Review background information • Take symbology pre-test (if experiencing display system • Participate in training	• Perform introductions • Perform preflight inspection • Record hobbs time

1

	Human Factors Specialist	Safety Pilot (Ownship)	Subject Pilot	Safety Pilot (Intruder)
ENGINE START/TAXI	_________ Engine Start Time **<u>Pre-Taxi Checks:</u>** ___ Turn on voice recorders ___ Press record on voice recorders ___ Time Sync Webcam ___ Begin recording webcam stream ___ Begin recording digital compass stream ___ Perform Manual Time Sync Protocol ___ Record engine start ___ Check alert volume • Remind subject pilot of verbalization & HF protocol • Remind subject to practice using zoom **<u>Pre-Takeoff Checks:</u>** ___ Verify voice recorders are recording ___ Verify time sync complete ___ Press Record for GoPro	• Confirm healthy state of aircraft • Conduct passenger briefing • Perform engine start checklist • Verify LAKE and THSHD are in GPS *LAKE:* 27° 49.40'N, 80° 42.45'W *THSHD :* 27° 58.64'N, 80° 46.18' W • Check alert volume • Call Clearance Delivery/Ground for taxi clearance • Monitor taxi of aircraft • Perform pre takeoff checklist • Review Encounter 1 Test Card • Contact grd/twr for run-up complete/ ready for departure	• Taxi aircraft complying with safety pilot instructions • Tune in MLB VOR into NAV 1, set OBS to 189 radial • Confirm understanding of HF protocol • Practice using zoom	• Confirm healthy state of aircraft • Conduct passenger briefing • Perform engine start checklist • Verify LAKE and THSHD are in GPS *LAKE:* 27° 49.40'N, 80° 42.45'W *THSHD :* 27° 58.64'N, 80° 46.18' W • Check alert volume • Call Clearance Delivery/Ground for taxi clearance • Taxi aircraft to runway • Perform pre takeoff checklist • Tune in MLB VOR into COM 1, set OBS to 189 radial • Review Encounter 1 Test Card • Contact grd/twr for run-up complete/ ready for departure

2

	Human Factors Specialist	Safety Pilot (Ownship)	Subject Pilot	Safety Pilot (Intruder)
INFLIGHT		• Obtain takeoff clearance • Monitor takeoff & climb • Identify MLB VOR morse code, monitor navigation • Request frequency change from MLB tower when outside MLB airspace • Switch frequency to air-air test frequency.	• Perform takeoff and climb to 2700 when able • When able intercept the MLB R189 radial southbound	• Obtain takeoff clearance • Monitor takeoff & climb • Identify MLB VOR morse code, monitor navigation • Request frequency change from MLB tower when outside MLB airspace • Switch frequency to air-air test frequency.
	• **RUN ENCOUNTER 1 TEST CARD** • Record time of scan • Record time of visual acquisition from safety pilot, HF specialist, and subject pilot • Record time of evasive action • Record type of evasive action • Administer post-event questionnaire	• **RUN ENCOUNTER 1 TEST CARD**	• Answer post-event questionnaire	• **RUN ENCOUNTER 1 TEST CARD**
	• **RUN ENCOUNTER 2 TEST CARD** • Record time of scan • Record time of visual acquisition from safety pilot, HF specialist, and subject pilot • Record time of evasive action • Record type of evasive action	• Vector subject pilot to ENCOUNTER 2 start point • **RUN ENCOUNTER 2 TEST CARD** • Instruct safety pilot to fly a counter clockwise pattern around the lake, beginning at the southeast edge. • Report "LAKE turning westbound" on air to air frequency when turning left at LAKE	• Fly vectors instructed by safety pilot • Fly counterclockwise pattern around the lake	• **RUN ENCOUNTER 2 TEST CARD**

3

	Human Factors Specialist	Safety Pilot (Ownship)	Subject Pilot	Safety Pilot (Intruder)
INFLIGHT	• Administer post-event questionnaire	• Report "WEST2 turning southbound" on air to air frequency when turning left at WEST2 • Report "SWLKE turning eastbound" on air to air frequency when turning left at SWLKE • Report "SOU4 turning northbound when turning left at SOU4"	• Answer post-event questionnaire	
	• **RUN ENCOUNTER 3 TEST CARD** • Record time of scan • Record time of visual acquisition from safety pilot, HF specialist, and subject pilot • Record time of evasive action • Record time of evasive action • Record type of evasive action • Administer post-event questionnaire	• Instruct subject pilot to re-intercept counter clockwise pattern around the lake • **RUN ENCOUNTER 3 TEST CARD** • Report "LAKE turning westbound" on air to air frequency when turning left at LAKE • Report "WEST2 turning southbound" on air to air frequency when turning left at WEST2 • Report "SWLKE turning eastbound" on air to air frequency when turning left at SWLKE • Report "SOU4 turning northbound when turning left at SOU4"	• Fly counterclockwise pattern around the lake • Answer post-event questionnaire	• **RUN ENCOUNTER 3 TEST CARD**

4

	Human Factors Specialist	Safety Pilot (Ownship)	Subject Pilot	Safety Pilot (Intruder)
INFLIGHT	• **RUN ENCOUNTER 4 TEST CARD** • Record time of scan • Record time of visual acquisition from safety pilot, HF specialist, and subject pilot • Record time of evasive action • Record type of evasive action • Administer post-event questionnaire	• Vector subject pilot to ENCOUNTER 4 start point • Instruct subject pilot to fly a left hand pattern for the simulated runway 32 • **RUN ENCOUNTER 4 TEST CARD** • Report "Turning left crosswind" • Report "Turning left downwind" • Report "Turning left base" • Report "Turning final"	• Fly vectors instructed by safety pilot • Fly left hand pattern for the simulated runway 32 • Answer post-event questionnaire	• **RUN ENCOUNTER 4 TEST CARD**
	• **RUN ENCOUNTER 5 TEST CARD** • Record time of scan • Record time of visual acquisition from safety pilot, HF specialist, and subject pilot • Record time of evasive action • Record type of evasive action • Administer post-event questionnaire	• Instruct subject pilot to re-enter left hand traffic pattern for simulated runway 32 • **RUN ENCOUNTER 5 TEST CARD** • Report "Turning left crosswind" • Report "Turning left downwind" • Report "Turning left base" • Report "Turning final"	• Fly left hand pattern for the simulated runway 32 • Answer post-event questionnaire	• **RUN ENCOUNTER 5 TEST CARD**

5

	Human Factors Specialist	Safety Pilot (Ownship)	Subject Pilot	Safety Pilot (Intruder)
INFLIGHT		• Set GPS course direct to KMLB • Instruct subject pilot to fly direct to KMLB • Confirm on air to air frequency, frequency change to MLB tower • Get MLB ATIS • Call MLB tower • Instruct subject pilot to descend and navigate to runway as necessary • Talk subject pilot through pattern and landing • Verify landing clearance RECEIVED • Monitor subject pilot flying and landing	• Fly direct to KMLB • Fly pattern for MLB • Perform landing	• Set GPS course direct to KMLB • Instruct subject pilot to fly direct to KMLB • Confirm on air to air frequency, frequency change to MLB tower • Get MLB ATIS • Call MLB tower • Descend and navigate to runway as necessary • Verify landing clearance RECEIVED

6

	Human Factors Specialist	Safety Pilot (Ownship)	Subject Pilot	Safety Pilot (Intruder)
TAXI/ENGINE SHUTDOWN	**<u>Pre-Shutdown Checks:</u>** ___ Perform manual time sync ___ Press stop on voice recorders ___ Turn off voice recorders ___ Stop recording webcam ___ Stop recording digital compass ___ Stop recording GoPro _____ Record Eng Shutdown Time **<u>Post-Shutdown Checks:</u>** ___ Record Hobbs ___ Remove laptop from aircraft for charging ___ Remove GoPro from aircraft for charging	• When clear of runway, perform post landing checklist • Obtain taxi clearance • Perform engine shutdown checklist	• Taxi aircraft back to parking	• When clear of runway, perform post landing checklist • Obtain taxi clearance • Taxi back to parking • Perform engine shutdown checklist
POSTFLIGHT	• Recap flight with participant • Conduct post-evaluation questionnaire • Answer any questions **<u>On Ground Checks:</u>** ___ Charge laptop ___ Charge Go Pro	• Record hobbs time • Check fuel quantity, refuel for next flight if necessary	• Recap flight • Perform post-evaluation questionnaire • Pose any questions to experimenter	• Record hobbs time • Check fuel quantity, refuel for next flight if necessary

7

Appendix B2: High Density Flight Protocol

Human Factors Flight Testing Protocol – High Density Ops Flight Testing

	Human Factors Specialist	Safety Pilot (Ownship)	Subject Pilot
PREFLIGHT	• Perform introductions • Review background information with participant • Administer symbology pre-test (if subject experiencing display system) • Conduct training **<u>Preflight Checks:</u>** Verify that the following are in the aircraft. ___ Voice recorders (2) ___ Patchcord cables (3) ___ Laptop (>half battery) ___ Headset with webcam and digital compass ___ USB Extender ___ AAA batteries ___ Clipboards (2) ___ Headsets (4 total) ___ Go Pro & mounts ___ Check charge on voice recorders (if flashing, replace batteries) ___ Verify fuel quantity	• Perform introductions • Perform preflight inspection • Record hobbs time	• Perform introductions • Sign Consent Form • Review background information • Take symbology pre-test (if experiencing display system • Participate in training

1

	Human Factors Specialist	Safety Pilot (Ownship)	Subject Pilot
ENGINE START/TAXI	_________ Engine Start Time **<u>Pre-Taxi Checks:</u>** ___ Turn on voice recorders ___ Press record on voice recorders ___ Time Sync Webcam ___ Begin recording webcam stream ___ Begin recording digital compass stream ___ Perform Manual Time Sync Protocol ___ Record engine start ___ Check alert volume • Remind subject pilot of verbalization & HF protocol **<u>Pre-Takeoff Checks:</u>** ___ Verify voice recorders are recording ___ Verify time sync complete	• Confirm healthy state of aircraft • Conduct passenger briefing • Perform engine start checklist • Call Clearance Delivery/ Ground for taxi clearance • Monitor taxi of aircraft • Perform pre takeoff checklist • Contact grd/twr for run-up complete/ ready for departure	• Taxi aircraft complying with safety pilot instructions • Confirm understanding of HF protocol
INFLIGHT	For each encounter: • Record time of scan • Record time of visual acquisition from safety pilot, HF specialist, and subject pilot • Record time of evasive action • Record type of evasive action • Administer post-event questionnaire	• Obtain takeoff clearance • Talk subject pilot through takeoff and climb • Brief subject pilot on pattern speeds • Monitor subject pilot's flight • Verify landing clearance RECEIVED • Talk subject pilot through landing • Monitor subject pilot's landing • REPEAT until 1 hour has passed in the traffic pattern.	• Perform takeoff stay in pattern • Perform touch and go • Answer post-event questionnaire (if applicable)

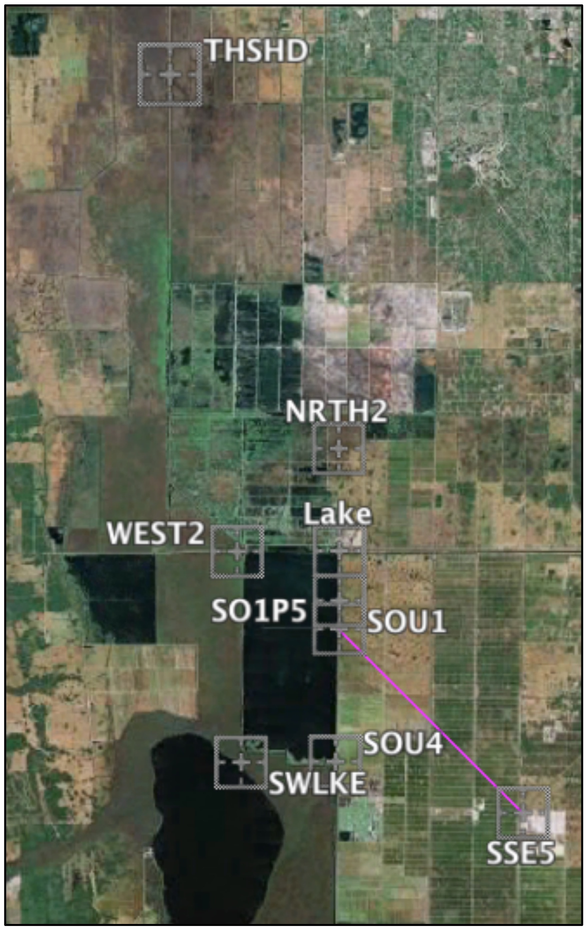
2

	Human Factors Specialist	Safety Pilot (Ownship)	Subject Pilot
TAXI/ENGINE SHUTDOWN	**<u>Pre-Shutdown Checks:</u>** ___ Press stop on voice recorders ___ Turn off voice recorders ___ Stop recording webcam ___ Stop recording digital compass **<u>Post-Shutdown Checks:</u>** ___ Record Hobbs ___ Remove laptop from aircraft for charging ___ Remove GPS Go Pro from aircraft for charging	• When clear of runway, perform post landing checklist • Obtain taxi clearance • Perform engine shutdown checklist	• Taxi aircraft back to parking
POSTFLIGHT	• Recap flight with participant • Conduct post-evaluation questionnaire • Answer any questions **<u>On Ground Checks:</u>** ___ Charge laptop ___ Charge GoPro	• Record hobbs time • Check fuel quantity, refuel for next flight if necessary	• Recap flight • Perform post-evaluation questionnaire • Pose any questions to experimenter

Appendix C

Planned Encounter Test Cards

Appendix C1: Planned Encounter Waypoints



Florida				
LAKE	KMLB 195/018	27° 49.400'N	80° 42.450'W	Anchor point for KMLB algorithm tests
NRTH3	3 nm north of LAKE	27° 52.400'N	80° 42.450'W	
NRTH3	5 nm north of LAKE	27° 54.400'N	80° 42.450'W	
SOP33	0.33 nm south of LAKE	27° 49.070'N	80° 42.450'W	Turn point for 2000' parallel course to WEST5-LAKE-EAST5
SOU1	1 nm south of LAKE	27° 48.400'N	80° 42.450'W	
SO1P5	1.5 nm south of LAKE	27° 47.900'N	80° 42.450'W	
SOU2	2 nm south of LAKE	27° 47.400'N	80° 42.450'W	
SOCTR	2.5 nm south of LAKE	27° 46.900'N	80° 42.450'W	
SO3P3	3.3 nm south of LAKE	27° 46.100'N	80° 42.450'W	
SO3P5	3.5 nm south of LAKE	27° 45.900'N	80° 42.450'W	
SOU5	5 nm south of LAKE	27° 44.400'N	80° 42.450'W	
EAST1	1 nm east of LAKE	27° 49.400'N	80° 41.310'W	
EAST2	2 nm east of LAKE	27° 49.400'N	80° 40.170'W	
EAST3	3 nm east of LAKE	27° 49.400'N	80° 39.030'W	
EAST4	4 nm east of LAKE	27° 49.400'N	80° 37.890'W	
EAST5	5 nm east of LAKE	27° 49.400'N	80° 36.750'W	
WEST5	5 nm west of LAKE	27° 49.400'N	80° 48.150'W	
SWP33	0.33 nm south of WEST5	27° 49.070'N	80° 48.150'W	
SEP33	0.33 nm south of EAST5	27° 49.070'N	80° 36.750'W	
SE3	3 nm southeast of LAKE	27° 47.275'N	80° 40.042'W	3 nm from LAKE on 45-degree intercept to WEST5-EAST5 course
SE4	4 nm southeast of LAKE	27° 46.571'N	80° 39.234'W	4 nm from LAKE on 45-degree intercept to WEST5-EAST5 course
SE5	5 nm southeast of LAKE	27° 45.874'N	80° 38.430'W	5 nm from LAKE on 45-degree intercept to WEST5-EAST5 course
VPFFU	14 nm southeast of KDAB	28° 57.084'N	81° 00.336'W	Anchor for PHC3 KDAB data collection point
MCOTP	MCO 095/015	28° 25.640'N	81° 01.650'W	Anchor for PHC3 KMCO data collection point
WEST2	2 nm west of LAKE	27°49'23.45"N	80°44'42.20"W	
SWLKE	Southwest Corner of lake	27°45'18.11"N	80°44'36.67"W	
SOU4	4 nm south of LAKE	27°45'19.28"N	80°42'32.84"W	
NRTH2	2 nm north of LAKE	27°51'23.56"N	80°42'28.86"W	
SSE5	5 nm SE of SO1P5	27°44'19.43"N	80°38'26.54"W	5 nm from SO1P5 on 45-degree intercept to course
THSHD	Threshold of Simulated Runway	27°58'38.63"N	80°46'11.21"W	

Appendix C2: Scenario 1 Test Card – Horizontal Low Closure Rate Encounter

TSAA Human Factors Tests

Link Type **ADS-B**	Ownship Alt/Climb Rate **2700 ft/0 FPM**	Intruder Alt/Climb Rate **2700 ft/0 FPM**
Test Location **MLB**	Ownship Speed **115 KIAS**	Intruder Speed **130 KIAS**
	Ownship MC/Turn Rate **189 deg/no turn**	Intruder MC/Turn Rate **189 deg/no turn**

Test Point AHF1 – Low Horizontal Closure Rate

A) Ownship departs MLB and intercepts the MLB 189 radial, climbs to 2,700 feet.

B) Intruder departs following ownship and also intercepts MLB 189 radial southbound, climbs to 2,700.

Start point – **MLB R-189 DME6**
End point – **TPSTR**

Intruder reports when set up does not go as planned. (No call assumes run will proceed as planned)

C) HF specialist records run start time: _______________

D) Intruder closes on Ownship, maintaining visual contact, adjusting speed to force alert before TPSTR (MLB R189 DME 16)

E) Minimum distance: **0.1nm**

F) **Breakaway if intruder loses visual contact with Ownship within 0.25nm.**

G) Following alert annunciation, intruder will change course, and ownship will remain on previous course.

H) Once aircraft establish adequate separation following breakaway, **ownship** and **intruder** proceed to Encounter 2 start points.

NOTES

Altitudes as required to maintain VFR conditions and comply with FAR 91.159 if necessary.

One crewmember will maintain outside visual contact at all times

If visual contact is lost after start of run, Intruder will call "BREAKAWAY" via VHF comm (test frequency) and execute breakaway maneuver -

- Ownship – **UP and LEFT – Heading 090**
- Intruder – **DOWN and RIGHT – Heading 270**

Planned time of encounter (from run start to termination): *10 min*

Test Frequency:

Pilot/FTE Observations

Appendix C3: Scenario 2 Test Card – Vertical High Closure Rate Encounter

TSAA Human Factors Tests		
Link Type **ADS-B**	Ownship Alt/Climb Rate **2700/0 FPM**	Intruder Alt/Climb Rate **OS+1000/-1000 FPM**
Test Location **MLB**	Ownship Speed **115 KIAS**	Intruder Speed **130 KIAS**
	Ownship MC/Turn Rate **186 deg/no turn**	Intruder MC/Turn Rate **231 deg/no turn**

Test Point AHF2 – High Vertical Closure Rate, 45 deg Intercept

A)	Both aircraft proceed to run start points. Both aircraft establish both aircraft on test altitude/speed/heading. Ownship start point – **WEST2** Ownship end point **– SWLKE** Intruder start point – **LAKE**
B)	Ownship starts counterclockwise path around lake. **Intruder altitude 1000 feet above ownship.**
C)	Once ownship reports "WEST2 Southbound" and intruder is established at LAKE, intruder confirms visual contact with ownship and calls "START RUN" and proceeds south-westbound to intercept the ownship at on the west side of the lake.
D)	HF specialist records run start time: ______________
E)	Intruder closes on Ownship, maintaining visual contact. **At LAKE, Intruder begins 1000 FPM descent to force alert from above.** Minimum distance: **0.1nm** **Breakaway if Intruder does not establish visual contact before LAKE, or loses visual contact with Ownship at any time thereafter.**
F)	Following alert annunciation, intruder will proceed to Encounter 3 start point, and ownship continues counterclockwise pattern around the lake.

NOTES

Altitudes as required to maintain VFR conditions and comply with FAR 91.159 if necessary.

One crewmember will maintain outside visual contact at all times

If Intruder has not established visual contact prior to LAKE, or loses visual contact thereafter, Intruder will call "BREAKAWAY" via VHF comm (test frequency) and execute breakaway maneuver –

- Ownship – **DOWN and LEFT – Heading 090**
- Intruder – **UP and RIGHT – Heading 270**

Planned time of encounter (from run start to termination): *3 min*

Test Frequency:

Pilot/FTE Observations

Appendix C4: Scenario 3 Test Card – Head On Encounter

TSAA Human Factors Tests		
Link Type **ADS-B**	Ownship Alt/Climb Rate **2700/0 FPM**	Intruder Alt/Climb Rate **2500/0 FPM**
Test Location **MLB**	Ownship Speed **115 KIAS**	Intruder Speed **115 KIAS**
	Ownship MC/Turn Rate **006 deg/no turn**	Intruder MC/Turn Rate **186 deg/no turn**

Test Point AHF3 – Head On, Medium Closure Rate

A)	Ownship continues to fly around the lake edge counter clockwise. Intruder proceeds to intruder start point. Ownship start point – **SOU4** Run Center Point – **SOU1** Intruder start point – **NRTH2**
B)	Once ownship reports "SOU4 Northbound" and intruder is established at NRTH2: • Ownship confirms visual contact with intruder • Intruder confirms visual contact with ownship and calls "START RUN" and proceed southbound to intercept the ownship.
C)	HF specialist records run start time: ______________
D)	Each aircraft establish ground track **RIGHT** of lake edge or canal aligned with GPS course to SOU1 Minimum distance: **200 ft vertical, 0.1nm horizontal** **Breakaway if no visual acquisition within 1 nm separation.**
E)	Following encounter, intruder will break right and proceed to Encounter 4 start point at 2,500 feet, and ownship proceeds to simulated runway and enters left traffic pattern.

NOTES

Altitudes as required to maintain VFR conditions and comply with FAR 91.159 if necessary.

One crewmember will maintain outside visual contact at all times

If visual contact is not established by 0.5 nm to Run Center or is lost thereafter (or within 1 nm separation), both aircraft will call "BREAKAWAY" via VHF Comm (test frequency) and execute breakaway maneuver –

- Ownship – **UP and RIGHT – Heading 090**
- Intruder – **DOWN and RIGHT – Heading 270**

Planned time of encounter (from run start to termination): *2 min*

Test Frequency:

Pilot/FTE Observations

Appendix C5: Scenario 4 Test Card – Overtaking on Final Encounter

TSAA Human Factors Tests		
Link Type **ADS-B**	Ownship Alt/Climb Rate **As Req/-500 FPM**	Intruder Alt/Climb Rate **As Req/-1500 FPM**
Test Location **MLB**	Ownship Speed **80 KIAS**	Intruder Speed **130 KIAS**
	Ownship MC/Turn Rate **090 deg/no turn**	Intruder MC/Turn Rate **090 deg/no turn**
Test Point AHF4 – Overtaking on Final		

A)	Ownship fly left hand pattern to simulated runway 09. (Staying at pattern altitude until final) Intruder proceed to FNL4 and circle at 2000 feet. Ownship start point – **FNL1 (1 mile final from THSHD)** Intruder start point – **FNL3 (3 mile final from THSHD)**
B)	Ownship reports turning base for 09, Intruder proceeds inbound to FNL3.
C)	Ownship reports turning final for 09, Intruder confirms visual contact with ownship and calls "START RUN", intruder begins steep descent toward runway. Minimum distance: **0.1nm** **Breakaway if no visual acquisition within 0.5 nm separation.**
D)	HF specialist records run start time: ______________
E)	Once alert annunciates, **ownship** continues flying the pattern, **intruder** proceeds left to Encounter 5 start point.

NOTES

Altitudes as required to maintain VFR conditions and comply with FAR 91.159 if necessary.

One crewmember will maintain outside visual contact at all times

If intruder loses visual contact within 3 mile final, intruder will call "BREAKAWAY" via VHF Comm (test frequency) and execute breakaway maneuver –

- Ownship – **GO AROUND, BREAK RIGHT – Heading 180**
- Intruder – **GO AROUND, BREAK LEFT – Heading 360**

Planned time of encounter (from run start to termination): *2 min*

Test Frequency:

Pilot/FTE Observations

Appendix C6: Scenario 5 Test Card – Entry vs. Downwind Encounter

TSAA Human Factors Tests		
Link Type **ADS-B**	Ownship Alt/Climb Rate **1100/0 FPM**	Intruder Alt/Climb Rate **1100/0 FPM**
Test Location **MLB**	Ownship Speed **90 KIAS**	Intruder Speed **90 KIAS**
	Ownship MC/Turn Rate **270 deg/no turn**	Intruder MC/Turn Rate **225 deg/no turn**
Test Point AHF5 – Entry vs. Downwind		

A)	Ownship fly left hand pattern to simulated runway 09. Intruder proceed to 3 NE of THSHD and circle at 1500 feet. Ownship start point – **Crosswind Turn** Intruder start point – **3 NE of THSHD**
B)	Ownship reports turning crosswind for 09, Intruder confirms visual contact with ownship and calls "START RUN", Intruder descends to 1,100 feet and proceeds inbound to midfield downwind. Minimum distance: **0.1 nm** **Breakaway if no visual acquisition within 0.5 nm separation.**
C)	HF specialist records run start time: ______________
E)	Following encounter, **ownship** and **intruder** fly back to KMLB independently.

NOTES

Altitudes as required to maintain VFR conditions and comply with FAR 91.159 if necessary.

One crewmember will maintain outside visual contact at all times

For co-altitude intercept, if visual contact is not established within 0.5 nm separation (or lost thereafter), intruder will call "BREAKAWAY" via VHF Comm (test frequency) and execute breakaway maneuver –

- Ownship – **UP and LEFT – Heading 180**
- Intruder – **DOWN and RIGHT – Heading 360**

Planned time of encounter (from run start to termination): *2 min*

Test Frequency:

Pilot/FTE Observations

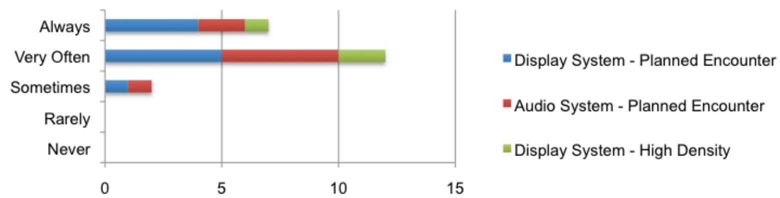
Appendix D

Subjective Feedback

Appendix D1: Alerting

Trust

Did you feel like you could trust the system?



- **Display – Planned Encounter Comments:**
  - "Alerts were late (2) and sometimes came from areas I thought to be devoid of traffic as I had scanned the area just previously. Again no development observed on the screen."
  - "The traffic called out was accurate so I learned to trust it pretty quickly"
  - "I did not get any false alerts."
  - "I have zero doubts about the accuracy of the system. I would say this one would be more accurate than the TIS systems I have dealt with."
  - "Lack of noise cancelling headset made it difficult to hear."
- **Audio – Planned Encounter Comments:**
  - "There were a few 'traffic pattern' alerts that seemed to be a distraction on landing, trying to visually acquire the target might have lead to a loss of control of the aircraft. I did ignore an alert of traffic behind us in the landing pattern and made no attempt to locate it."
  - "A couple of the alerts were later than expected (2)."
  - "Hardware can fail. This is a great tool but human self intervention has its value."
  - "Trusting the alerts was difficult without a visual sighting of the plane. I would assume it would get better the more you used it."
  - "accurate, reliable"
  - "Once you get used to the tendencies of the system, yes. If you have experience using the current TIS and know how it gives false alerts about your aircraft, then you might think it's just you and one of "those" alerts"
- **Display – High Density Comments:**
  - "The alerts were accurate."
  - "A few aircraft were encountered that did not display on the traffic alert system, however the alert system did make an excellent supplement to normal VFR visual traffic scanning"

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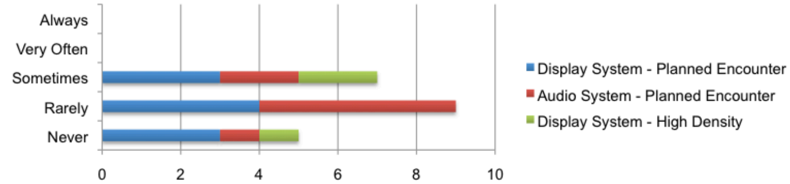
Missed Alerts

Does the system miss genuine threats?



- **Display – Planned Encounter Comments**
  - "Would be nice if scale would automatically scale down as any traffic gets close. That way if you are on a large map the threat does not look like it is right on top of you when it is announced and you could make better decisions."
  - "Planes equipped without transponders or ADS-B will never be picked up on this system."
  - "Sometimes saw plane and had no display or audio. Other times the display traffic disappeared. We had sporadic problems with the equipment."
  - "it did not pick up an airplane that was over the square lake about 1000 feet below"
  - "I didn't notice any traffic that wasn't alerted, just sometimes the alerts were later that I would have liked." (2)
  - "I felt confident the system was picking up all conflicts. "
- **Audio – Planned Encounter Comments**
  - "I didn't notice any traffic that wasn't alerted, just sometimes the alerts were later that I would have liked."
  - "Did not miss on this test. How would I know otherwise? Based on usage very very good and I am confident that it would not miss conflicts."
- **Display – High Density Comments**
  - "Some visually observed traffic was not displayed."
  - "At times there was traffic that it did not pick up and made me nervous."

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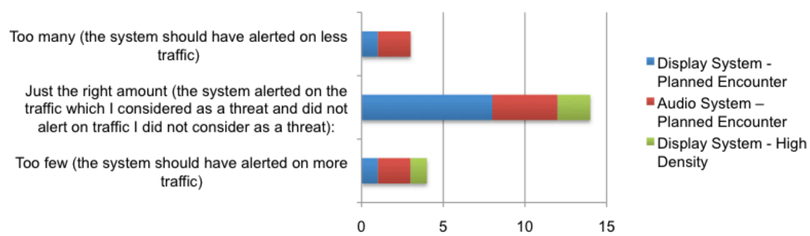
Appropriateness of Alerts

How appropriate did you find the alerts given?



- **Display – Planned Encounter Comments**
  - "The system gave ground traffic while we were on the ground."
  - "Traffic seemed to pop up late and close. Again, better position of the screen and a screen easier to read."
  - "It was annoying on the ground to get aural warnings - display is ok"
  - "The traffic that was called out was close"
  - "Again, during high workload periods, I think there was perhaps too much aural information. But, all alerts were appropriate given the speed and proximity of the traffic."
- **Audio – Planned Encounter Comments**
  - "There were alerts while on the ground which were annoying; alerts of traffic behind might have benefitted from more information about closure rate."
  - "There were a couple of times when traffic was seen visually but there was no alert. This may have been caused by problems with the system."
  - "It could have been deactivated on the ground."
  - "Head on risks appear to happen very fast. Earlier warning for head on would be of value."
  - "only alerts you when it is a threat"

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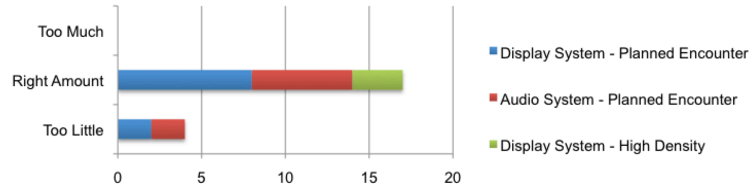
Alert Information

Did the alerts provide enough information to be useful?



- **Display – Planned Encounter: Comments:**
  - "Display of target and target information needs to enlarge as it becomes a threat."
  - "Aural alerts did not seem to always correlate with the developments on the screen. Perhaps I missed the traffic developing on the screen due to poor position and small symbols"
  - "I liked that the direction was the first thing said. I did notice that sometimes, as soon as she stated the direction I was immediately looking for the traffic in that direction and noticed that I missed the altitude."
  - "During high workload periods, such as in the traffic pattern, I think there was too much information. Otherwise, there was an appropriate amount of information."
- **Audio – Planned Encounter: Comments:**
  - "Would have been nice to hear 'closing fast' on a fast converging target. Would be most helpful to determine a need for evasive action with targets from behind that are not easy to visually acquire."
  - "The alerts were generally timely and had accurate info. They gave accurate info for where to look."
  - "exactly what you need to know"
  - "The most important thing is direction to immediately start looking that way, and then whether to look up or down. I missed the distance a few times"

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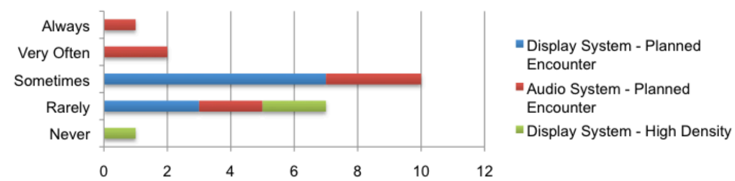
Aural Updates

Were there cases where you may have preferred more constant aural updates on traffic during an encounter



- **Display – Planned Encounter: Comments:**
  - "Have the frequency of updates increase as threat increases."
  - "Earlier warning"
  - "Could have been more often at greater distance when there is a high closure rate and a high likelihood of a collision."
  - "In the high wing it was hard to see the traffic above and behind me. If the system knew blind spots for your aircraft so that it would alert those differently and more often that may be helpful. same applies to traffic on close pattern work. maneuvering near the ground, I would like to concentrate on landing the plane. if the traffic would update me on the converging traffic more often, especially for blind spot areas, it may help me to make a decision for evasive maneuvering."
  - "When the traffic was coming from the rear I would have liked an update on the position of the traffic."
  - "I feel that if traffic was very close, just in case the pilot did not have a target in sight, brief position updates could be a good idea. On the same target, perhaps updates in intervals could be useful."
  - "Approaching the airport."
  - "If I visually could pick them up its is fine, but more guidance would be helpful until then"
- **Audio – Planned Encounter: Comments:**
  - "If a target is moving across different angles, a higher update rate might be useful - i.e. 'Traffic 2 o-clock' which becomes 'Traffic "Now" 1 o-clock' would imply it is the same target now at a new position"
  - "The alerts were often enough to give good guidance. More often would have been distracting."
  - "Since I found the need to repeat most messages I am of the opinion that more updates would be better."
  - "Many times I felt there was a long lag between the time I was alerted and the next alert. I would have liked to have known how serious the treat was in many cases too."
  - "becomes repetitive, mute option is helpful, brings your attention to the traffic"
  - "The traffic behind me since in a Piper aircraft unlike Cessna with the back window, you cannot see behind you. I had to remember that I was able to turn around and look. In a Piper Warrior, you really have no option besides to turn away a little and look if you can. It would be cool if it could give you more updates on distance as it gets closer, and maybe even differ in the intensity of the alert as the threat becomes more imminent."

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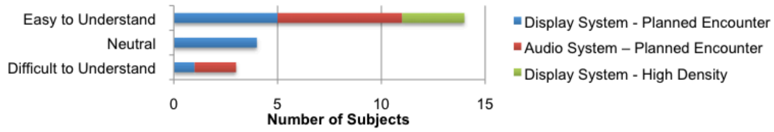
Aural Alert Clarity



Display – Planned Encounter: Comments:

- "Not always difficult, but certain words ("Same" altitude) were not clear to me" (2)
- "Voice came through cabin speaker and I could hear it through the headset. Obviously better if it came through the headset."
- "The voice was easy to understand. Some other aural warning systems I have used have panic in the voice. The rate was good"
- "I understood everything that was announced."

Audio – Planned Encounter: Comments:

- "Pacing of speech was good, clear and easy to understand"
- "Easy to understand. Volume was just right"
- "The phrase "Same Altitude" not good. Perhaps "Your altitude" would be better. I needed to repeat messages. If I had a choice I would have a parameter setting to automatically say it twice OR something to grab my attention first then the warning message."
- "I am sure if I had it mounted in my plane I would understand more clearly what the alert was telling me. When it said descend I was not clear if it was telling me to descend or if it was telling me the other plane was descending."

Display – High Density: Comments:

- "It was easy to understand. At times not sure if the system was saying less or left."

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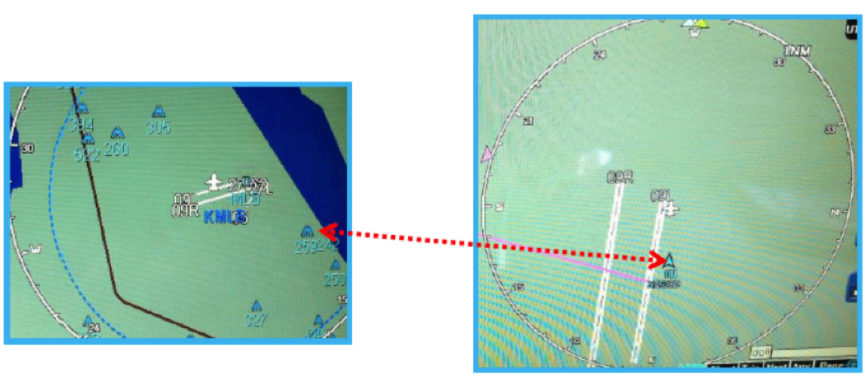
Appendix D2: Readability

Post - Flight Feedback Readability

- **Symbol size too small**
- **Font size on relative altitude, call sign, and vertical trend arrow too small**
- **Obstacle shape and color interfered with cyan target symbol**
- **Background map color also interfered with cyan target symbol color**
- **Screen mounted too low**



*Photos courtesy of R. Joslin

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Appendix D3: Design feature value

Mute Functionality

- **How useful did you find the repeat capability of the system?**

	Audio System - Planned Encounter
Never used it	7
Sometimes useful	1
Always useful	0

- **Comments**
  - "Did not find a reason to mute alerts."(2)
  - "It is helpful when you are looking for traffic, some pilots could use it just to avoid being annoyed by the system and disregard the traffic."
  - "Didn't really need it. Possibly in a very congested airspace, or one where you are talking to ATC and they are currently talking to you or giving you a direction to go. Or if you are already talking to the other pilot if they happen to be on frequency."
- **Experimenter Observation:**
  - While one subject didn't remember doing so, he did mute an alert on the ground while holding short of the runway.

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Repeat Functionality

- **How useful did you find the repeat capability of the system?**

	Audio System - Planned Encounter
Never used it	4
Sometimes useful	2
Always useful	2

- **Comments**
  - "Only tested on the ground, I don't recall using it in flight."
  - "The repeat button is very useful for times when the pilot was busy. Being able to repeat the alert was very useful."
  - "Needed it. The first message was a jolt. The repeat made it sink in."
  - "it was clear enough the first time"
  - "Flying the plane is always the priority. I almost even forgot it was there, but it's better to keep your eyes outside looking for the traffic, or on the traffic rather than looking for that button. It would be much nicer to have a very simple LCD display that could indicate climb, descent, level, the direction to look in, and how far, and possibly speed or time to collision"

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Call Sign

- **How useful did you find the call sign information on the display?**

	Display System - Planned Encounter	Display System - High Density
Never used it	6	2
Sometimes useful	3	1
Always useful	1	

Proximate Traffic

- **How useful did you find the indication of proximate traffic on the display?**

	Display System - Planned Encounter	Display System - High Density
Always helped me identify the threat	4	2
Sometimes helped me identify the threat	6	1
Did not help nor hinder me in identifying the threat.		
Sometimes made it more difficult to identify the threat.		
Always made it more difficult to identify the threat.		

Vertical Trend

- **How useful did you find the indication of vertical trend (climbing, level, descending) in the aural call out of traffic?**

	Audio System - Planned Encounter
Never used it	1
Sometimes useful	1
Always useful	6

- **Comments**
  - "Useful to know what the target aircraft is doing to determine if evasive action is required."
  - "Gives you a better idea of what the traffic is doing, very helpful to determine what evasive action to take"
  - "If it's climbing, or descending it's nice to know because you can gauge if it is going to miss you or not. Level coming at you is obviously a problem."

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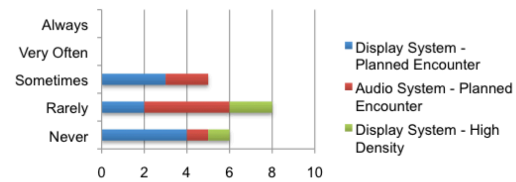
Appendix D4: TSAA Interference

Interference with ATC Communication

How often did the system interfere with normal ATC communication?



- **Display – Planned Encounter Comments**
  - “ATC not available on test aircraft.”
  - “On the ground during taxi and takeoff. Need an easy way to mute it.”
  - “Could see this becoming an issue if you are talking to ATC flying IFR.”
  - “I was not communicating with ATC. Previous experience with other traffic systems have interfered with ATC instructions, especially in the pattern.”
  - “This only occurred on the final approach and while taxiing”
  - “If the plane is calling final and an alert happened then I could miss relevant information”
- **Audio – Planned Encounter Comments**
  - “Did not experience any issues with this, I was not talking to ATC, the PIC was.”
- **Display – High Density Comments**
  - “Once or twice the alert was loud and would cut off the ATC.”
  - “Only once, during climb-out on upwind, the system picked up traffic on downwind during ATC communication with our aircraft.”
  - “The potential is there, likely is fixed if mute is used.”

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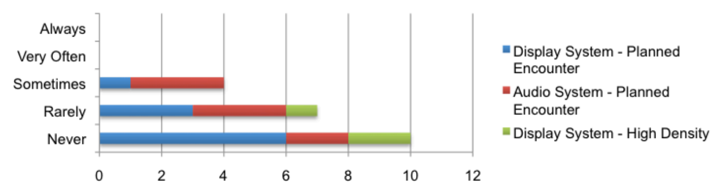
Interference with Crew Tasks

How often did the system interfere with other crew tasks?



- **Display – Planned Encounter Comments**
  - “Traffic scan is a very high priority and this is just another tool for that job.”
  - “I didn't have issues managing cockpit tasks. the audible alerts help to to have to scan the traffic display”
  - “When it was more distracting, such as in the traffic pattern, performance did drop. During low workload periods, I felt I had a higher success rate locating the traffic.”
  - “Since both pilots could hear, they could work around it”
- **Audio – Planned Encounter Comments**
  - “The occasional resets and need to restart the test equipment caused minor altitude drifts while reinitializing the test equipment.”
  - “Traffic alerts in the traffic pattern were timely, but could cause distraction. Training in the use during high pilot workloads would be helpful.”
  - “Had to divide my attention while in traffic pattern, wasn't completely focused on flying the airplane”

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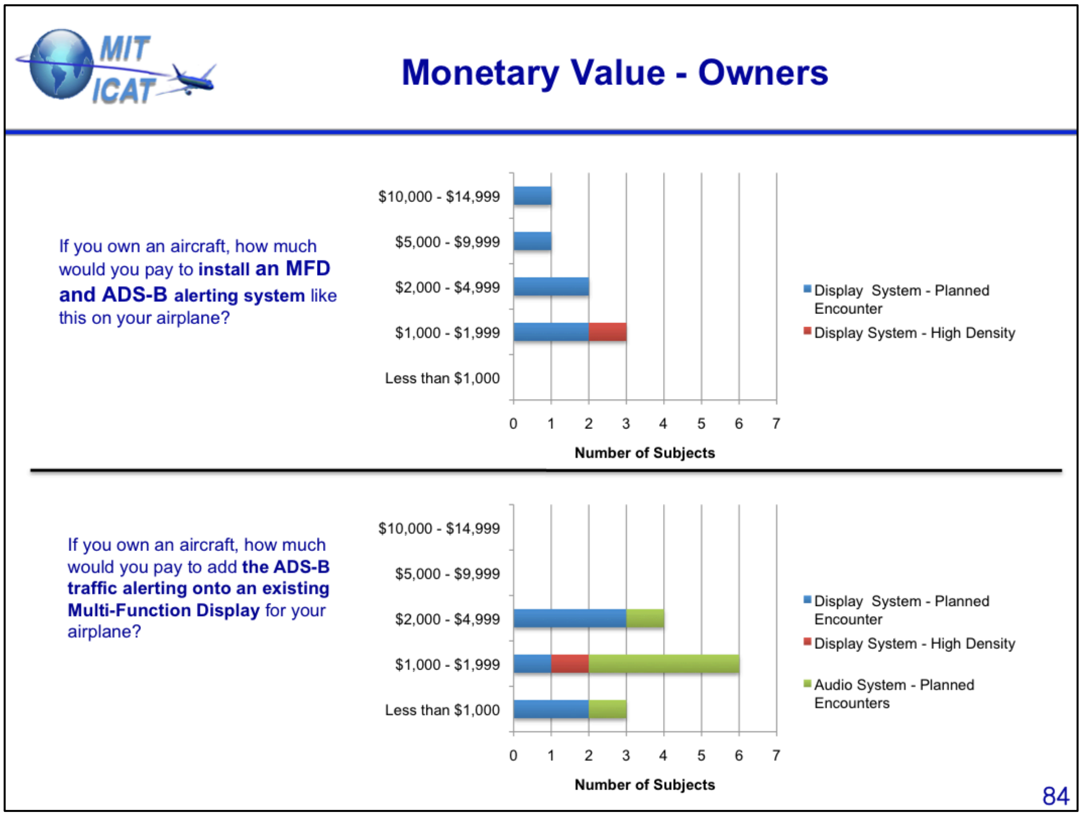
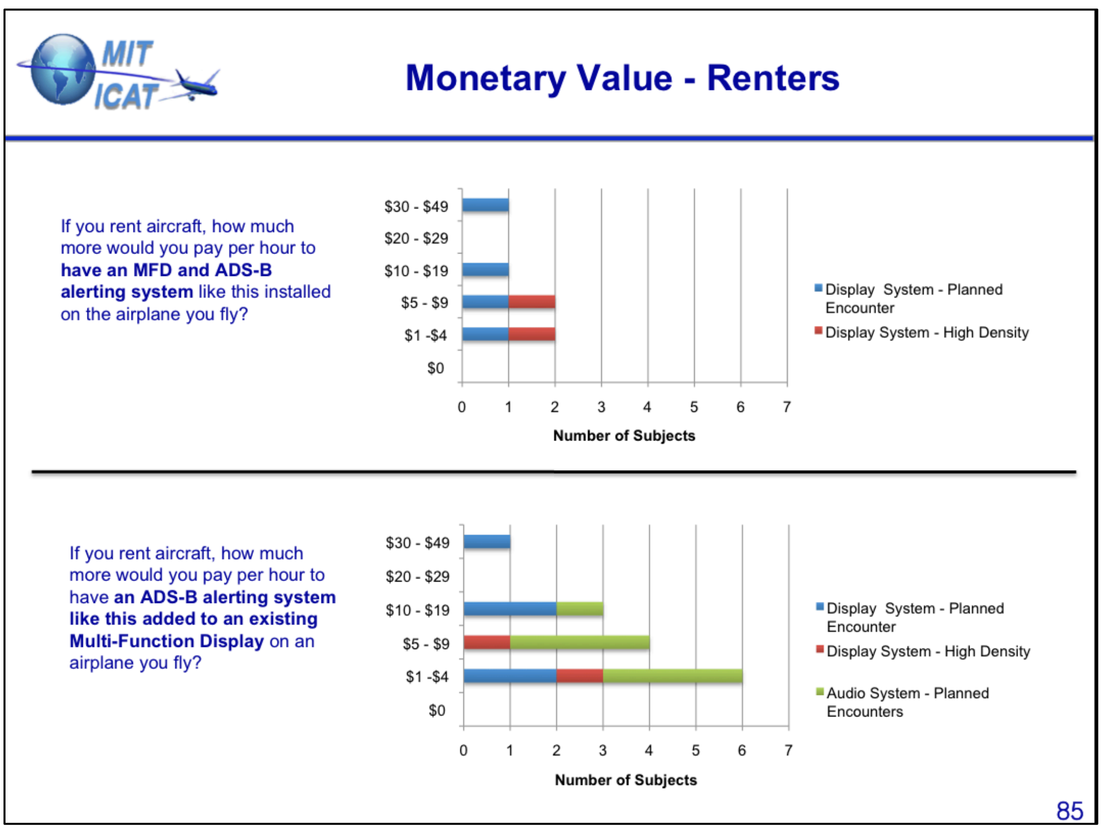
Appendix D5: Monetary Value of TSAA



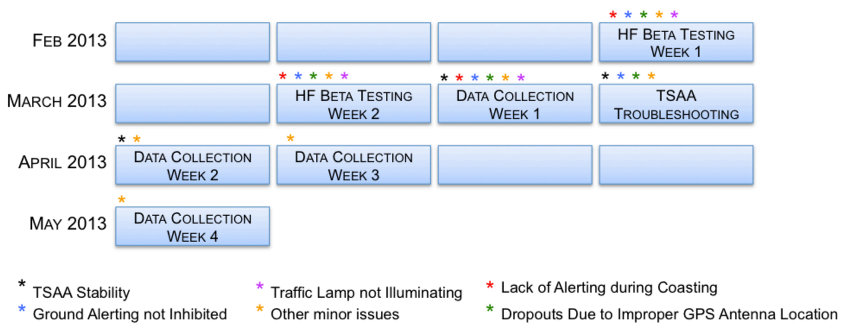


Appendix E:

Identified Prototype Issues

Prototype Issues

- **Throughout the data collection period, a number of discrepancies in the TSAA prototype were identified.**
- **The encounters where problems directly effected the system (in the form of late alerts, missed alerts, etc...) were segregated out of the analysis.**
  - In most cases, a scenario was repeated if the run was not successful, so we have a full set of planned encounter data for the majority of subjects
- **A few minor issues remained after the 2nd week of data collection, but those did not substantially impact the HF tests**



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Identified Prototype Issues

- **Ground targets were not suppressed in prototype**
- **The system had stability problems that required reboots of the system**
- **Dropouts of target track resulted in several late alerts**
- **Traffic lamp was not illuminating during alerts**

- **Non-Resolved Issues:**
  - Occasionally, the system picked up its own shadow and visually alerts on it (no aural alert was noticed)
  - Alert symbol defaults to a yellow solid circle for TIS-B targets
  - Occasional dropouts of the word “Traffic” in audio call
  - Occasional “gear down” message preceded traffic call during an alert
  - In 3 cases, we saw during an alert that the MFD was not showing alert target on the display and the alert textual message was flip flopping with another message on the bottom right corner of the display

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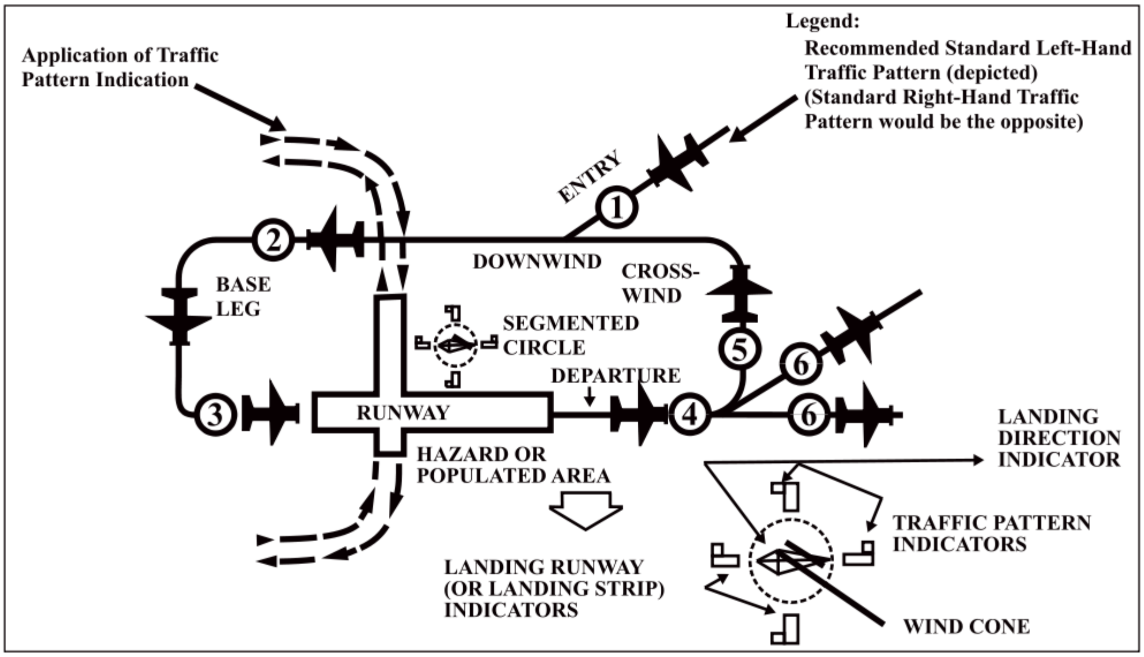
Appendix F

Traffic Pattern Description (FAA AIM 4-3-3) [14]



EXAMPLE-
Key to traffic pattern operations

1. *Enter pattern in level flight, abeam the midpoint of the runway, at pattern altitude. (1,000' AGL is recommended pattern altitude unless established otherwise. . .)*

2. *Maintain pattern altitude until abeam approach end of the landing runway on downwind leg.*

3. *Complete turn to final at least 1/4 mile from the runway.*

4. *Continue straight ahead until beyond departure end of runway.*

5. *If remaining in the traffic pattern, commence turn to crosswind leg beyond the departure end of the runway within 300 feet of pattern altitude.*

6. *If departing the traffic pattern, continue straight out, or exit with a 45 degree turn (to the left when in a left-hand traffic pattern; to the right when in a right-hand traffic pattern) beyond the departure end of the runway, after reaching pattern altitude.*