HUMAN FACTORS STUDIES OF AN ADS-B BASED TRAFFIC ALERTING SYSTEM FOR GENERAL AVIATION

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

by

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Abstract

Several recent high profile mid-air collisions highlight the fact that 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 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 added cost of a MFD.

TSAA System performance & basic usability was tested using human in the loop studies using a total of 50 general aviation pilots. The studies also evaluated a number of design issues in order to provide recommendation for the final TSAA design. The system was found to be usable and generally effective for all of the encounter scenarios analyzed in both the audio-only and display systems. Performance was significantly improved in the enroute scenarios when a Cockpit Display of Traffic Information (CDTI) was available compared with aural alerts only. In most cases, pilots became aware and responded to traffic earlier when a display was available. Miss distance also increased. Analysis of the audio only system showed that performance improved when alerts were provided to the pilot when compared to performance without a traffic system for a head-on case highlighting the benefit of TSAA.

Performance analysis of the final TSAA design showed that 98.7% of all collisions were avoided when TSAA was used. The 1.3% of collisions that did occur were due to the pilots' conscience decision to disregard an alert.

The TSAA system was evaluated for functionality and usability. The findings of these studies will contribute to TSAA standards development for the FAA and design recommendations for the avionics manufacturers.

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Acronyms

AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-R	Automatic Dependent Surveillance – Rebroadcast
AIM	Aeronautical Information Manual
ATC	Air Traffic Control
ATP	Airline Transport Pilot
CAZ	Collision Airspace Zone
CDTI	Cockpit Display of Traffic Information
CFI	Certified Flight Instructor
CFII	Certified Flight Instructor – Instrument
DOT	Department of Transportation
FAA	Federal Aviation Administration
FT	Feet
GA	General Aviation
GPS	Global Positioning Service
HCR	High Closure Rate
HITL	Human-In-The-Loop
ID	Identification
LTD	Limited
MEI	Multi-Engine Instructor
MIN	Minute
MFD	Multi-Function Display

MOPS	Minimum Operational Performance Standards
MSL	Mean Sea Level
NACp	Navigation Accuracy Category for position
NACv	Navigation Accuracy Category for velocity
NextGen	Next Generation Air Transportation System
NM	Nautical Mile
NTSB	National Transportation and Safety Board
PAZ	Protected Airspace Zone
RT	Reaction Time
RTC	Reinforced Traffic Caution
TAS	Traffic Advisory System
TCAS	Traffic Collision Avoidance System
TIS	Traffic Information Service
TIS-B	Traffic Information Service - Broadcast
TSAA	Traffic Situation Awareness with Alerting Application

Chapter 1

Introduction

1.1 Motivation

Several recent high profile mid-air collisions highlight the fact that mid-air collisions are a concern for general aviation (GA). One recent example occurred in 2009 where a Eurocopter helicopter and Piper airplane collided over the Hudson River, killing everyone onboard both aircraft. The National Transportation and Safety Board (NTSB) highlighted a probable cause for this accident as "1) the inherent limitations of the see-and-avoid concept, which made it difficult for the airplane pilot to see the helicopter until the final seconds before the collision," and a contributing factor as "both pilots' ineffective use of available information from their aircraft's electronic traffic advisory system to maintain awareness of nearby aircraft" [1]. 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 [2].

As was highlighted by the Hudson River accident, collisions continue to occur despite the use of traffic alerting systems that have been developed for general aviation aircraft such as Traffic Information Systems (TIS) and Traffic Advisory Systems (TAS). The TIS system 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 & 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, through transponder range interrogation, that are located in a given proximity, displays the location and trend information on a MFD, and provides aural alerts to help pilots locate conflicting traffic. Traffic Collision Avoidance System (TCAS) 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 nor TIS are designed to provide resolution guidance. Though all existing systems contribute to situation awareness in the cockpit, because of the quality of the surveillance, 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.

An analysis of 112 mid-air collisions involving general aviation aircraft between 2001 and 2010 uncovered that 59% of collisions occurred in the airport environment [3]. There is a gap in the capabilities of current traffic alerting systems in the environment where most collisions occur.

ADS-B introduces higher quality surveillance information, which provides the capability to provide a reliable alert in the condensed environment in which general aviation operates. ADS-B is a Global Positioning Service (GPS) based surveillance system that provides more precision than radar and a faster update rate (1 second). [4]. ADS-B is not limited by horizontal line of sight reception; it can 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 accounts for maneuvering flight, which is a capability the current state-of-the-art technology does not provide.

ADS-B has been mandated by the Federal Aviation Administration (FAA) in support of the Next Generation Air Transportation System (NextGen) implementation. Using the enhanced information provided by 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. Additionally, the benefits of TSAA may compel some users to install ADS-B equipment in their aircraft prior to the FAA mandate [5].

As can be seen in Figure 1-1, the three key elements of TSAA are 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 involving general aviation pilots.
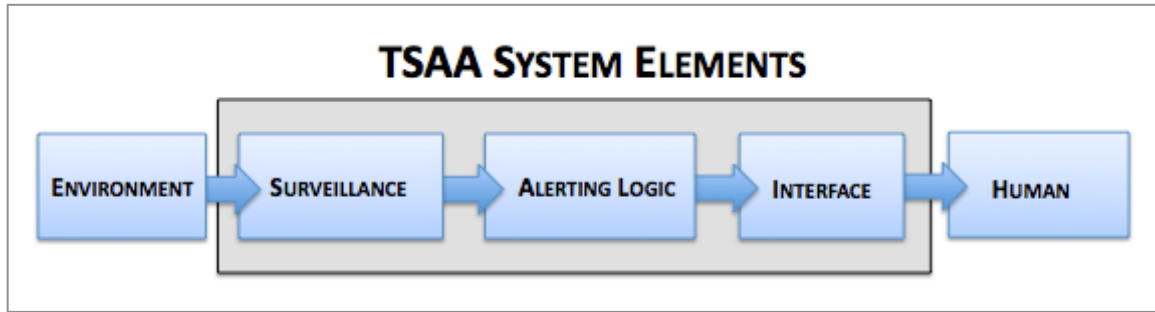
Figure 1-1. TSAA System Elements

Chapter 2

System Design

2.1 Design Philosophy

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

1. The TSAA system was designed to enhance situation awareness and provide traffic alerting. It was not designed to provide guidance or resolution of conflicts in order to minimize the cost associated with certification.

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. In addition to fixed wing applications, TSAA was designed to be used with helicopters. 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 [6]. In addition to a number of system requirements, this document provides guidance on display symbology and functionality. FAA Advisory Circular 20-172, Airworthiness Approval for ADS-B In Systems and Applications, also provides guidance on display development [7]. 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 [8].

2.2 TSAA Overall Design

With the above objectives in mind, the TSAA system was developed with two designs. The primary design is referred to as TSAA Class II where the system includes both audio alerts as well as a cockpit display of traffic information (CDTI). In some cases, the overall cost of the TSAA system could be prohibitive for users who do not currently have a MFD installed in their aircraft. Cockpit space could also be limited in many aircraft such as the Robinson 44 helicopter cockpit shown in Figure 2-1. 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 equipment refers to an audio alert system which includes only a light in the forward field of view to indicate when an alert is active. TSAA Class I equipment does not include a cockpit display of traffic information.

Figure 2-1. R44 Cockpit – Example of Limited Cockpit Space

2.2.1 TSAA Alerting Criteria

From Figure 2-2, recall the three elements of the TSAA System are surveillance, alerting logic, and interface. 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 studies, however the final algorithm parameters are still in development.
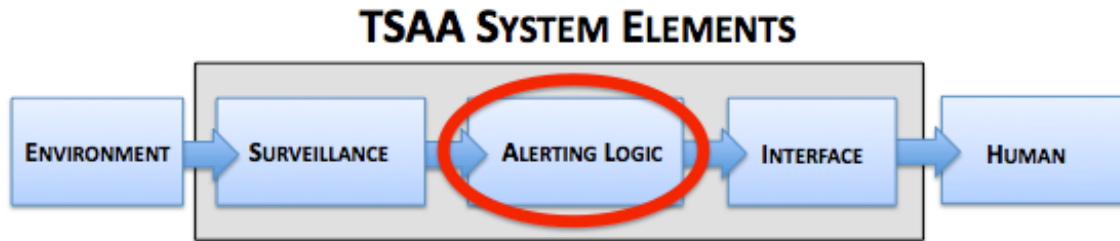
Figure 2-2. TSAA System Elements (Highlighting Alerting Logic)

The alerting system inputs information from ownship and target surveillance to determine whether a collision threat exists with other aircraft. The system calculates the range, altitude, bearing, and closure rate of all 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 2.3, 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 2-3). The size of the PAZ is scaled based on 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 +/- 300 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 2-3). The radius of the CAZ is 500 feet and the altitude ranges +/- 200 feet.
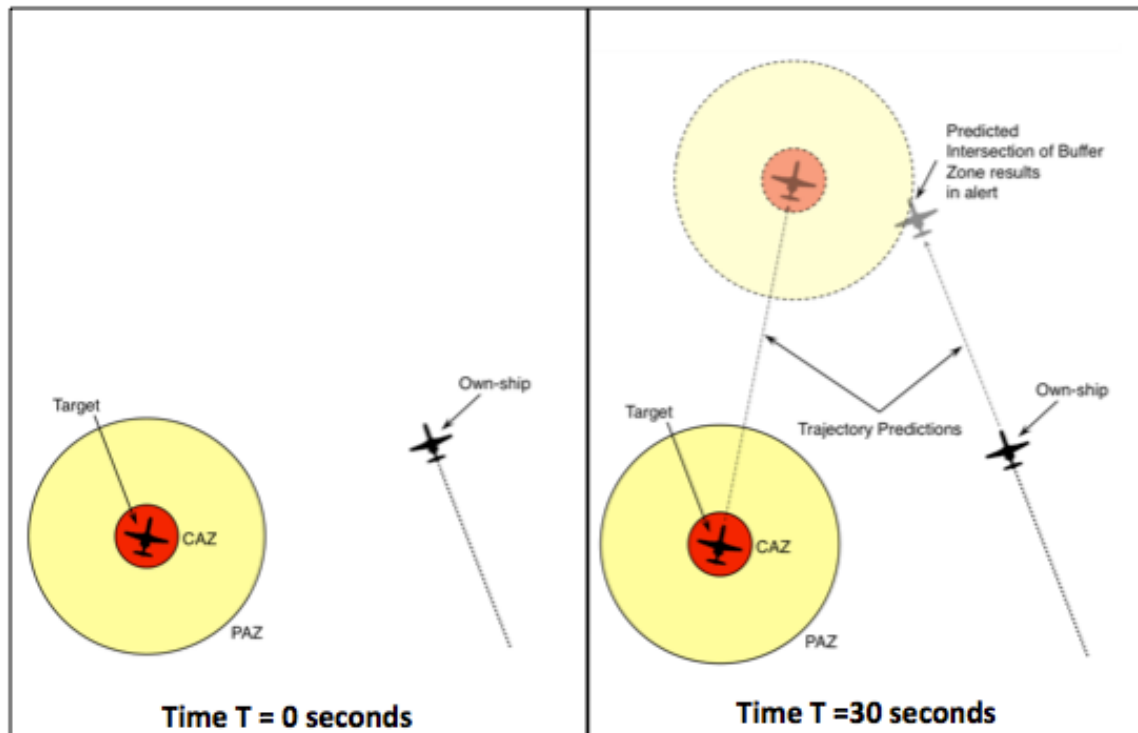
Figure 2-3. Sample Conflict Describing Alerting Criteria

The system propagates target and ownship position 30 seconds into the future as is shown on the right side of Figure 2-3. 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 *Reinforced Traffic Caution Alert* is annunciated.

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

The TSAA interface consists of an audio component and a visual component. Both components are described below.

Audio Interface

The audio interface is present in both the Class I and II TSAA systems. The aural alerts are annunciated for both the *Traffic Caution Alert* and the *Reinforced Traffic Caution Alert* and include azimuth, range, relative altitude, and vertical trend information (e.g. "Traffic, 3 o'clock, 2 miles, high, descending"). The *Reinforced Traffic Caution Alert* is differentiated using a higher prosodic urgency "Traffic" call compared to the *Traffic Caution Alert*. Multiple aural alerts are queued and an aural alert would complete before another alert annunciated, thus alerts are not interrupted mid-sentence.

Display Interface - Baseline CDTI Symbology

The TSAA Class II system included a CDTI. Examples of the CDTI are shown in Figure 2-4 and 2-5. Figure 2-4 shows a situation on a black background that does not include terrain information; Figure 2-5 shows the same situation on a map background option that includes terrain information.
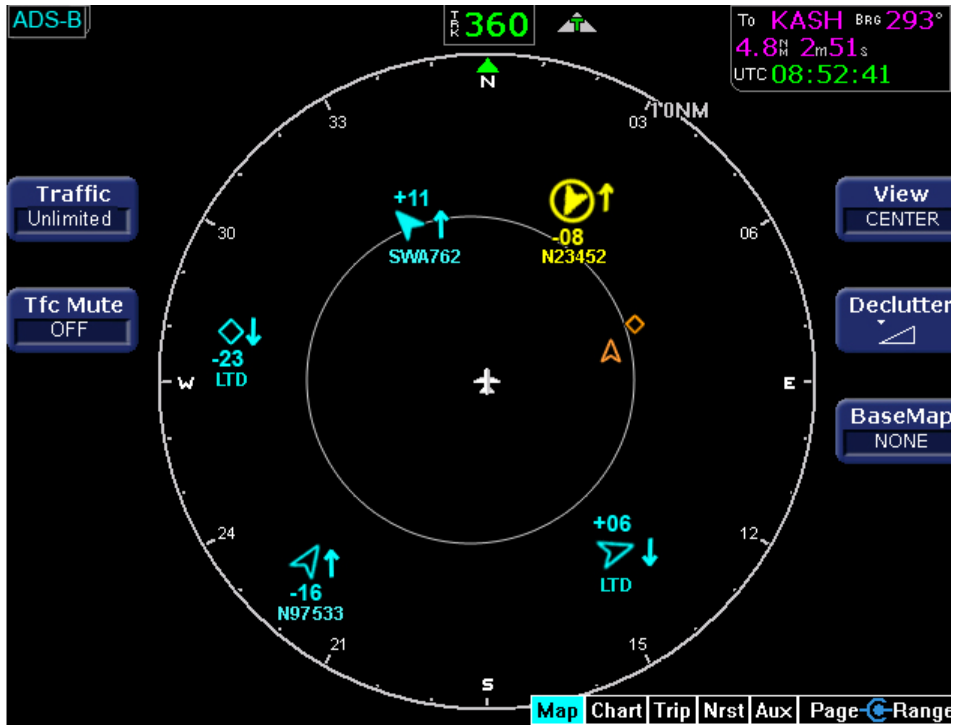
Figure 2-4. Sample Scenario on MFD Black Background
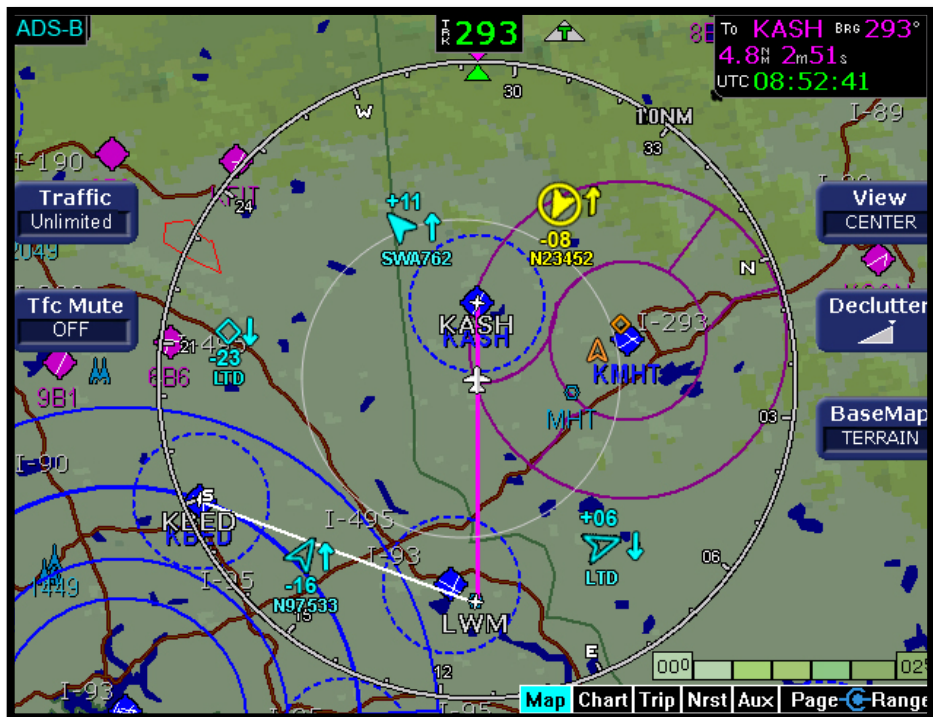
Figure 2-5. Sample Scenario on MFD Map Background

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Display symbology for the TSAA system was based on FAA standards for traffic with ADS-B information [6]. 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 2-6) whenever directional information is valid.

Figure 2-6. Directional Target

Non-directional targets are shown with a diamond (Figure 2-7) whenever directional information is not valid.

Figure 2-7. Non-Directional Target

As can be seen in Figure 2-8, 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. Ground targets are defined using a system similar to "weight on wheels" or airspeed calculations [6]. The TSAA system is an airborne system, thus no conflicts on the surface are alerted.

Figure 2-8. 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 2-9). Analysis was conducted to determine whether TSAA would conform to this precedent and display proximate traffic, or whether the inclusion would lead to confusion for pilots.
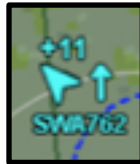
Figure 2-9. Proximate Target

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 2-10). This is the final design for depiction of non-qualified targets and other options for depiction were considered and are described in future chapters.
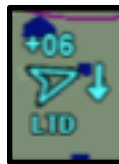
Figure 2-10. Non-Qualified Target

Display Interface - Alert CDTI Symbology

Both the *Traffic Caution Alert* and the *Reinforced Traffic Caution Alert* are depicted using the same caution symbol shown in Figure 2.11. These targets are depicted in yellow because both alerts are caution level. The two alerts are only discriminated by the prosodic urgency of the "Traffic" call in the *Reinforced Traffic Caution Alert,* but the aural alerts convey the same information. The alert symbol also includes a circle surrounding the directional target in order to allow discrimination by colorblind pilots.

Figure 2-11. 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.
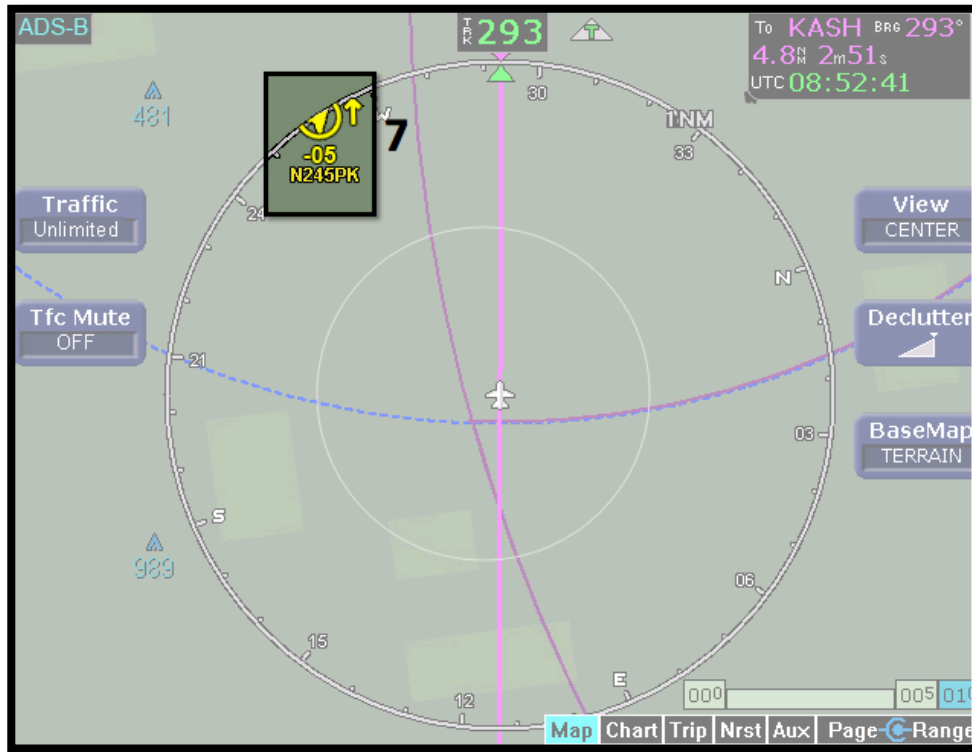
Figure 2-12. Off-Scale Alert Symbol

2.3 Design Issues

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 Office of Aviation Safety, FAA Flight Standards Service, Department of Transportation Volpe Center, and the Avidyne Corporation.

The baseline design was refined through a series of eight design reviews, and there were three residual issues from those reviews that were further investigated.

Two Levels of Caution Alert. One issue, which arose from the reviews, was question about the benefit of including two levels of caution alert. A system with two levels of caution alert was unprecedented in this type of application and there were concerns about significant certification effort. Also, it was unclear whether providing the *Reinforced Traffic Caution* was beneficial, considering it is depicted with the same symbol as the *Traffic Caution Alert* with an information update. It was sought to determine whether the *Reinforced Traffic Caution* added value to the system.

Depiction of Proximate traffic. Existing state-of-the-art traffic alerting systems include a proximate traffic depiction to direct attention to traffic in a given proximity to the ownship. Aircraft within 6 nm horizontally and plus/minus 1,200 feet vertically in relation to the ownship are considered proximate. These aircraft are traditionally depicted using a filled in symbol. As can be seen in Figure 2-13, the traffic outside of the proximate range (N23452) is shown with a basic directional symbol, while the aircraft within the range (SWA762) is shown with a filled directional symbol. The proximate depiction is used as a visual acquisition aid and to differentiate traffic that may be greater threat due to proximity to ownship.

While there is value in maintaining commonality with other traffic systems, there was concern that the proximate traffic indication was inconsistent with the TSAA alerting criteria and may cause confusion. Recall from above that the TSAA alerting criteria for the *Traffic Caution Alert* is sized based on closure rate of traffic, translating into the level of threat of the traffic. Proximate depiction is only based on fixed distance and altitude from own-ship, which is not necessarily a measure of threat. As can be seen in Figure 2-13, targets may be depicted as proximate if they are flying away from the ownship (SWA762), while traffic with high closure rates may not be depicted as proximate despite a greater threat level (N23452).
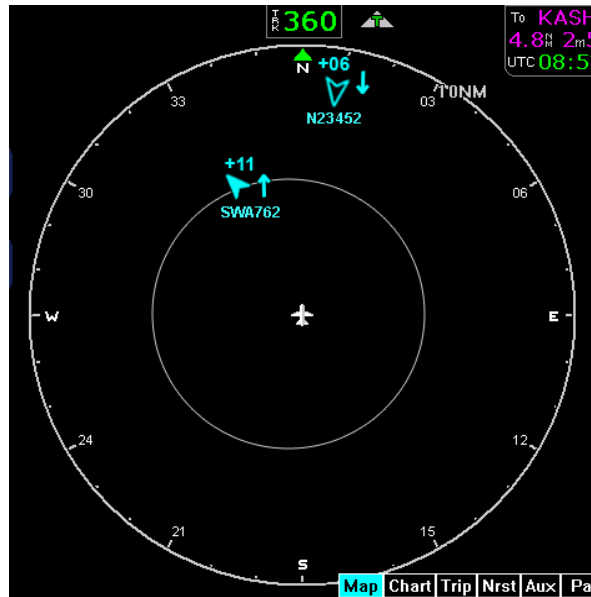
Figure 2-13. Sample Scenario with Non-Proximate Threat

This dissonance between the alerting system and the user could lead to non-conformance with the system [9]. Zuschlag and Chandra specifically probed the proximate indication and found that pilots were on average 9% more correct in identifying a higher threat target when they were not given a proximate indication [10]. The overall question was whether to maintain consistency with TCAS and introduce an inconsistency in logic, or whether to remove proximate traffic from the design to maintain consistency with the alerting logic.

Depiction of Non-Qualified Targets. Non-qualified targets are those that do not have sufficient surveillance data quality (integrity, accuracy, or update rate) for TSAA to issue a reliable alert. A parallel study is being conducted to evaluate whether secondary surveillance (TIS-B) data quality is sufficient to issue an alert or whether to only display these targets on the CDTI for situation awareness. Since there was the possibility that these targets do not have sufficient integrity to issue a reliable alert, this research evaluated how to manage non-qualified targets.

There was question whether to differentiate these targets that will never alert (non-qualified targets) from the targets that will alert (qualified targets) upon predicted penetration of the buffer zones. Wickens and Colcombe evaluated the consequences of imperfect alerting associated with CDTI displays and found that as an alerting

system became more prone to false alerts, pilot compliance decreased [11]. There was concern about loss of trust in the TSAA system if non-qualified targets were not differentiated. Xu and Wickens also evaluated effects of reliability on pilots' conflict detection with CDTI and found that imperfect automation led to an increase in performance when reliability remained high [12]. This increase in performance was due to higher vigilance on the CDTI. In the context of aviation however, any vigilance on the traffic display is attention away from basic flight tasks. Thus, it is possible that any loss in trust in the system could manifest as decreased performance on basic flight tasks. There were a number of options of how to differentiate non-qualified targets from qualified targets. Many options were discussed prior to settling for the "LTD" designator.

Summary

The concerns listed above were probed through a series of three human factors simulations where pilots were presented with traffic encounter scenarios and expected to respond to traffic. Subjective response regarding the encounters and the systems was also gathered to gauge pilot perception of the TSAA system.

Chapter 3

Methodology

In order to evaluate the TSAA system and investigate identified human interface issues described in Chapter 2, three studies were designed and conducted. Throughout the process of conducting the human factors studies, two main methods were utilized to test basic usability of the system for the audio only and the display based systems as well as to evaluate system issues.

3.1 Human-in-the-Loop Simulation

The primary method used in the TSAA human factors studies was a human-in-the-loop simulation. Pilots actively controlled an aircraft & were presented with traffic scenarios, which were specifically designed to provide controlled encounters that would test the TSAA system in different ways.

Participants were instructed to fly specific flight profiles and presented with traffic encounters. Pilots were to assume they had a co-pilot and were instructed to verbalize where they were scanning and when the traffic was visually acquired (if in forward field of view). Upon visual acquisition (or assumed visual acquisition if traffic was not in forward field of view), pilots responded to traffic, as they deemed appropriate.

Experimental System

The experimental system consisted of a part task flight simulator with X-Plane based flight dynamics. As can be seen in Figure 3-1, the out-the-window view was

displayed on a 42 inch television monitor while the TSAA system depicted traffic on an Avidyne multi-function display (MFD) prototype on another computer monitor located to the right of the main screen. The MFD monitor did not block any of the instruments in the cockpit that the participant required to fly the aircraft. The base aircraft was a Cessna 172SP with "steam gauges." Participants controlled the simulator using the yoke, rudder pedals, & buttons on the yoke.

Figure 3-1. Simulator Setup

In addition to the display based system, an audio only system was also developed. As can be seen in Figure 3-2, the equipment for the audio based system was a replicate of the display based system, however the Multi-Function Display was replaced with a yellow circle in the pilots forward field of view which illuminated when an alert state was active.
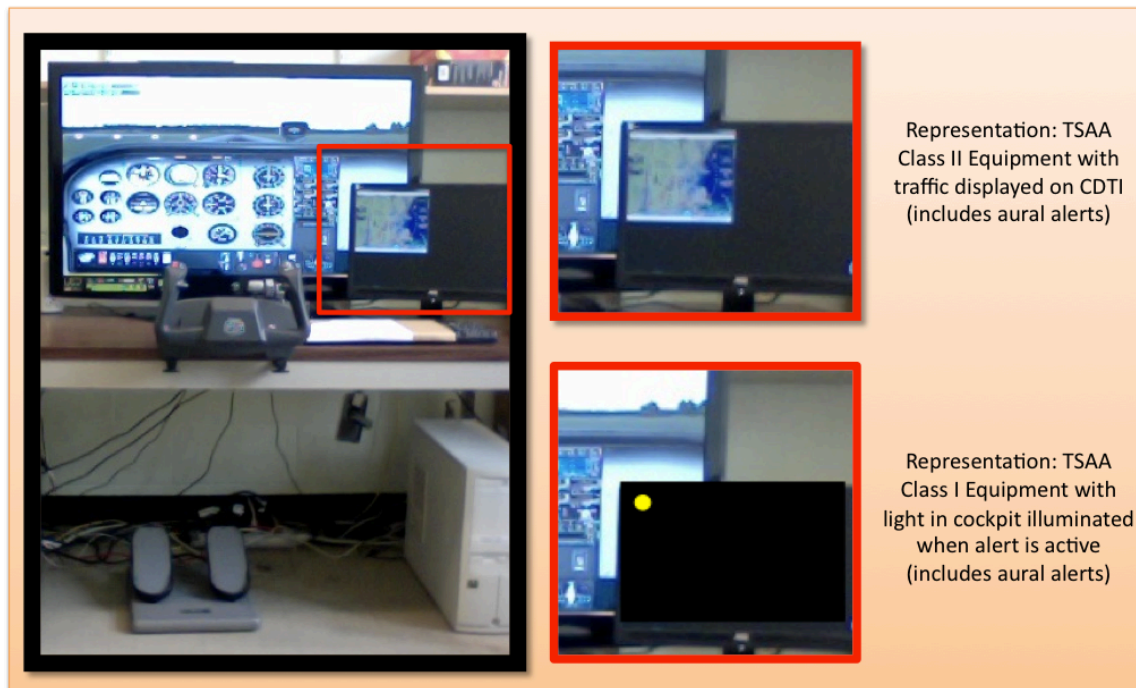
Figure 3-2. TSAA Class I and II Simulation Equipment

Since pilots were manually controlling the aircraft, in order to have controlled encounters, it was necessary to develop a traffic generation system that would respond to variation in ownship trajectory (speed, altitude, heading or track). Without this feedback, traffic alerts would not be repeatable due to variability in subject flying. Thus, a traffic generator was developed to repeatably execute scenarios in both the enroute and the highly maneuvering traffic pattern environment. Specific scenarios were designed, and guidance strategies were developed to allow the encounter to be maintained in a realistic manner. The target would home in on the ownship until it reached a breakaway point, at which the target would stop its homing behavior and continue on its planned flight profile. The experimenter would manually activate breakaway once the subject made a decision to take evasive action in order to avoid target homing during the escape maneuver. If the pilot did not take evasive action against the planned conflict, the target would home until 0.1 nm distance away from the ownship and then automatically break away. The MATLAB-based traffic generator was operating on a separate machine creating conflict and background traffic for each scenario. The traffic was rendered on the forward display (if in field of view) and on the MFD.

Figure 3-3 shows the simulation architecture. The pilot's control inputs were fed directly into X-Plane, which sent ownship position, attitude and velocity to the traffic generator. Based on the dynamics of the ownship, the traffic generator calculated updated target position and attitude and sent the information back into X –Plane. The ownship and target information were also continuously fed into the TSAA system where it was displayed on the MFD and annunciated aurally if an alert occurred.
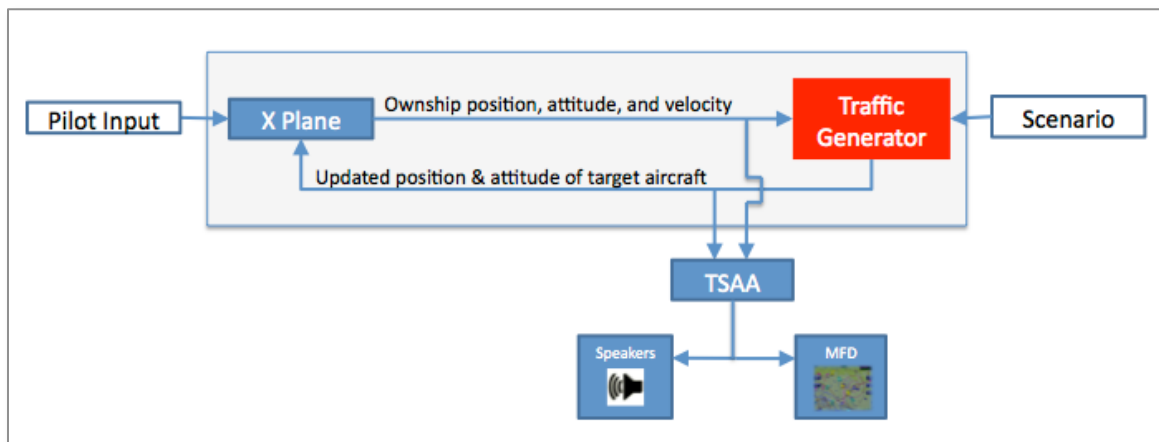
Figure 3-3. Simulation Architecture

The subject was given the capability to control the TSAA display range on the MFD using keyboard inputs. During all data collection runs, the MFD was fixed to a map background. As can be seen in Figure 3-4, declutter setting was set on the MFD to a clutter level that included special use airspace, towered and untowered airports, Class B and C airspace, and obstacles prioritized at a given range [13]. Participants were not given control over the declutter setting. The MFD was set to "Track-Up" view with the own-ship at the center of the screen. Background engine noise and Unicom radio chatter was playing for every run in order to set a more realistic noise environment for the simulation. Radio chatter did not contain any party line information to cue subjects to traffic in the area.
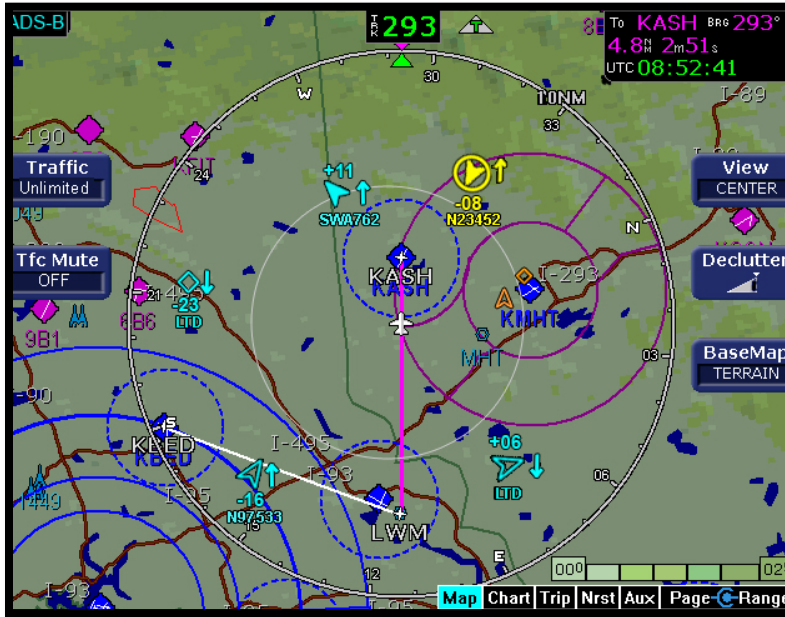
Figure 3-4. Sample MFD View

Scenarios

Encounter scenarios were representative of both the traffic pattern environment as well as the enroute environment. In addition to ownship and threat traffic on the MFD, there were between two and four background targets (within 5 nm for pattern cases and within 10 nm for enroute cases). Because the pilots were allowed to maneuver away from traffic, it was not possible to use time of closest approach as a reference time between scenarios and subjects. Therefore, a specific reference time was defined for each scenario and used for comparisons within and between subjects.

A complete set of scenarios developed is described in detail in Section 3-3. Table 3-1 lists the scenarios that were run using the human in the loop method.

Encounter 1	High Closure Rate Head-on
Encounter 2	Vertical High Closure Rate
Encounter 3	Multiple Intruder
Encounter 4	Base vs. Final
Encounter 5	Entry vs. Downwind
Encounter 6	Overtaking on Final
Encounter 7	Autorotating Helicopter
Encounter 8	Opposite Runway
Encounter 9	Teasing PAZ
Encounter 10	Extended Final

Table 3-1. Scenarios Used in the Human-in-the-Loop Method

Dependent Variables

Participants were instructed to fly specific flight profiles and presented with traffic encounters. Pilots were to assume they had a co-pilot and were instructed to verbalize where they were scanning and when the traffic was visually acquired (if in forward field of view). The time of awareness was taken by the initiation of the first "looking" call when participants stated "looking for traffic" on the target aircraft. 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 recorded for traffic apparent in the forward field of view. Upon visual acquisition (or assumed visual acquisition if traffic is not in forward field of view), pilots responded to traffic as they deemed appropriate. The type and dynamics of pilot evasive action were recorded as well as all scanning and visual acquisition times. The time of evasive response was determined as the time of flight control input in response to traffic. Type of response was classified into climb, descent, turn, go around, extend upwind, extend crosswind, extend downwind, short approach, 360 degree turn in pattern, abort takeoff, and no action. Number of near misses and collisions were counted for each encounter. A near miss was defined with a slant range miss distance of 0.1 nm (600 ft) or less. A collision was defined with a slant range miss distance of 0.01 nm (60 ft) or less.

Subjective evaluations were also collected from the participants, probing general usability, clutter, display issues, and system preference. Background questionnaires were completed prior to data collection and consisted of questions regarding pilot experience, access to aircraft, experience with traffic alerting systems, and prior experience with flight simulators. Post evaluation questionnaires were conducted at the end of the experiment probing the participants' perception of the best and worst features of the TSAA System, ease of understanding of the alerting criteria, as well as perceived value of the system. Pilots were also solicited for experiment feedback during the post evaluation questionnaires. In addition to background and post evaluations, intermediate subjective response was solicited regarding specific experiment configurations containing primarily questions regarding perceived trust in the system as well as preference for a specific configuration. In order to test pilot understanding of the symbology, a pre-test was also conducted following the review of background information prior to data collection runs.

All supplemental material regarding the studies which used this human-in-the-loop approach is provided in Appendix B and C.

Experimental Protocol

The experimental protocol consisted of the following tasks. Introduction to the study consisted of review of the consent form, background information, and symbology pre-test. Following the introduction, pilots flew two traffic pattern profiles without traffic or the MFD in order to become familiar with the simulator and learn the traffic pattern profile. These simulator familiarization runs were designed to reduce the learning curve introduced by using a flight simulator. Following the simulator familiarization, the data collection runs were conducted. Pilots were given initial conditions prior to any flight profile. In addition to the data collection runs, training runs were completed prior to each configuration being tested. During one of these training runs, the background on the MFD was set to black in order to expose pilots to that background. All other runs using the display system were conducted using a map background shown in Figure 3-4. Between runs with each system configuration, pilots were given a brief intermediate questionnaire regarding their perception of

that system. Following all data collection runs, a post evaluation questionnaire was conducted. The study took an average of 3 hours to complete for each subject, and participants were given the opportunity to take short breaks throughout the session.

3.2 Video Playbacks of Encounter Scenarios

The second method used during the human factors studies was based on pilot perception of traffic encounters rolling on a multi-function-display. This was a simple approach used to rapidly expose subjects to controlled scenarios. Pilots were presented with 18 pre-recorded encounter videos and were instructed to select the scan selection and urgency selection whenever a target was considered a threat.

Experimental System

Figure 3-5 depicts the interface pilots used during the task. The left monitor consisted of the side task and scan simulator, while the right monitor contained an MFD running a pseudo TSAA simulation with pre-recorded traffic situations. The details of the systems are provided below.
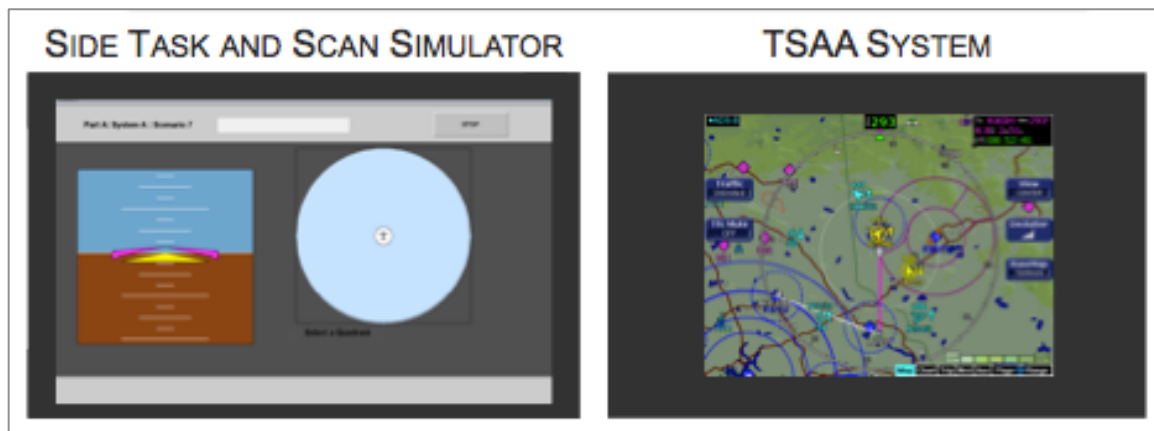
Figure 3-5. Experimental Setup: Side Task and Scan Simulator (left) and MFD (right)

As seen in Figure 3-5, a MFD with recordings of traffic was presented to the pilots. The Avidyne MFD prototype was run on an MFD PC virtual machine. Scenarios were predefined and loaded onto the virtual machine. A pseudo – TSAA system was mimicked on the MFD where alert times were pre-determined using the TSAA

algorithm and manually input into the recording. At these alert times, the audio alert would annunciate and accompany the change in symbology on the display. The subject was given the capability to control range on the MFD using keyboard inputs. Start time was recorded and synced with the data system in order to correlate scan selection responses with the events occurring on the MFD.

Pilots were presented with 18 pre-recorded encounter videos and were instructed to select the scan selection and urgency selection whenever a target was considered a threat. Because of the concern that this task was not realistic, a side task was developed in order to provide a more realistic division of pilot attention. The side task was designed and tested to require continuous attention on the MFD so that a performance penalty in the side task would occur if the pilot transferred their attention away from the side task. This was implemented specifically to prevent pilots from over-focusing on the MFD. As can be seen on the left hand system in Figure 3-5, the side task consisted of a flight director tracking task where the flight director commanded an oscillatory pitch profile. The participant was provided with a joystick to control the aircraft reference symbol (shown in yellow) and superimpose it onto the flight director steering command bar (shown in purple). The difference between the steering command bar and aircraft reference symbol was continuously recorded. The root-mean-squared values were calculated for each scenario and were used to derive a score for the side task. The score was presented to the participant following each scenario and was provided primarily as a motivation for the participant to perform well on the side task, however the score was not used as a dependent variable.

In order to evaluate pilot response to the system, a scan simulator was displayed with a circle next to the side task interface in Figure 3-6, which was a top down view of the aircraft. Participants would click the direction on the blue circle where they would scan for traffic. As can be seen in Figure 3-7, once the subject selected a location corresponding to where they would visually scan for a threat, an urgency selection appeared underneath the location selection. The subject was then expected to select their perceived urgency regarding the specific threat addressed by the scan

selection. Once the subject selected an urgency level, the data system defaulted back to Figure 3-6 awaiting the next scan selection.
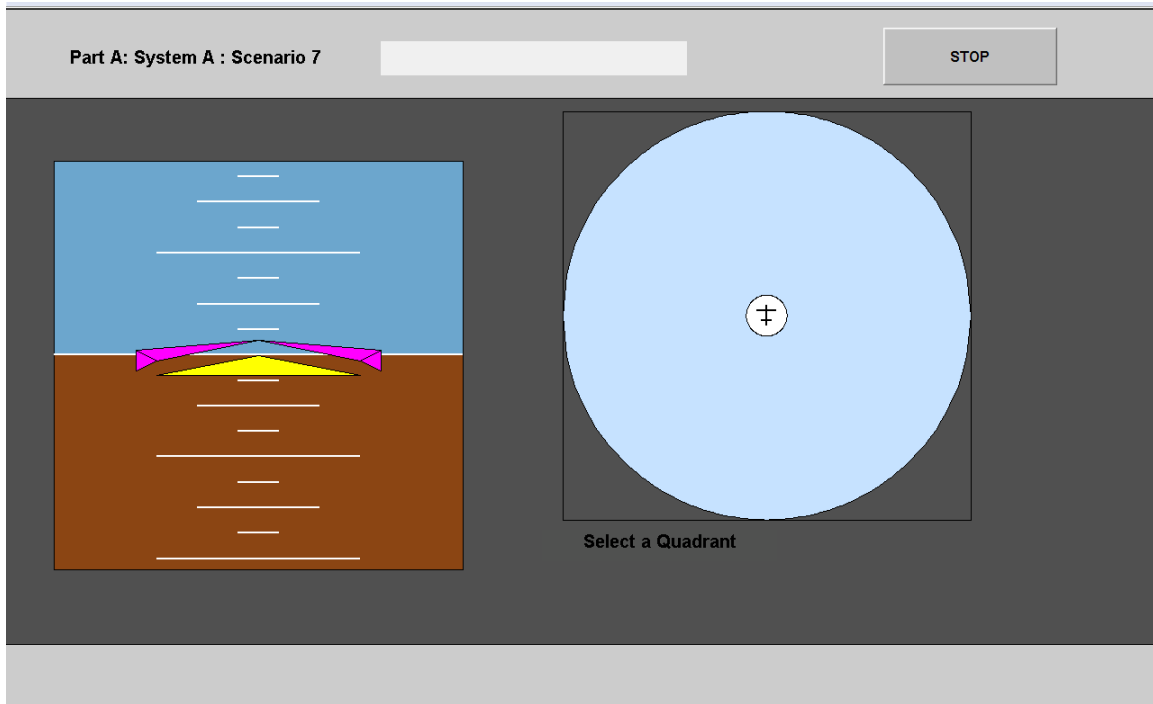
Figure 3-6. Side Task and Scan Simulator (Screenshot Before Scan Selection)
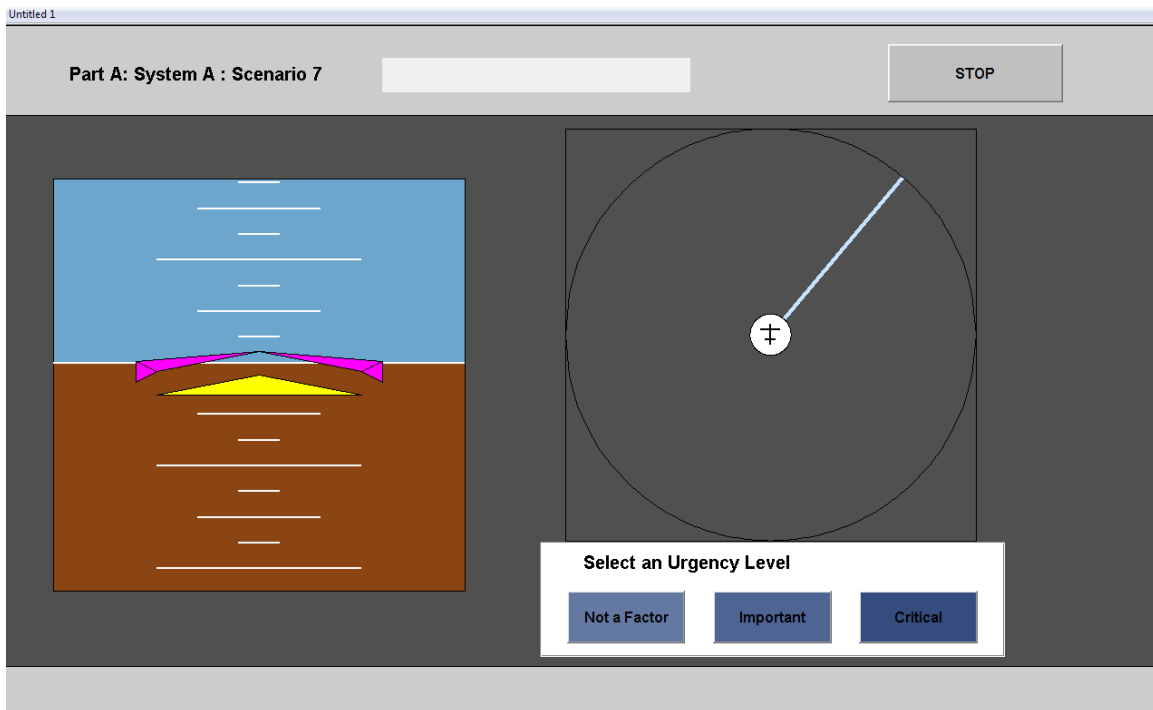
Figure 3-7. Side Task and Scan Simulator (Screenshot After Scan Selection)

Pilots also flew the profile using an audio only system. In this system, the MFD was removed and only the side task and scan simulator were active. Participants were instructed to fly a flight director profile using a joystick, where upon annunciation of an aural alert, the subject selected the location where he would scan for traffic as well as identify his perceived urgency of the threat. Reaction time as well as performance on the flight side task was measured.

Scenarios

Encounter scenarios were representative of both the traffic pattern environment as well as the enroute environment. In addition to ownship and threat traffic on the MFD, there were between two and four background targets (within 5 nm for pattern cases and within 10 nm for enroute cases). Note that reference times for the scenarios run in this method were defined by time of closest approach. This was a consistent reference since pilots were not manually flying the encounter.

A complete set of scenarios developed is described in detail in Section 3-3. Table 3-2 lists the scenarios that were run using the video playback method.

Encounter 1	High Closure Rate Head-On
Encounter 3	Multiple Intruder
Encounter 4	Base vs. Final
Encounter 5	Entry vs. Downwind
Encounter 7	Autorotating Helicopter
Encounter 9	Teasing PAZ
Encounter 10	Extended Final
Encounter 11	Normal Closure Rate Head-On
Encounter 12	Level vs. Climbing/Descending
Encounter 13	Level vs. Maneuvering
Encounter 14	Off-Scale Alert

Table 3-2. Scenarios Used in the Video Playback Method

Dependent Variables

Identification times, reaction times, and pre-reaction times were identified for all scenarios as is shown in Figure 3-8. *Identification time* was defined as the difference between the time of closest approach and the time of first important scan selection on the conflict traffic. *Pre-reaction time* was defined as the time of the first important scan selection compared to the time of the beginning of the first audio alert. *Reaction time* was defined as the time of the first conflict scan selection following an alert. Each of these parameters was compared to analyze differences in the independent variables.
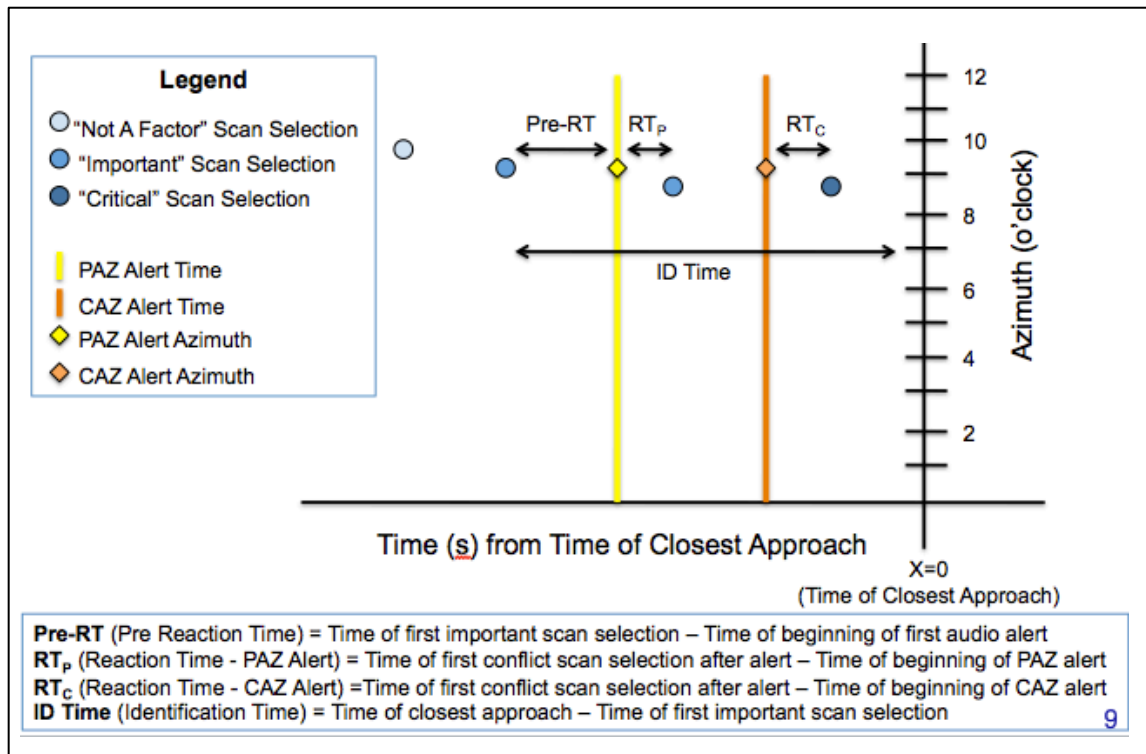
Figure 3-8. Graphical Depiction of Reaction Time and Identification Time Definitions

Subjective evaluations were also collected from the participants, probing general usability, clutter, display issues, and system preference. Background questionnaires were completed prior to data collection and consisted of questions regarding pilot experience, access to aircraft, experience with traffic alerting systems, and prior experience with flight simulators. Post evaluation questionnaires were conducted at the end of the experiment probing the participants' perception of the best and worst

features of the TSAA System, ease of understanding of the alerting criteria, as well as their perceived value of the system. In addition to background and post evaluations, intermediate subjective response was solicited regarding specific experiment configurations containing primarily questions regarding perceived trust in the system as well as preference for a specific configuration.

All supplemental material regarding the studies utilizing this video playback approach is provided in Appendix A.

Experimental Protocol

The experimental protocol consisted of the following tasks. Introduction to the study consisted of review of the consent form and background information. Following the introduction, the data collection runs were conducted. Pilots were given initial conditions prior to any flight profile along with a default setting for the MFD range. In addition to the data collection runs, training runs were completed prior to each configuration being tested in the data collection runs. During one of these training runs, the background on the MFD was set to black in order to expose pilots to that background. All other runs using the display system were conducted using a map background shown in Figure 3-4. Intermediate subjective evaluations were run following each specific configuration during data collection. Following all data collection runs, a post evaluation questionnaire was conducted. The study took an average of 2.5 hours to complete for each subject, and participants were given the opportunity to take short breaks throughout the session.

3.3 Encounter Scenarios

The scenarios listed in Table 3-3 are described in detail below. Note that most pattern scenarios were initialized with the ownship on the runway prior to takeoff, and all enroute cases initialized with the ownship straight and level at a specified altitude. The extended final encounter described below initialized at 2000 feet MSL with the ownship established on an extended final to the runway.

Encounter 1	High Closure Rate Head-On
Encounter 2	Vertical High Closure Rate
Encounter 3	Multiple Intruder
Encounter 4	Base vs. Final
Encounter 5	Entry vs. Downwind
Encounter 6	Overtaking on Final
Encounter 7	Autorotating Helicopter
Encounter 8	Opposite Runway
Encounter 9	Teasing PAZ
Encounter 10	Extended Final
Encounter 11	Normal Closure Rate Head-On
Encounter 12	Level vs. Climbing/Descending
Encounter 13	Level vs. Maneuvering
Encounter 14	Off-Scale Alert

Table 3-3. Scenarios Used in Human Factors Studies

1. *High Closure Rate Head-On Scenario* **(Encounter 1)**

    As can be seen from Figure 3-9, during this encounter, targets approached from directly ahead. The azimuth was altered by 15 degrees left and right during identical comparisons in order to minimize the chance of pilot recognition of the same encounter. During the high closure rate encounter, targets approached at upwards of 300 knots. These were rendered as jet aircraft in the out-the-window display, and the flight profiles for the ownship consisted of level flight above 10,000 feet mean sea level (MSL) where no speed restrictions exist. The reference time for this scenario was defined as the time that the target aircraft appeared which was approximately 12 seconds after run start.
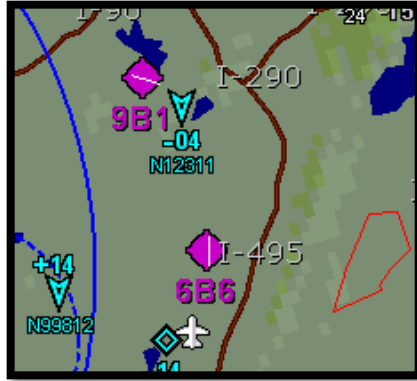
Figure 3-9. High Closure Rate Head-On Encounter

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

As is shown in Figure 3-10, the target in this scenario was 2,000 feet above, paralleling the ownship course, and slightly converging from the right. At a given time, the target would begin a steep descent (1500 ft/min or more) in order to force a collision from above. For identical comparison scenarios, the scenario geometry was reflected so the encounter came from the left. The reference time for this scenario was defined as the time that the target aircraft began descending.

Figure 3-10. Vertical High Closure Rate Encounter

3. *Multiple Intruder Scenario* **(Encounter 3)**

As is shown in Figure 3-11, there were two conflict traffic in this scenario designed to alert near simultaneously. The ownship was flying straight and level at 10,500 feet in this profile. One target approaches from 12 o'clock

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(Encounter 1) while the other target approaches from 3 o'clock (Encounter 2). The three 3 o'clock target parallels the ownship course from 1,500 feet above and descends into the ownship to force a conflict at the proper time. Both targets had the identical planned conflict time in order to gauge pilot response to multiple simultaneous traffic alerts. The reference time for this scenario was defined as the time of first alert.
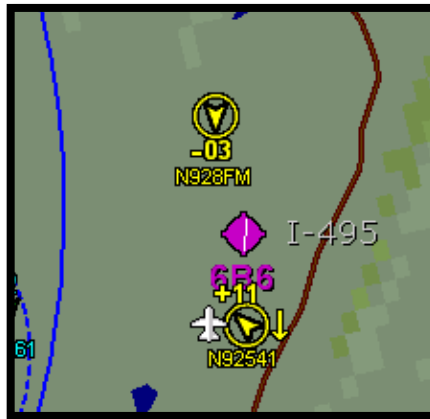
Figure 3-11. Multiple Intruder Encounter

4. *Base vs. Final Scenario* **(Encounter 4)**

    As is shown in Figure 3-12, the target in this scenario was on extended final to the runway and the ownship was on base leg of the traffic pattern. The conflict point was set to be the ownship base to final turn. The reference time for this scenario was defined as the time the ownship crossed the threshold of the opposite runway on downwind. E.g., if the ownship departed runway 21, reference time would be the time the ownship came abeam the 03 numbers on downwind.
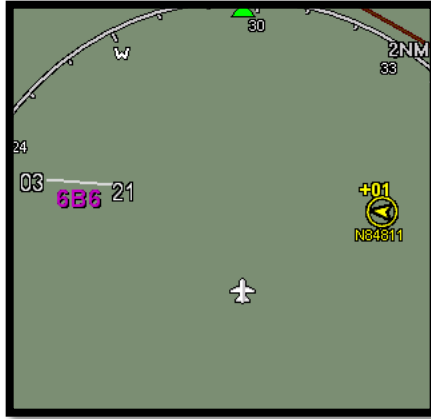
Figure 3-12. Base vs. Final Encounter

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

As is shown in Figure 3-13, the target in this scenario was on a 45-degree entry to midfield downwind and the ownship was in the pattern established on downwind. The reference time for this scenario was defined as the time that the target appears in the scenario, which was approximately 12 seconds after run start.
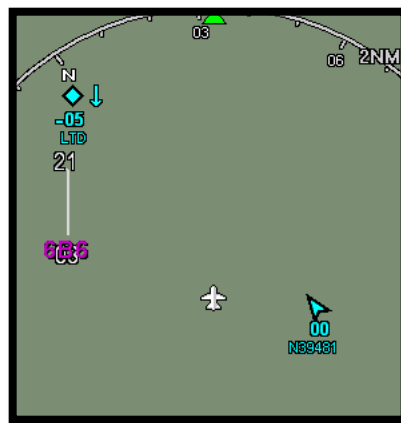
Figure 3-13. Entry vs. Downwind Encounter

6. *Overtaking on Final Scenario* **(Encounter 6)**

As is shown in Figure 3-14, the target in this encounter was a jet on extended final. The scenario was designed to unravel once the ownship turns final and high closure rate traffic approaches from behind. The conflict point in this

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situation was the threshold of the runway. The reference time for this scenario was defined as the time of first alert.

Figure 3-14. Overtaking on Final Encounter

7. *Autorotating Helicopter Scenario* **(Encounter 7)**

As is shown in Figure 3-15, the target in this encounter was a helicopter performing an autorotation onto the runway. The ownship was in the traffic pattern for the same runway. The helicopter remained hovering over mid-field right downwind until the ownship turned final. Once the ownship turned final, the helicopter began an autorotation. The conflict point for this scenario was the threshold of the runway. The reference time for this scenario was defined as the time of first alert.
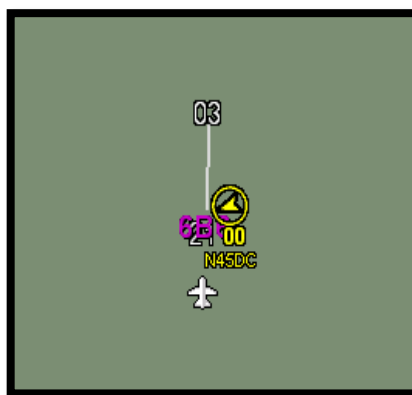
Figure 3-15. Autorotating Helicopter Encounter

8. *Opposite Runway Scenario* **(Encounter 8)**

    As is shown in Figure 3-16, the target in this encounter was an aircraft
    making an approach for landing to the opposite runway the ownship was
    departing on. The reference time for this scenario was the time the target
    appeared in the scenario, which was approximately 12 seconds after run
    start.

Figure 3-16. Opposite Runway Encounter

9. *Teasing PAZ Scenario* **(Encounter 9)**

    As is shown in Figure 3-17, the target in this encounter was an aircraft
    maneuvering two miles to the right of the ownship at a similar altitude. This
    scenario was designed such that the target would maneuver in and out of the
    PAZ, however was no real threat to the ownship. This conflict was used to
    gauge nuisance alert perception. The reference time for this scenario was
    defined as the time the target appeared in the scenario, which was
    approximately 12 seconds after run start.

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Figure 3-17. Teasing PAZ Encounter

10. Extended Final Scenario (Encounter 10)

As is shown in Figure 3-18, the target in this encounter was an aircraft in the traffic pattern. The ownship was also inbound to the runway on an extended final. The conflict was set to occur once the target turned base. The conflict point was the target's base to final turn. The reference time for this scenario was defined as the time the target aircraft turned base.

Figure 3-18. Extended Final Encounter

11. Head-On (Normal Closure Rate) Scenario (Encounter 11)

As is shown in 3-19, this head-on encounter was very similar to Encounter 1, however in this scenario, the target was only traveling on the order of 120 knots and it also included a vertical component in the encounter with the target climbing or descending into the ownship.
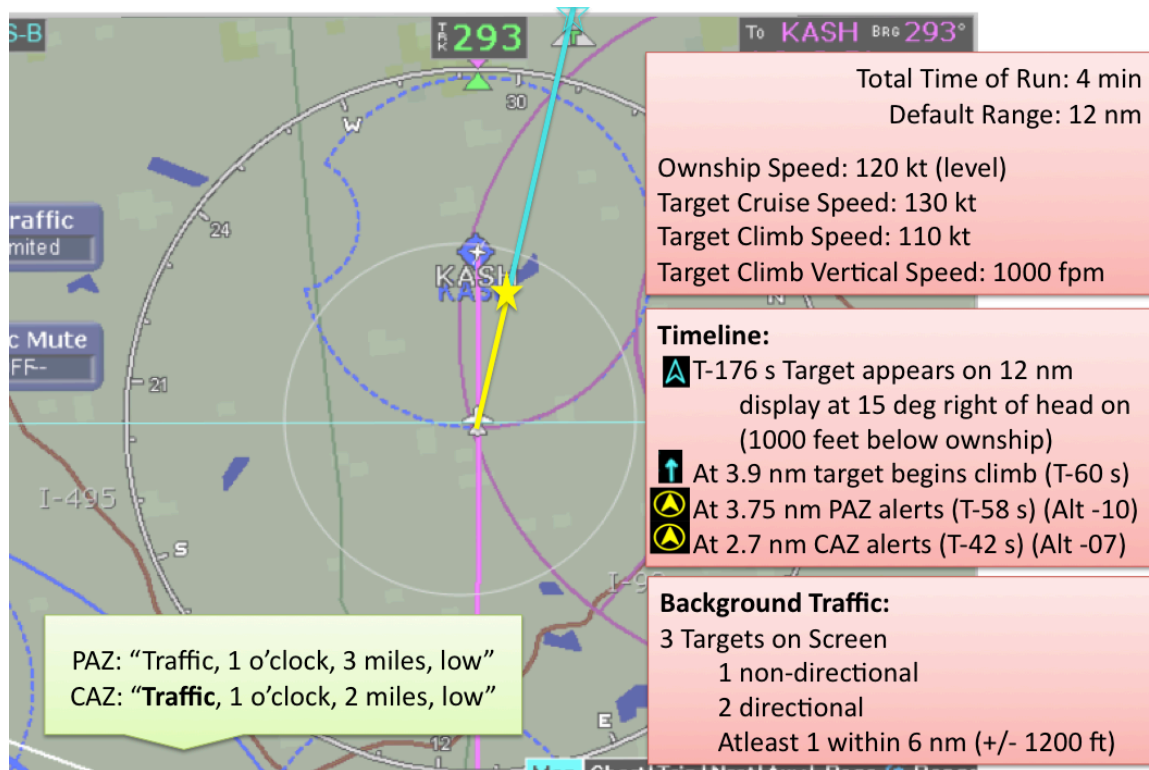
Figure 3-19. Head-On Encounter Description

12. *Level vs Climb/Descent Scenario* **(Encounter 12)**

As can be seen in Figure 3-20, in this encounter, the target was flying level 1000 feet below the ownship on a converging course from 2 o'clock. At a given time, the ownship began a descent creating a conflict with the target. In order to minimize recognition by the pilot, during the comparison scenarios the ownship would climb into a conflict from 10 o'clock.
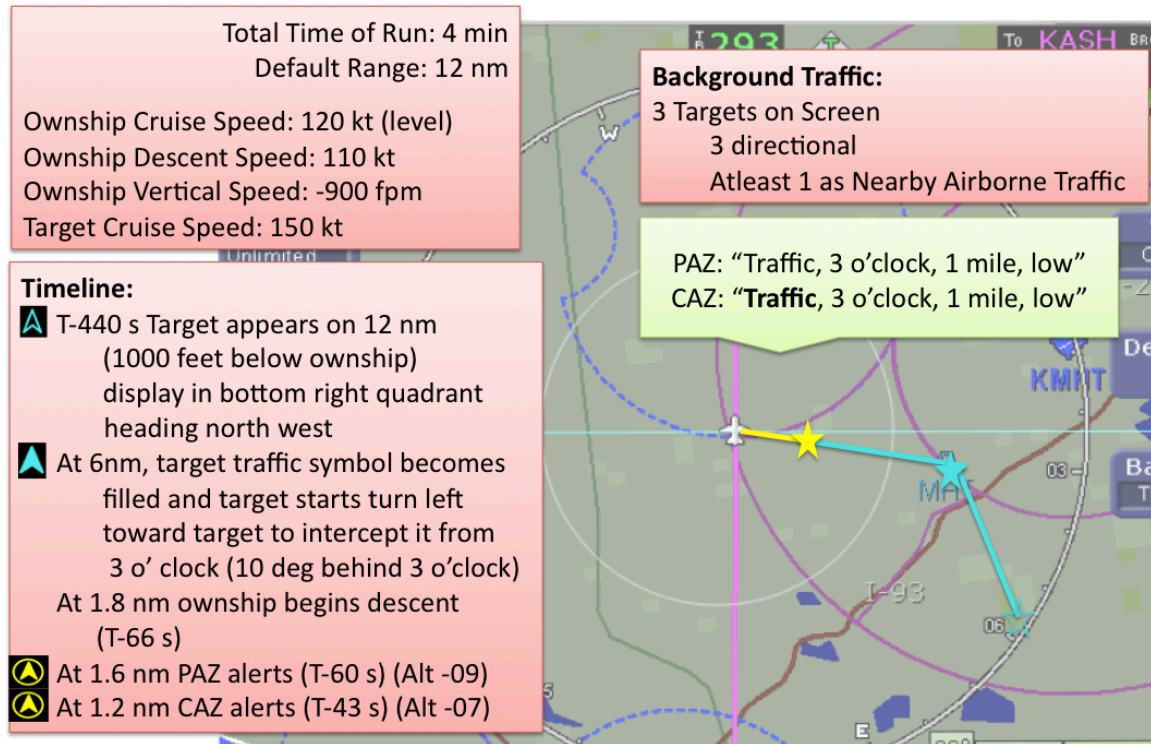
Figure 3-20. Level vs. Climbing/Descending Encounter Description

13. Level vs. Maneuvering Scenario (*Encounter 13*)

As can be seen in Figure 3-21, in this encounter, the target began two miles in front of the ownship who was flying straight and level. At a given time, the target began a right turn for a rectangular course. The target was not actually on a collision course with the ownship, however, an alert annunciated on the "downwind" leg of the rectangular course due to the higher closure rate.

Total Time of Run: 4 min
Default Range: 6 nm

Ownship: Level 120 knots
Target Speed: 80 knots (flying rectangular
    course)

Background Traffic:
3 Targets on Screen
    2 directional

PAZ: "Traffic, 1 o'clock, 1 mile, same altitude"

Timeline:
Run Start:
▲   Target is 3 miles ahead of ownship
        travelling same direction (same alt)
▲ After 90 s: Target turns right 90 deg for
        half mile
⊛ After 22 s: Target turns right 90 degrees
        for one mile
        PAZ Annunciates
▲ Once traffic and ownship are abeam
        each other, PAZ alert goes away
▲ After 44 s: Target turns right 90 deg for
        half mile
▲ After 22 s: Target turns right 90 deg to
        follow ownship

Figure 3-21. Level vs. Maneuvering Encounter Description

14. *Off Scale Alert Scenario* **(Encounter 14)**

As is shown in Figure 3-22, this scenario was used to test the off-scale alert
symbology. A background traffic was embedded at close range in order to lure
the participant into a close zoom level. The actual threat target, however,
approached with very high closure rate, thus the pilot would receive an alert
while the target was outside the range of the display and receive an off-scale
alert symbol. This encounter was designed similarly to the high closure rate
(Encounter 1) described above, however the target approached from 2 o'clock.
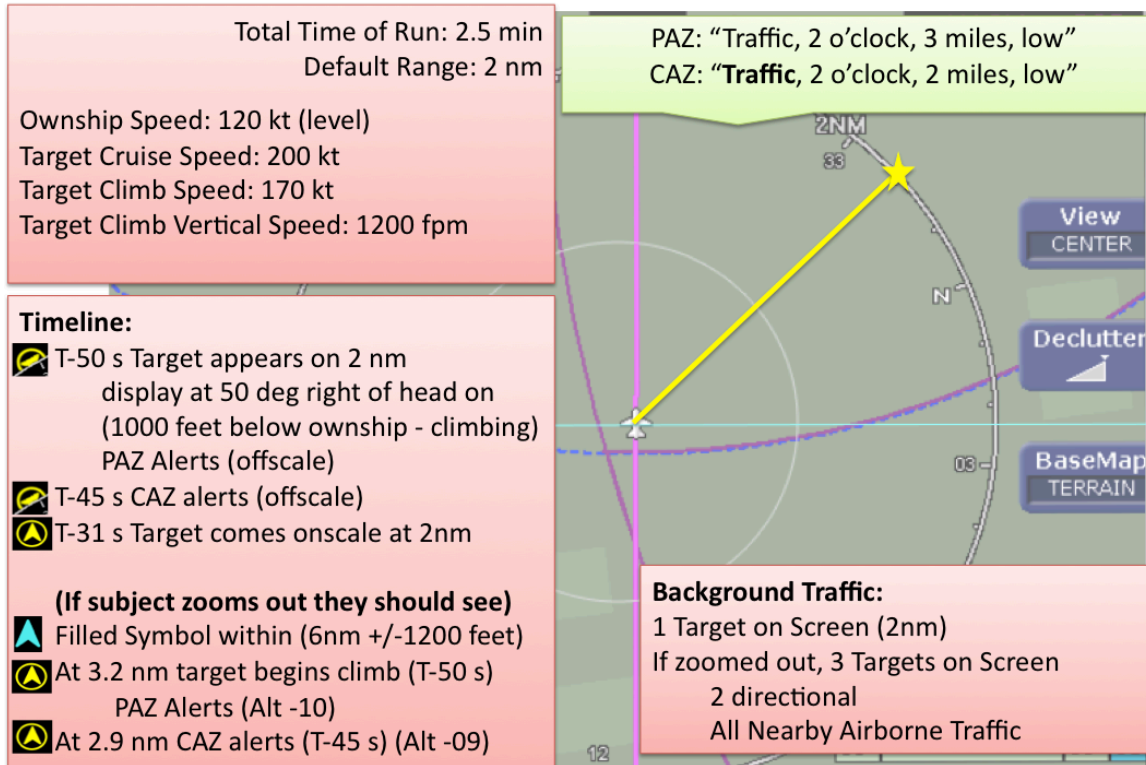
Figure 3-22. Off-Scale Alert Encounter Description

3.4 TSAA Versions

Three versions of TSAA were developed throughout the experimental process. TSAA Version 3.0 was representative of the final interface design presented in Section 2.2.2. The following developmental versions are described below and highlight main differences between the version and the final design.

1. TSAA Version 1.0: The depiction of proximate traffic was under consideration at this point, thus the experimenter was given the option of whether to include proximate traffic in each scenario. The differentiation of non-qualified targets was also under deliberation, thus the experimenter was given control to depict non-qualified targets using a non-directional diamond or a basic directional symbol. The aural annunciation of traffic did not include vertical trend information in this version ("Traffic, 2 o'clock, high, 3 miles"). This system input ideal ADS-B data.

2. TSAA Version 2.0: Proximate traffic was included in this version and non-qualified targets were depicted with a "LTD" designator in the call sign field. The aural annunciation of traffic did not include vertical trend information in this version ("Traffic, 2 o'clock, high, 3 miles"). This system also input ideal ADS-B data.

3. TSAA Version 3.0: Again, proximate traffic was included and non-qualified targets were shown with a "LTD" designator. The aural annunciation in version 3.0 included vertical trend information ("Traffic, 2 o'clock, high, 3 miles, descending"). This system input realistic quality ADS-B data.

Chapter 4

TSAA System Interface Refinement

A number of detailed studies were performed to evaluate the interface options in response to issues. These included evaluating the effect of depicting proximate traffic and non-qualified traffic as well as the benefit of including vertical trend information in the aural annunciation of traffic.

4.1 Proximate Traffic

As discussed in Section 2.3, there was the concern that proximate traffic may cause confusion for pilots due to an inconsistency in alerting criteria. An experiment was designed to probe whether the proximate depiction of traffic caused confusion or aided the pilot in threat assessment.

4.1.1 Experimental Design

The video playback approach described in Section 3.2 was used for this study. TSAA Version 1.0 was the baseline for this experiment. The proximate traffic comparison was a between subjects design. As can be seen in Figure 4.1, one half of the subjects experienced a system with proximate traffic depicted, while the other half of the subjects experienced a system without proximate traffic depicted. The basic symbols would fill when the traffic was within 6 nm, plus/minus 1,200 ft of the ownship position.
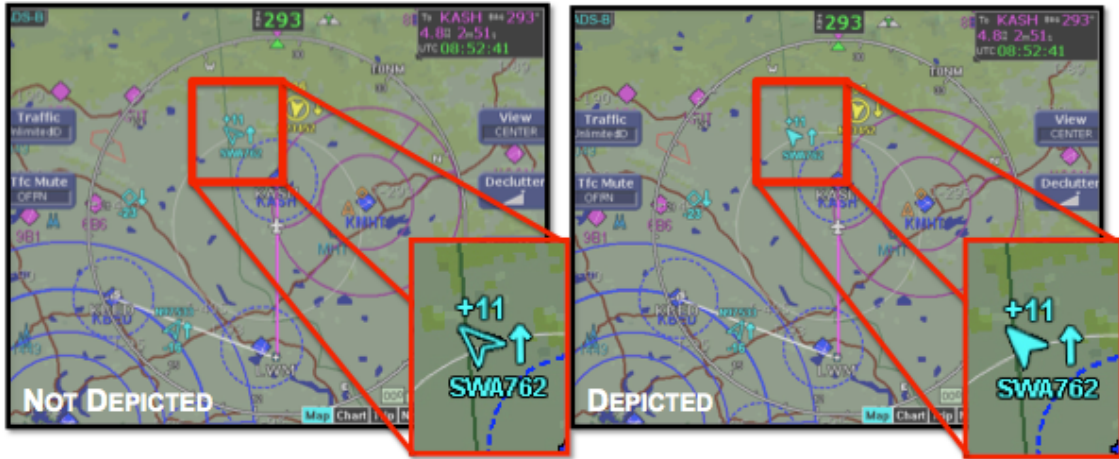
Figure 4-1. Proximate Traffic Comparison: (Left – Proximate Traffic Not Depicted, Right-Proximate Traffic Depicted).

The participants for this study consisted of 12 general aviation pilots ranging in certification from private pilot to flight instructor, shown in Table 4-1. Participants were recruited from flight schools and flying clubs in the greater Boston area.

	Non-Prox	Prox
# Subjects	6	6
Mean Total Time	530	489
Mean Hours (Past 90 days)	8	14
Mean Hours (Previous 12 months)	50	70
Total Total Time	3178	2934
Private	4	1
Private/Instrument	1	3
Commercial/Instrument	1	2
ATP	0	0
CFI(I)/MEI	1	0
Ground Instructor	0	1

Table 4-1. Participant Experience for Proximate Study

Two high closure rate scenarios (Encounter 1 in Section 3.3) where the TSAA alert annunciated prior to the target reaching 6 nm relative distance were embedded into the scenarios. These scenarios were designed to directly probe for any confusion which may occur due to inconsistency in the alerting criteria.

SYSTEM A:
DIFFERENTIATED NON-QUALIFIED TARGETS

7. Base vs Final	Qualified
11. Level vs Maneuvering	Qualified
3. Head on	Non-Qualified Differentiated
8. High Closure Rate Traffic	Qualified
9. Autorotating Target	Qualified
6. Level vs Descending	Non-Qualified Differentiated
15. Teasing PAZ	Qualified
1. Head on	Qualified

SYSTEM B:
NON-DIFFERENTIATED NON-QUALIFIED TARGETS

4. Level vs Descending	Qualified
16. Off Scale Alert	Qualified
14. Multiple Intruder	Qualfied
2. Head on	Non-Qualified Non- Differentiated
13. Entry vs Downwind	Qualified
10. Final vs Base	Qualified
5. Level vs Climb	Non-Qualified Non- Differentiated
12. High Closure Rate Traffic	Qualified

Figure 4-2. Scenario Sequence Used for Proximate Study

The scenarios were split between two systems shown in Figure 4.2. In order to account for order effects, half of each group of subjects ran System A first, while the other half of each group ran System B first. An intentional learning effect was embedded into the order of the scenarios to build confidence in the system (having a number of qualified cases prior to presenting a non-qualified case).

4.1.2 Results and Conclusions

Proximate traffic depiction was manipulated as a between subjects variable during this study. The group who experienced proximate traffic consistently identified targets as threats earlier than those who did not experience proximate traffic depiction $(F(1,16)=12.92$, $p<0.001)$. Figure 4-3 shows the distribution of identification times for each scenario (y axis), with proximate distributions shown in blue box plots while non-proximate distributions are shown in red box plots. The alerts are shown as yellow (PAZ) or orange (CAZ) diamonds. One can also see that pilots were identifying threats well before the alerts annunciated. In 68% of the cases, conflicts were identified as threats before any alert annunciated.
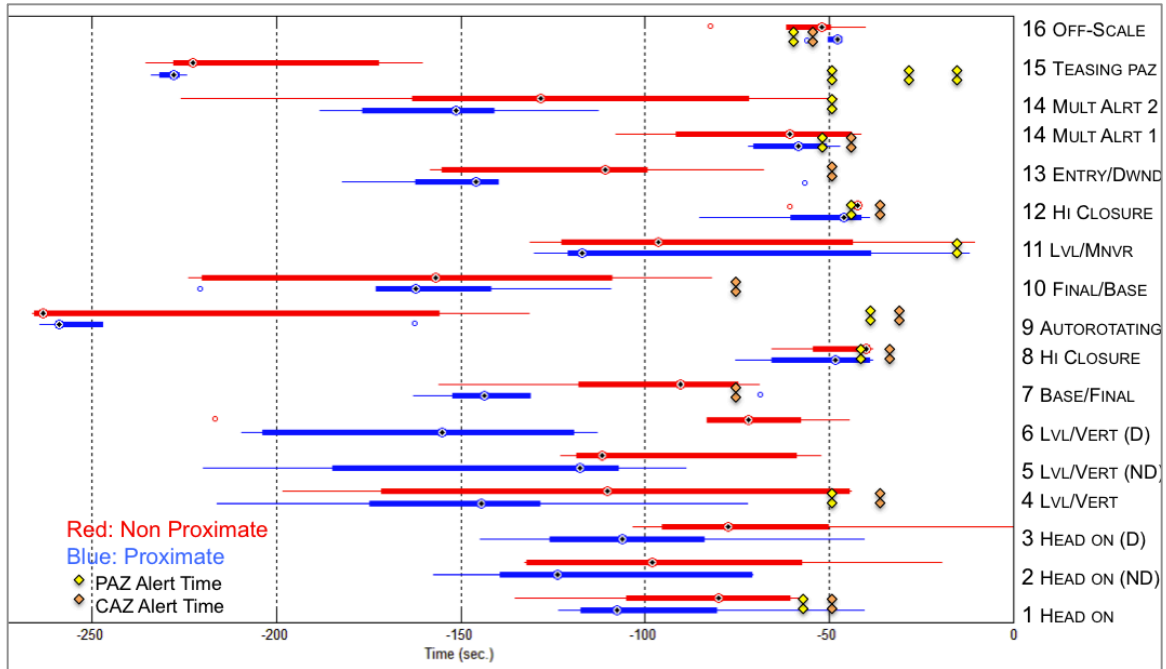
Figure 4-3. Identification Time Distributions for Proximate Comparison for Each Scenario

There was no significant difference in side task performance, pre-reaction time, and reaction time between the groups who experienced proximate traffic and those who did not. There was a specific post evaluation question probing the usefulness of the proximate depiction. Figure 4-4 shows that general subjective response to this question was positive, where there were no cases where subjects indicated that the proximate traffic made it more difficult to identify the threat.
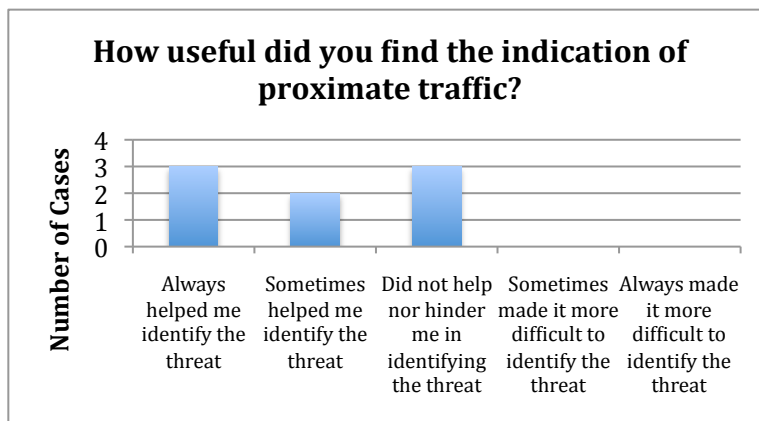
Figure 4-4. Subjective Response to Proximate Traffic Usefulness.

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Due to the benefit apparent in conflict recognition and subjective response, it was recommended to include proximate traffic depiction in the design of the TSAA system.

4.2 Non-Qualified Targets

There was the chance that there could be targets that meet the minimum qualifications to be displayed on the CDTI, however do not meet the minimum qualifications for the TSAA to issue an alert. These non-qualified targets were those which do not have sufficient data quality (integrity, accuracy, or update rate) for the TSAA to issue a reliable alert. Because this issue had not previously been encountered, there was no precedence or guidance on whether to display non-qualified targets, whether to differentiate them from qualified targets, or how to display these targets.

4.2.1 Display of Non-Qualified Targets

There was concern of a loss of trust in the TSAA system if the pilot visually observed a target that was not displayed on the CDTI. In order to investigate whether to display non-qualified targets on the CDTI, an experiment was designed.

Experimental Design

Using the human-in-the-loop approach described in Section 3.1 and TSAA Version 2.0, analysis of this issue in the display based system and the audio only system was evaluated. In both systems, non-qualified targets scenarios were embedded into the runs. In the display case, non-qualified targets were depicted with a "LTD" designator. In the audio system, there was no indication of non-qualified traffic unless the pilot visually acquired the traffic out the window. In both the audio and display systems, 2 Head-On scenarios (Encounter 1 in Section 3-3) were embedded where in one encounter a qualified target approached from the forward field of view; in the other encounter, a non-qualified target approached from the same field of view. Both of these targets were visible in the out-the-window display.

Results and Conclusions

It can be seen in Figure 4-5 that the miss distances for the audio system are on the order of 0.20 nm less than the miss distances for the display. One can also see that pilots missed the qualified target in the audio system by 0.07 nm more than they missed the non-qualified target in the audio system ($z=2.10$, $p=0.036$). When comparing the audio non-qualified encounter to the display non-qualified encounter, the miss distance when the display was available was 0.34 nm higher than in the audio case ($z= -1.80$, $p=0.073$).
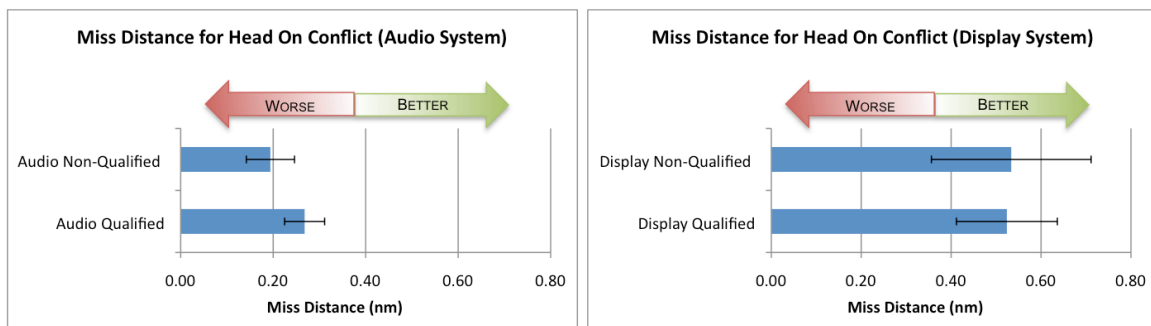
Figure 4-5. Miss Distance for Head-On Conflict.

The number of near misses were also calculated for each of the cases listed in Table 4-2. As can be seen, the audio non-qualified case involved the most number of near misses. Introducing an alert into the audio system decreased the number of near misses by 38%. The display system with qualified targets was shown to be the most effective where no near misses were observed. Overall, it can be seen that performance suffered without alerting or the CDTI.

Audio System	# of Near Misses (Maximum 16)	Display System	# of Near Misses (Maximum 16)
Non-Qualified	7 (44%)	Non-Qualified	3 (19%)
Qualified	1 (6%)	Qualified	0 (0%)

Table 4-2. Number of Near Misses for Head-On Conflict.

It can be seen in Figure 4-6 that there was indication of lack of trust for the audio system. In discussions with the pilots, they indicated this lack of trust was due to the non-qualified target experienced in the audio system. The pilots who lost trust iterated that they were unsure whether the system was functional once they

experienced that encounter. This loss of trust in the system parallels the concern with not displaying non-qualified targets on the display. Due to the potential loss of trust in the system, a design decision was made to display non-qualified targets on the CDTI.
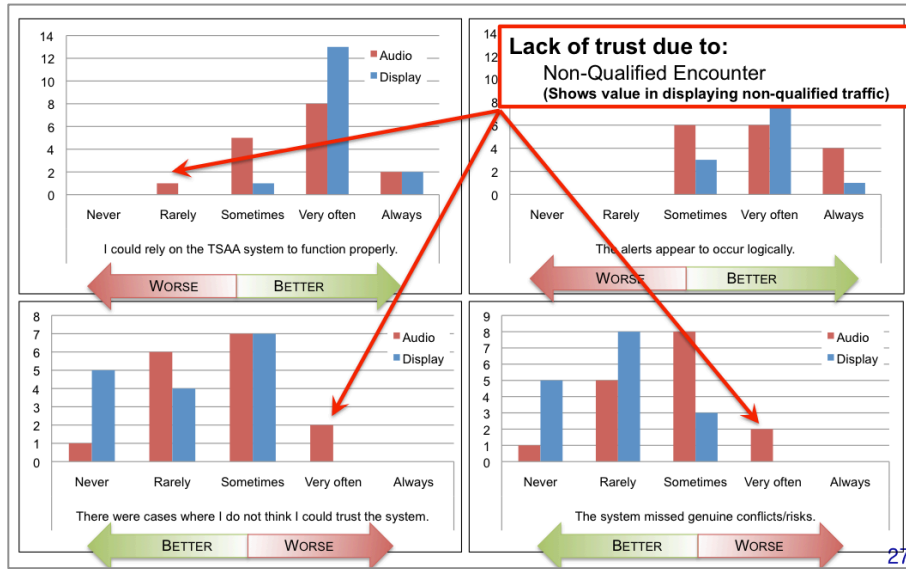
Figure 4-6. Trust Questionnaire Subjective Response

4.2.2 Modes of Differentiation of Non-Qualified Targets

Since the decision was made to display non-qualified targets, the next consideration that arose was how to display these targets. One method to display the targets was to display them exactly like the qualified targets, essentially not differentiating them from targets that would get an alert. Again, the concern with this method was a loss of trust in the TSAA system if pilots visually acquire a conflict target and realize they did not get an alert on the traffic and become unsure whether the system is functional. This issue is explored in the following section.

The other option was to differentiate non-qualified targets in some form on the CDTI. The Volpe National Transportation Systems Center conducted a study on intuitiveness of various traffic symbols and found that an explicit data quality tag was effective in signifying limited quality targets [14]. In response to precedent consistency, the TSAA team proposed a version of explicit data quality tag seen in Figure 4-7, which was composed of a "LTD" to indicate limited data. In addition to

that option, Figure 4-8 shows another option that was considered where all non-qualified targets would be indicated with a non-directional diamond. The non-directional target and limited designator options were both tested in the human factors studies described in the following sections.

Figure 4-7. LTD Designator for Non-Qualified Targets

Figure 4-8. Non-Directional Target to Designate Non-Qualified Targets.

4.2.3 Differentiation of Non-Qualified Targets from Qualified Targets

In order to test whether differentiation between qualified and non-qualified targets was necessary, a study was conducted using video playbacks of scenario encounters described in Section 3.2. TSAA Version 1.0 was used for this experiment.

Experimental Design

Sixteen conflict scenarios were split between two systems, which are shown in Figure 4-9. In the differentiated system, non-qualified targets were always depicted with a non-directional diamond. In the non-differentiated system, some non-qualified targets were depicted as a non-directional diamond and are others depicted as directional targets depending on the quality of information. In retrospect, it became apparent that a confound emerged because the differentiated system was depicted with a non-directional diamond, losing directionality on those targets. Had this information been revealed prior to the study, it would have been conducted differently.

The experiment was a within subjects comparison. The encounters, which were repeated for the non-qualified target comparison, were the "Head-On" (Encounter 11 in Section 3-3) as well as a "vertically maneuvering ownship vs. a level target" scenario (Encounter 12 in Section 3-3).

Figure 4-9. Non-Qualified Target Differentiation Comparison.
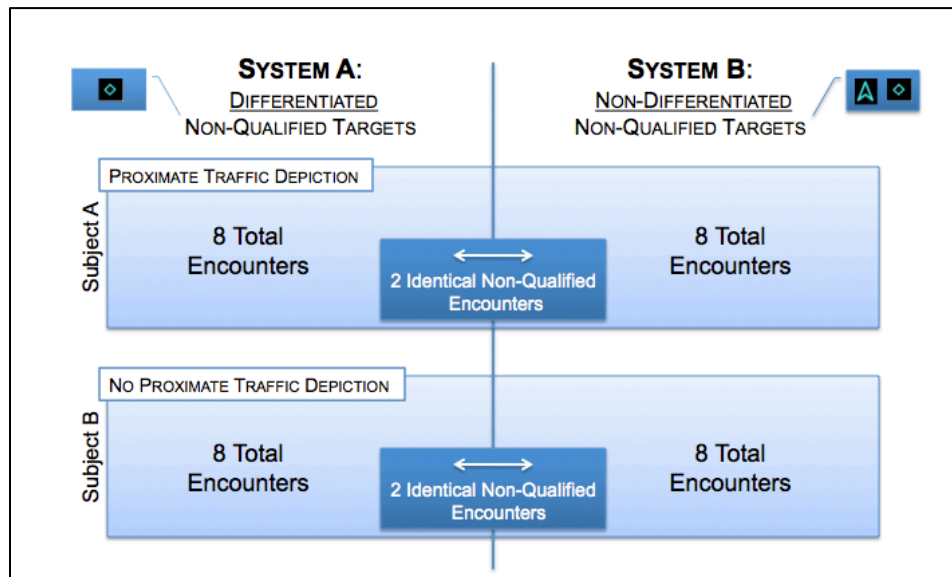
Figure 4-10. Test Matrix for Differentiation Comparison.

The participants for this study consisted of 18 general aviation pilots ranging in certification from private pilot to airline transport pilot as is shown in Table 4-3. Participants were recruited from flight schools and flying clubs in the greater Boston area.

Total Participant Flight Time	21682
Mean Total Time	1049
Mean Hours (Past 90 days)	23
Mean Hours (Previous 12 months)	90
Private	5
Private/Instrument	7
Commercial/Instrument	5
ATP	1
CFI(I)/MEI	3
Ground Instructor	1

Table 4-3. Participant Experience for Non-Qualified Target Differentiation Study

The systems were counterbalanced where half of the subjects ran the differentiated system first, while the other half ran the non-differentiated system first. Also embedded was an intentional learning effect into the order of the scenarios to build confidence in the system (having a number of qualified cases prior to presenting a non-qualified case). All of the encounters are listed in Figure 4-11 which highlights the actual sequence of the profiles that were run. Shaded scenarios represent encounters with non-qualified targets.

Figure 4-11. Sequence for Encounter Scenarios Used in Differentiation Study.

Results and Conclusions

Overall, there was no significant difference in identification times between the differentiated system and the non-differentiated system for either of the comparison scenarios as can be seen in Figure 4-12. In addition, there was no significant difference in side task performance between systems as well as no significant difference in subjective response to trust between systems which can be seen in Figure 4-13.
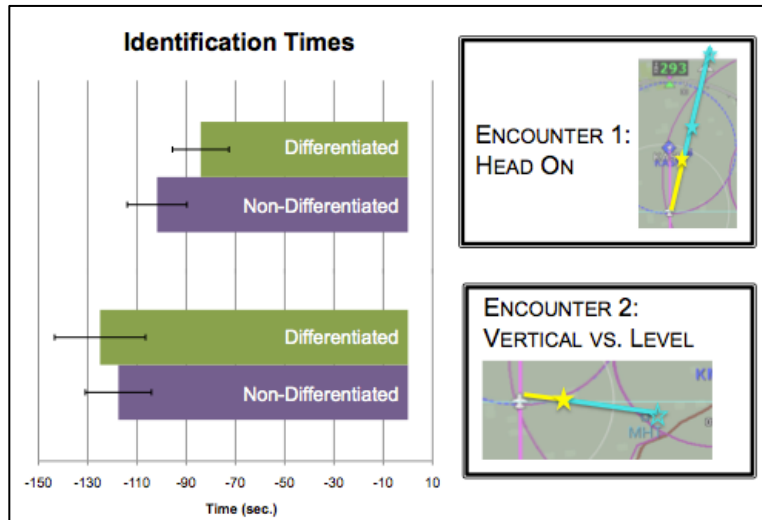
Figure 4-12. Identification Times for Non-Qualified Differentiation Comparison Encounters.
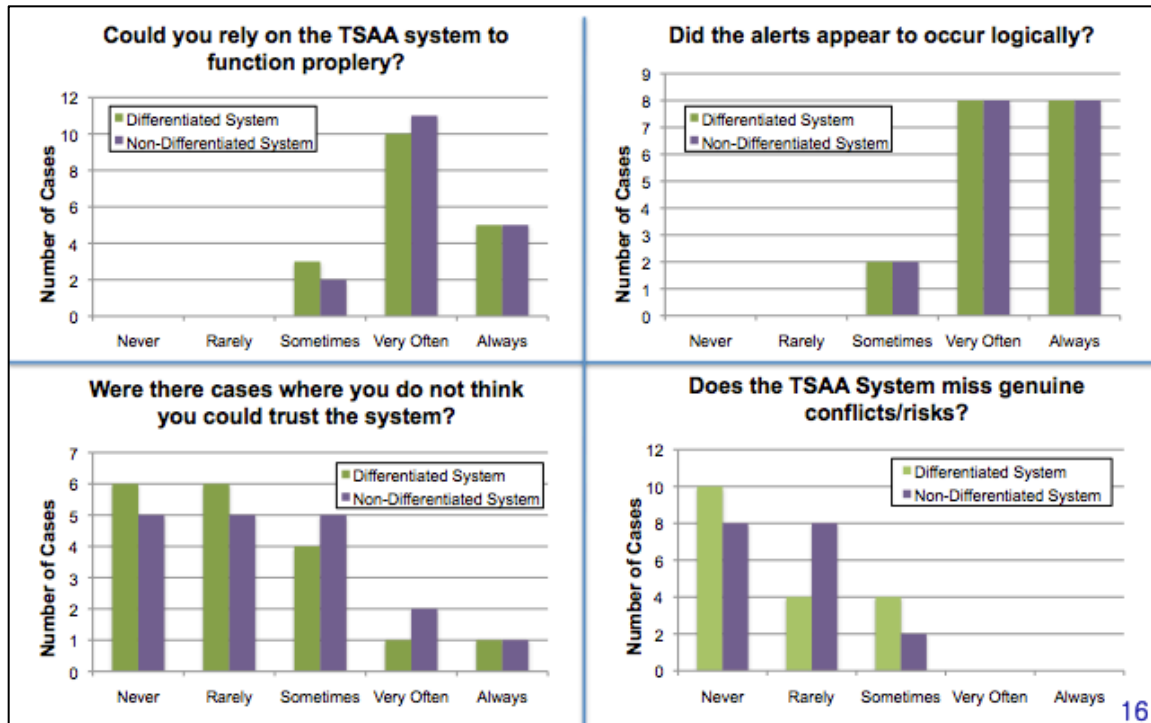
Figure 4-13. Subjective Response for Non-Qualified Differentiation Comparison.

In terms of subjective preference between the differentiated and non-differentiated system, the responses were split. 8 out of 18 participants preferred the differentiated system. During post system interviews, pilots revealed that the main reason for their preference for the differentiated system was clarity as to which targets would alert and which would not. 7 out of 18 participants preferred the non-differentiated system. Again during post system interviews, the pilots revealed that the main reason for the preference for the non-differentiated system was value in maintaining directionality on the targets.

It was apparent that a confound emerged because the differentiated system was depicted with a non-directional diamond, losing directionality on those targets. Pilots perceived that there was value in maintaining directionality as well as differentiating targets. An alternate designation for non-qualified targets was chosen for analysis in further studies.

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4.3 Vertical Trend Information in Aural Annunciation

During preliminary experiments it was observed that pilots did not consistently respond to vertical closure rate encounters. It was considered that adding vertical trend information into the aural traffic annunciation could provide better threat assessment. A possible disadvantage to including vertical trend information in the audio call was the increase in syllable count and increases in the duration of the alert. This could delay subsequent alerts by an extra 1-2 seconds in the case that an alert was queued. A human in the loop experiment was designed to determine whether there was benefit in annunciating vertical trend.

4.3.1 Experimental Design

The study was a between subjects design. TSAA Version 2.0 was used for the subjects who did not experience vertical trend information. TSAA Version 3.0 was used for subjects who experienced vertical trend information in the audio call.

Participants flew flight profiles with scenarios that included a vertically maneuvering target (Encounter 2 in Section 3-3). This scenario was run using the display based system and the audio only system. In order to maintain similar data quality for the target between Version 2.0 and 3.0, the target was assigned an ADS-R data quality in Version 3.0 which was not expected to significantly change target dynamics. A description of the target type is provided in Section 5-2.

The participants for this study consisted of 32 general aviation pilots ranging in certification from private pilot to airline transport pilot. Participants were recruited from flight schools and flying clubs in the greater Boston area. Descriptions of pilot experience are provided in Tables 4-4 and 4-5 for each group.

Total Participant Flight Time (hours)	13086
Mean Total Time (hours)	818
Mean Hours (Past 90 days)	16
Mean Hours (Previous 12 months)	58
Private	6
Private/Instrument	4
Commercial/Instrument	5
ATP	1
CFI(I)/MEI	1

Table 4-4. Participant Experience for Group without Vertical Trend Information

Total Participant Flight Time (hours)	14674
Mean Total Time (hours)	917
Mean Hours (Past 90 days)	22
Mean Hours (Previous 12 months)	75
Private	9
Private/Instrument	3
Commercial/Instrument	4
ATP	0
CFI(I)/MEI	2

Table 4-5. Participant Experience for Group with Vertical Trend Information

4.3.2 Results and Conclusions

		Without Vert Trend	With Vert Trend
Scenario	TSAA System	# Near Misses	# Near Misses
Vertical HCR	Audio	12 (75%)	6 (38%)
Vertical HCR	Display	5 (31%)	2 (13%)

Table 4-6. Number of Near Misses for Systems with and without Vertical Trend Information

For the vertical high closure rate encounter, differences in miss distances and time of evasive action were observed for both the display system and the audio system. As can be seen by Figure 4-14, in the audio based system, the average miss distance increased by .25 nm going from 0.07 nm without the vertical trend to 0.32 nm with the vertical trend information (z=2.88, p=0.004). In the display based system, the average miss distance increased by 0.36 nm going from 0.11 nm without the vertical trend information to 0.47 nm with the vertical trend information (z=3.41, p=0.001).

In addition to the increase in miss distance, it can be seen in Figure 4-15 that when the vertical trend was included, pilots that experienced the vertical trend information using the display system took evasive action on average 15.5 seconds earlier than pilots that did not receive vertical trend on the display based system (z=2.99, p=0.003). In the audio system, pilots maneuvered on average 9.1 seconds earlier when the vertical trend information was provided (z=-2.20, p=0.028).
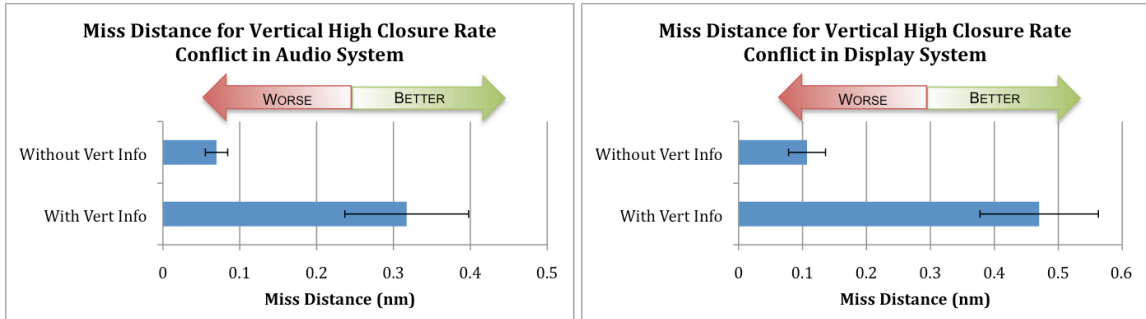
Figure 4-14. Miss Distance for the Vertical High Closure Rate Conflict for the Audio (left) and Display (right) Systems.
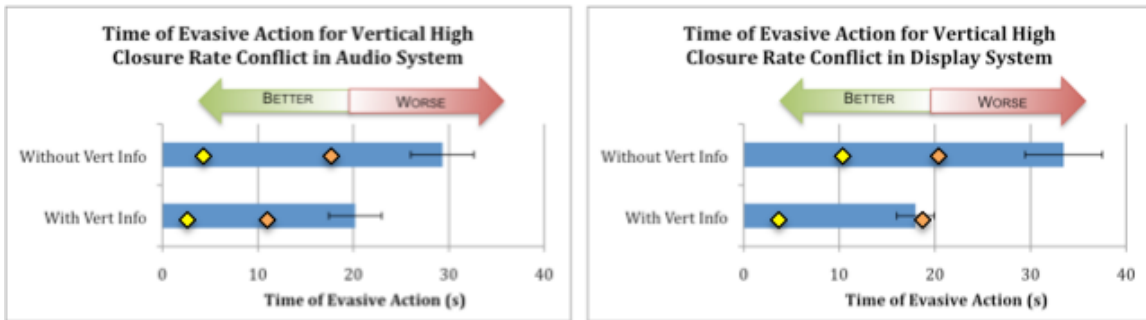
Figure 4-15. Time of Evasive Action for the Vertical High Closure Rate Conflict for the Audio (left) and Display (right) Systems.
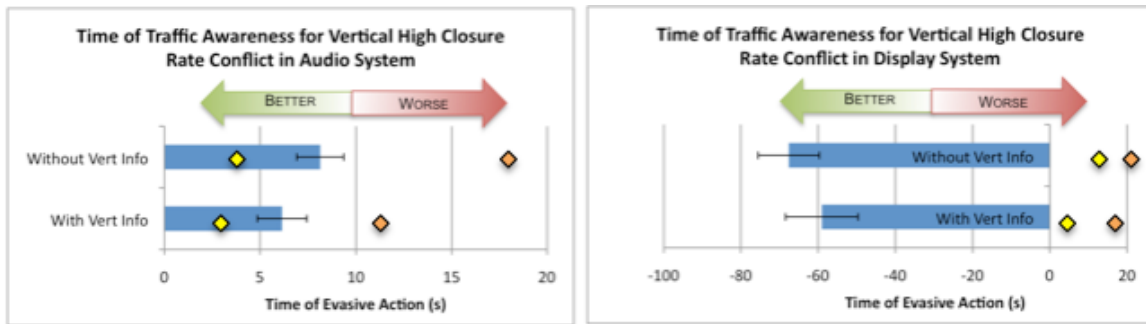
Figure 4-16. Time of Traffic Awareness for the Vertical High Closure Rate Conflict for the Audio (left) and Display (right) Systems.
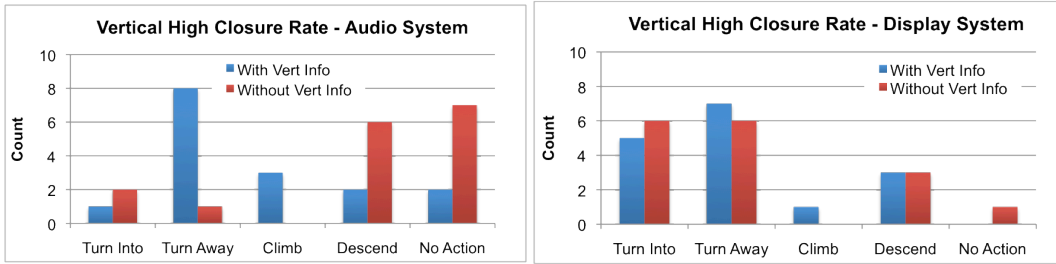
Figure 4-17. Type of Evasive Action for the Vertical High Closure Rate Conflict for the Audio (left) and Display (right) Systems.

Figure 4-17 shows the decrease in the number of participants who maneuvered when vertical trend information was provided. Over the shoulder experimenter observations during the test highlighted that participants in general were aware of the traffic well prior to when the target became a threat (45-60 s before the target began descending), however in the system that did not include the vertical trend in the audio call, pilots would scan the display to determine why the alert annunciated, essentially to determine whether the target remained at the un-conflicting altitude or whether it had begun descending and became a conflict. In this case it does appear that the addition of vertical trend information added value to the system.

4.4 Summary of Design Refinements

Based on the above studies, the following recommendations were made for the TSAA design.

- Depict proximate traffic
- Depict directionality whenever directionality is valid
- Differentiate non-qualified targets with a "LTD" designator
- Include vertical trend information in the aural annunciation of alerts

Three design options were evaluated using experimental techniques. The proximate traffic indication was evaluated to determine whether its inclusion caused confusion to the user or whether it aided the pilot in evaluating target threat. Results indicated that pilots who saw the proximate indication identified targets as threats earlier than pilots who did not see the proximate indication. Subjective results indicated no negative perceptions about the use of proximate depiction. Due to the

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benefit in evaluating target threat and positive subjective response, proximate traffic was included in the final TSAA design.

The evaluation of non-qualified targets found that retaining directional information, when valid, was important to the pilot as well as differentiating non-qualified targets from qualified targets. Due to the negative reaction to displaying targets with the non-directional diamond, the LTD designator was used to differentiate non-qualified targets. This designator was deemed appropriate by the pilot users in further studies. The recommendation for the final design for non-qualified targets was to differentiate non-qualified targets from qualified targets using the "LTD" to designate limited data quality.

The other design option evaluated was the inclusion of vertical trend information in the audio callout. Performance was evaluated with and without the information in the audio call to assess benefit. It was found that miss distances significantly increased during a vertical high closure rate encounter when the vertical trend information was included. Due to the observed benefit, the recommendation for final design was to include vertical trend information in the aural alert annunciation.

Chapter 5

System Performance

The TSAA design was evaluated in both the audio only and the display based systems. It was also tested using ideal quality ADS-B as well as realistic data quality. Performance testing was done using the human-in-the-loop approach described in Section 3.1.

5.1 Performance with Ideal ADS-B Quality

5.1.1 Experimental Design

In order to test the performance of the system, pilots were exposed to identical encounter scenarios, where in one case they would receive an alert and the other not receive an alert on the premise that the target was non-qualified. These non-qualified targets were differentiated using the LTD designator. This probe was embedded in the audio and display based systems. TSAA Version 2.0 was used in this study with ideal quality ADS-B.

The audio based system was a representation of TSAA Class I equipment. During this study, a yellow circle appeared on the MFD monitor in the forward field of view to provide visual cue of alert. The display based system was a representation of TSAA Class II equipment. Data was taken to ensure system performance was appropriate with both classes of equipment as well as to note any difference in performance between equipment classes.

The participants for this study consisted of 16 general aviation pilots ranging in certification from private pilot to airline transport pilot as is shown in Table 5-1. Participants were recruited from flight schools and flying clubs in the greater Boston area.

Total Participant Flight Time (hours)	13086
Mean Total Time (hours)	818
Mean Hours (Past 90 days)	16
Mean Hours (Previous 12 months)	58
Private	6
Private/Instrument	4
Commercial/Instrument	5
ATP	1
CFI(I)/MEI	1

Table 5-1. Participant Experience for System Performance with Ideal Data Quality Study

As can be seen in Figure 5-1, the two enroute scenarios which were directly compared were the Head-On (Encounter 1 in Section 3-3) and the Vertical High Closure Rate (Encounter 2 in Section 3-3). The two pattern scenarios which were directly compared were the Base vs. Final (Encounter 4 in Section 3-1) and the Entry vs Downwind (Encounter 5 in Section 3-3).
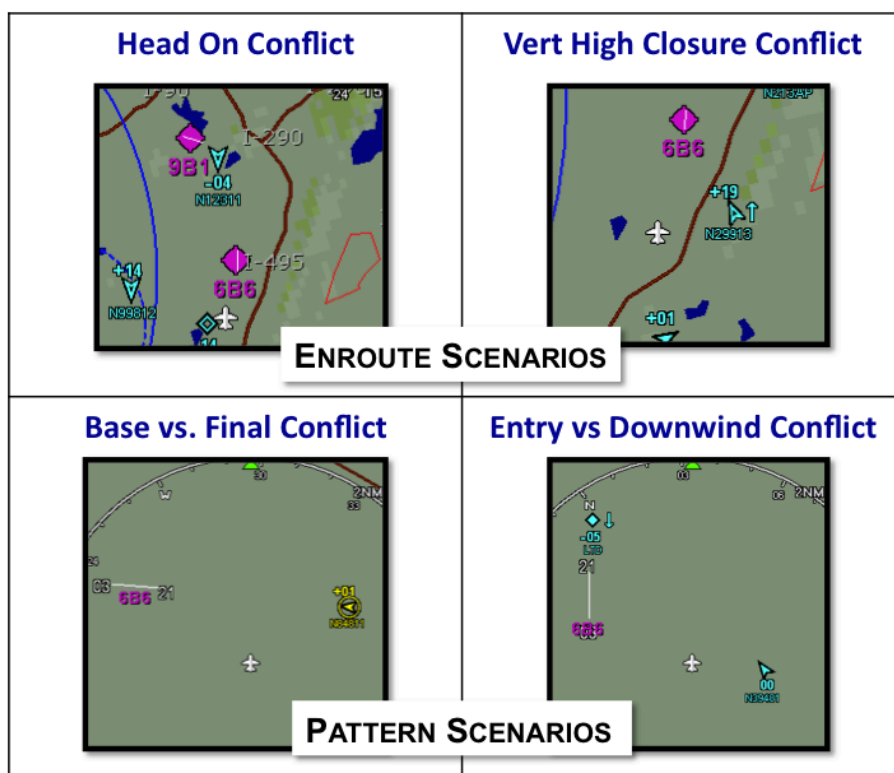
Figure 5-1. Comparison Scenarios for System Performance Study with Ideal Data

The scenarios listed in Figure 5-2 were presented in the order listed in Figure 5-3 and 5.4. The systems were counterbalanced where half of the subjects ran the audio-based system first while the other half ran the display system first. The order of the blocks was reversed in half of the cases. The sequence was designed to compensate for anticipated learning and fatigue curves. This yielded 4 counterbalancing groups.

1. Display 1st, Scenario Block Sequence Forward,

   Audio 2nd, Scenario Block Sequence Forward

2. Display 1st, Scenario Block Sequence Reverse,

   Audio 2nd, Scenario Block Sequence Reverse

3. Audio 1st, Scenario Block Sequence Forward,

   Display 2nd, Scenario Block Sequence Forward

4. Audio 1st, Scenario Block Sequence Reverse,

   Display 2nd, Scenario Block Sequence Reverse

Display Based System

1. Head on/High Closure Rate	8. Head on/High Closure Rate
Ownship: Level	Ownship: Level
Target: Level	Target: Level

2. Base vs Final (A4)	9. Base vs Final (A4)
Ownship: Base	Ownship: Base
Target: Final	Target: Final

3. Autorotating Target	10. Takeoff/Landing Opposite Rwy
Ownship: Final	Ownship: Takeoff
Target: Autorotating	Target: Landing

4. Entry vs Downwind	11. Entry vs Downwind
Ownship: Downwind	Ownship: Downwind
Target: Entering	Target: Entering

5. Multiple Intruder Case (+Off-scale)	12. Overtaking on Final
Ownship: Level	Ownship: Final
Target: Descending & Level	Target: Overtaking

6. Teasing PAZ	13. Final vs Base (A4)
Ownship: Level	Ownship: Final
Target: Level	Target: Base

7. High Closure Rate (Vertical)	14. High Closure Rate (Vertical)
Ownship: Level	Ownship: Level
Target: Climb	Target: Climb

Audio Based System

15. Entry vs Downwind
    Ownship: Downwind
    Target: Entering

16. Base vs Final (A4)
    Ownship: Base
    Target: Final

17. Head on/High Closure Rate
    Ownship: Level
    Target: Climb

18. Head on/High Closure Rate
    Ownship: Level
    Target: Climb

19. High Closure Rate (Vertical)
    Ownship: Level
    Target: Climb

Direct Comparison Scenarios
Qualified vs Non-Qualified

Qualified Scenarios

Non-Qualified Scenarios

Figure 5-2. Scenarios for Performance Evaluation with Ideal Data

Audio Based System – C1

15. Entry vs Downwind	
Ownship: Downwind	P8
Target: Entering	

16.. Base vs Final (A4)	
Ownship: Base	P9
Target: Final	

17. Head on/High Closure Rate	
Ownship: Level	
Target: Climb	

19. High Closure Rate (Vertical)	
Ownship: Level	E-block-4
Target: Climb	

18. Head on/High Closure Rate	
Ownship: Level	
Target: Climb	

Audio Based System- C2

18. Head on/High Closure Rate	
Ownship: Level	
Target: Climb	

19. High Closure Rate (Vertical)	E-block-4
Ownship: Level	
Target: Climb	

17. Head on/High Closure Rate	
Ownship: Level	
Target: Climb	

16.. Base vs Final (A4)	
Ownship: Base	P9
Target: Final	

15. Entry vs Downwind	
Ownship: Downwind	P8
Target: Entering	

Figure 5-3. Order of Scenarios for Audio Based System (Counterbalancing Sequence C1 and C2)

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Figure 5-4. Order of Scenarios for Display Based System (Counterbalancing Sequence C1 & C2)

5.1.2 Results and Conclusions

The benefit of the TSAA Class I and II systems was apparent in near miss analysis. Table 5-2 highlights the number of near misses for the display and audio systems compared to encounters with qualified and non-qualified targets. Benefit of the TSAA Class I equipment can be seen upon comparison of the head-on scenario where

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nearly half (44%) of encounters without a TSAA system (Audio – Non-Qualified) resulted in a near miss. Number of near misses dropped by 38% when an alert was provided in the audio system. One can see the reduction in near misses in the display system when an alert was annunciated for all compared encounters which shows the benefit provided by the TSAA Class II system. The Vertical High Closure Rate scenario was the most challenging as can be seen by the number of near misses for that encounter, however the best performance was seen in display system when an alert was provided. Only one of the cases was classified as a collision in all of the comparison cases. This collision occurred during the Base vs. Final encounter and was a result of the pilot's decision to consciously disregard the alert.

Scenario	Audio System		Display System	
	Non-Qualified	Qualified	Non-Qualified	Qualified
Head-On	7 (44%)	1 (6%)	3 (19%)	0 (0%)
Vertical HCR	Not Tested	12 (75%)	11 (69%)	5 (31%)
Base vs Final	Not Tested	2 (13%)	4 (25%)*	1 (6%)
Entry vs. Downwind	Not Tested	2 (13%)	5 (31%)	0 (0%)

Table 5-2. Number of Near Misses for Comparison Encounters Using Ideal Data Quality (Note *Indicates that a Collision Occurred)

Overall, performance was generally improved with the display system compared to the audio system for the enroute encounter scenarios. There was no significant difference in any of the parameters in the pattern cases with one exception for the miss distance in the Entry vs. Downwind case. The following results are presented with respect to each scenario that was compared.

Head-On Encounter

As can be seen in Figure 5-5, pilots became aware of the traffic 14 seconds earlier when using the display based system compared to when using the audio system in the head-on encounter (z =-2.06, p=0.040). From Figure 5-6, one can see that pilots took evasive action against the Head-On target on average 8 seconds earlier when given the display compared to without the display (z=-2.356, p=0.018). Figure 5-7 shows that pilots on average missed the target aircraft by 0.31 nm more when using the display system compared to the audio system (z=2.94, p=0.003). It can also be seen in Figure 5-7 that miss distances increased by 0.04 nm when an alert was given

(z=2.07, p=0.038). Overall, the display system with alerts provided the best performance. Figure 5-8 highlights the evasive responses pilots took to resolve the Head-On conflict. There were no obvious differences in type of evasive action between qualified and nonqualified target responses, nor differences between the display system and audio only system. Overall for the Head-On encounter, the display system consistently out performed the audio system, and there was a safer distance margin when alerts were provided in both the audio and display systems.
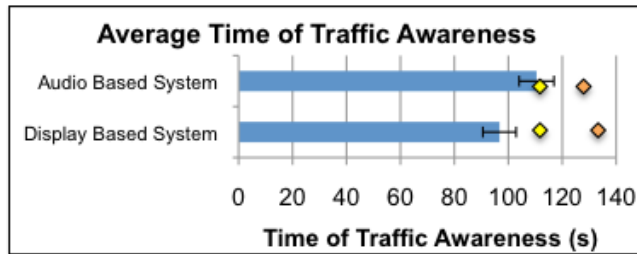
Figure 5-5. Traffic Awareness for Head-On Conflict
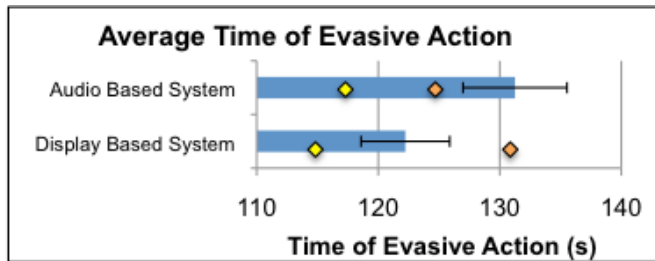
Figure 5-6. Evasive Action Time for Head-On Conflict
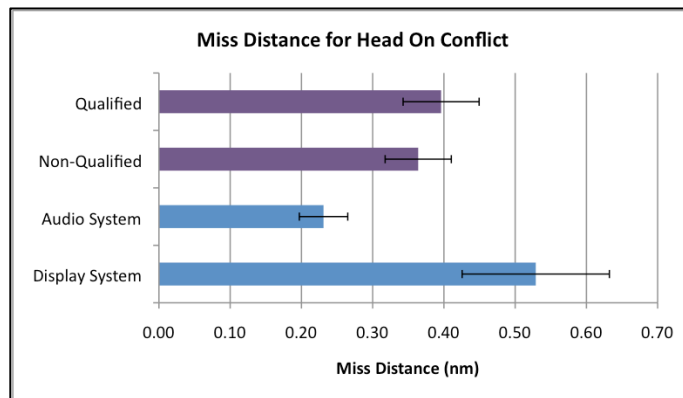
Figure 5-7. Miss Distance for Head-On Conflict
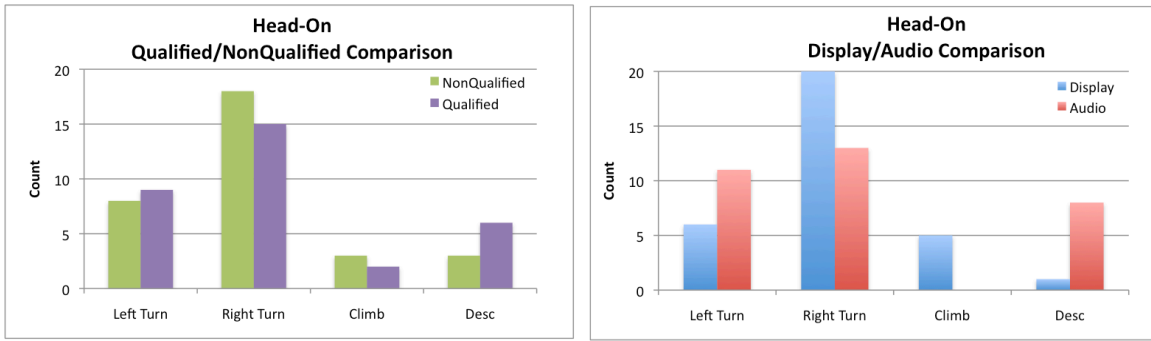
Figure 5-8. Type of Evasive Response for Head-On Encounter

Vertical High Closure Rate Encounter

The vertical high closure rate encounter appeared to be the most challenging for pilots as was seen in Table 5-2. It can be seen in Figure 5-9 that pilots became aware of the traffic 76 seconds earlier when using the display based system for the vertical high closure rate encounter (F=26.7, p<0.001). This is due to the geometry of the encounter, the pilot would not have visually acquired the target in the audio system so awareness would not have occurred until the alert annunciated, while in the display system, pilots were aware of the target due to the CDTI. In terms of evasive action, it can be seen in Figure 5-10 that pilots took on average 13 seconds longer to react to the vertical high closure rate conflict when they were not given an alert (z= -2.10, p =0.036). In Figure 5-11, one can see that pilots missed the target by 0.28 nm more when using the display based system (z=3.41, p=0.001). When comparing the qualified scenario to the non-qualified scenario in the display system, pilots missed the target by 0.23 nm more distance when an alert was annunciated, again highlighting the benefit of the TSAA system.
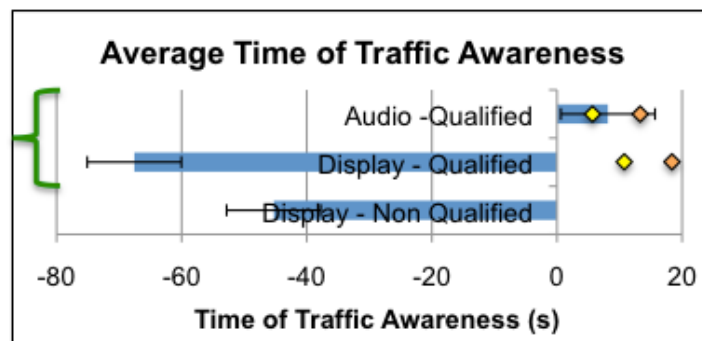
Figure 5-9. Traffic Awareness for Vertical High Closure Rate Conflict (with Reference to the Time that the Target Began Descending)

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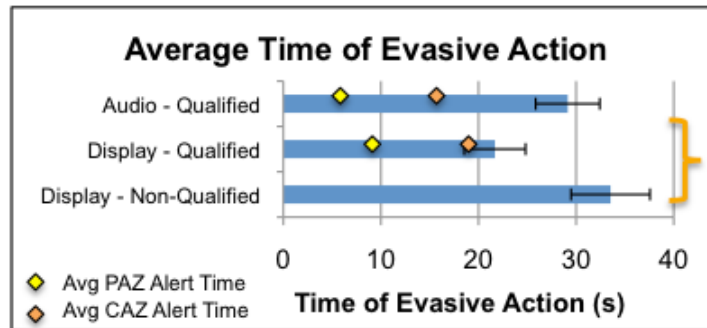
Figure 5-10. Time of Evasive Action for the Vertical High Closure Rate Conflict (with Reference to the Time that the Target Began Descending)
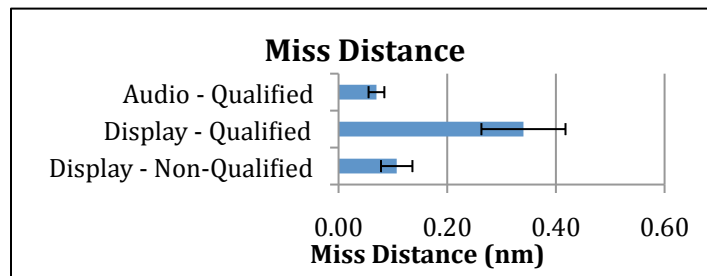
Figure 5-11. Miss Distance for Vertical High Closure Rate Conflict

Figure 5-12 highlights the type of evasive action that pilots took against the vertical high closure rate traffic. Note that the distribution of maneuvers is nearly identical for the qualified and non qualified target comparisons indicating that pilots are responding the same way despite whether they receive an alert or not. On the other hand, if one compares the response between display systems and audio only systems, there were seven participants who chose not to take evasive action at all in the audio system. Observations indicate that pilots believed they had separation from the traffic in the audio system because the only feedback they received was the aural information. Note that this version of TSAA did not include vertical trend information in the audio call out, which further motivates the benefit of including vertical trend in the audio call referenced in Section 4-3.
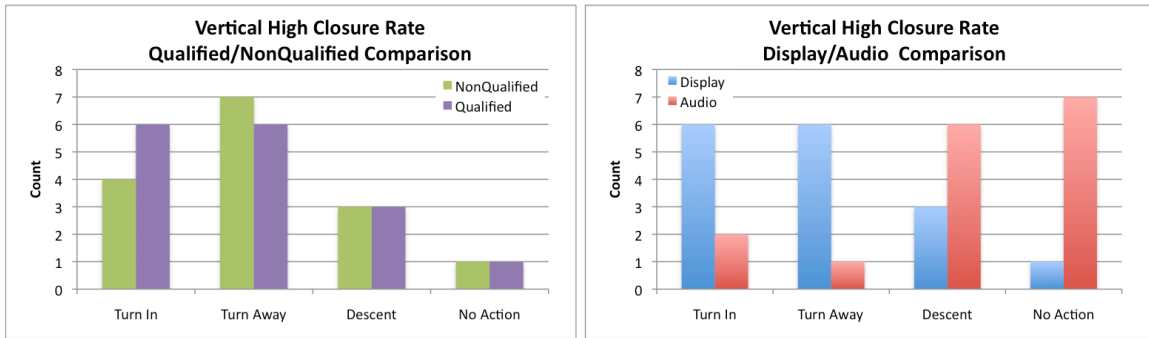
Figure 5-12. Type of Evasive Response for Vertical High Closure Rate Encounter

Base vs. Final Encounter

There was no observed difference in time of traffic awareness, time of evasive action, nor miss distance for the base vs. final encounter. In addition, as can be seen in Figure 5-16, the distribution of type of evasive response was nearly identical between qualified, non-qualified, display, and audio scenarios. Over the shoulder observations noted that pilots were primarily visual during pattern cases and were not focused on the CDTI. During this scenario, pilots generally acquired traffic visually upon their turn to downwind and elected to extend their downwind upon reaching abeam the numbers. This behavior was not dependent on what kind of system (display or audio only) nor the type of target (qualified or non-qualified) due to the nature of the traffic pattern operations.
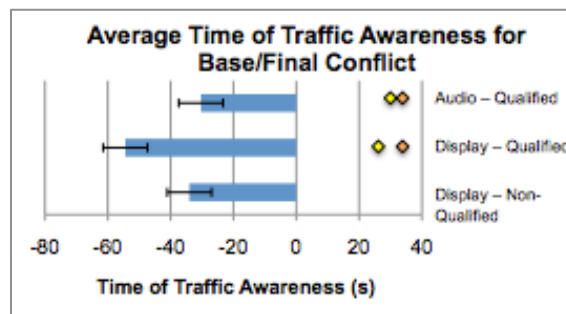
Figure 5-13. Time of Traffic Awareness for the Base vs. Final Conflict

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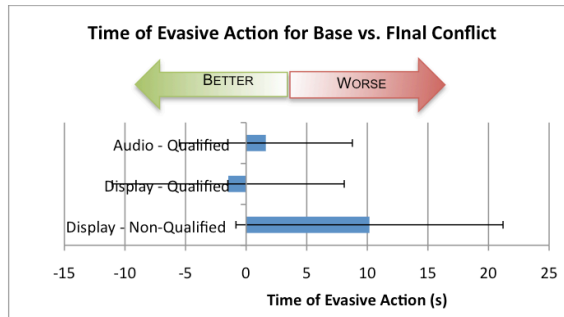
Figure 5-14. Time of Evasive Action for the Base vs. Final Conflict
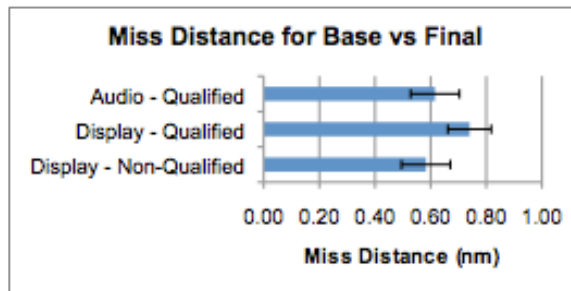
Figure 5-15. Miss Distance for the Base vs. Final Conflict
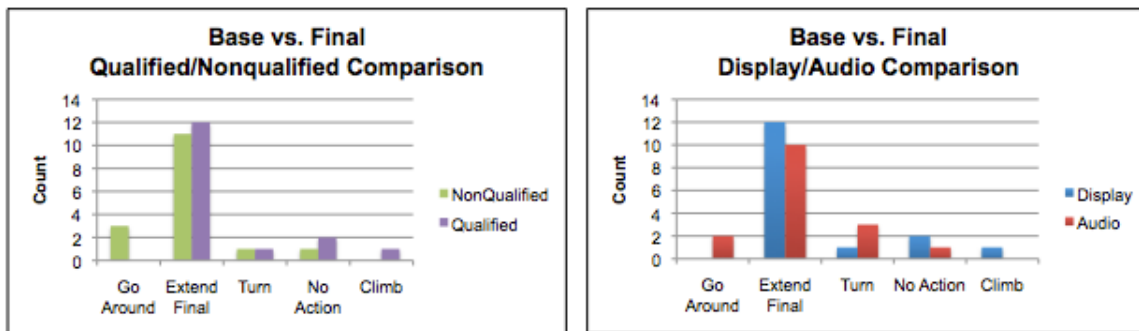
Figure 5-16. Type of Evasive Response for the Base vs. Final Encounter

Entry vs. Downwind Encounter

There was no significant difference in the time of traffic awareness or time of evasive response for the entry vs. downwind encounter. There was a significant difference in the miss distance between qualified and non-qualified targets. Figure 5-19 shows that the miss distance was 0.23 nm greater during the encounter with a qualified target compared to the nonqualified target when the display system was in use. Figure 5-20 shows that no obvious difference in distribution of the response to traffic existed. Similarly to the base vs. final encounter, this lack of major difference

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in performance could be attributed to the primarily visual flight regime of the traffic pattern.
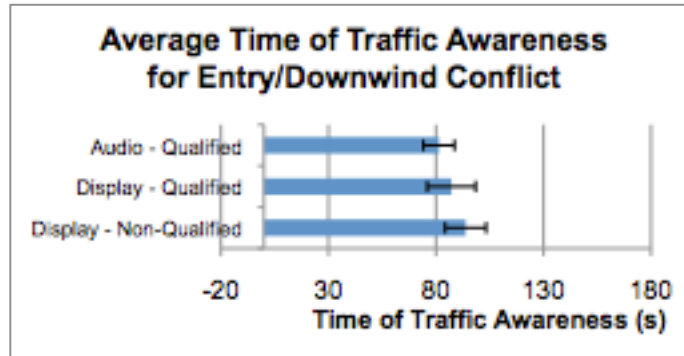
Figure 5-17. Time of Traffic Awareness for the Entry vs. Downwind Conflict
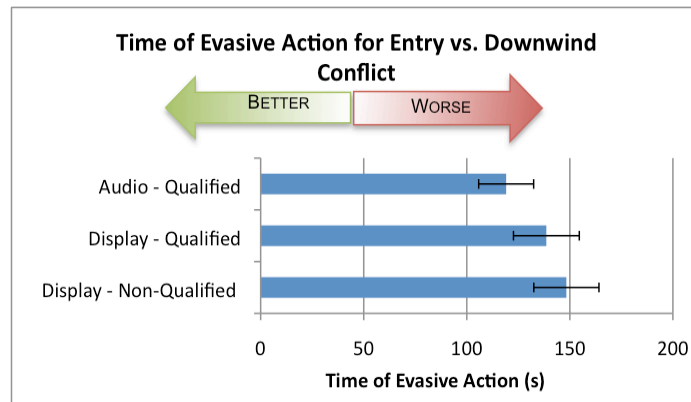
Figure 5-18. Time of Evasive Action for the Entry vs. Downwind Conflict
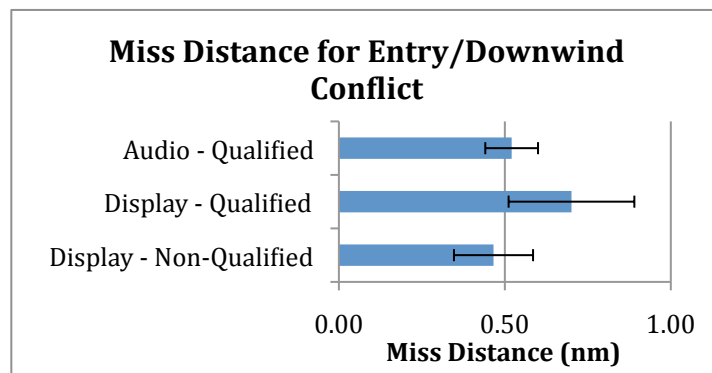
Figure 5-19. Miss Distance for the Entry vs. Downwind Encounter
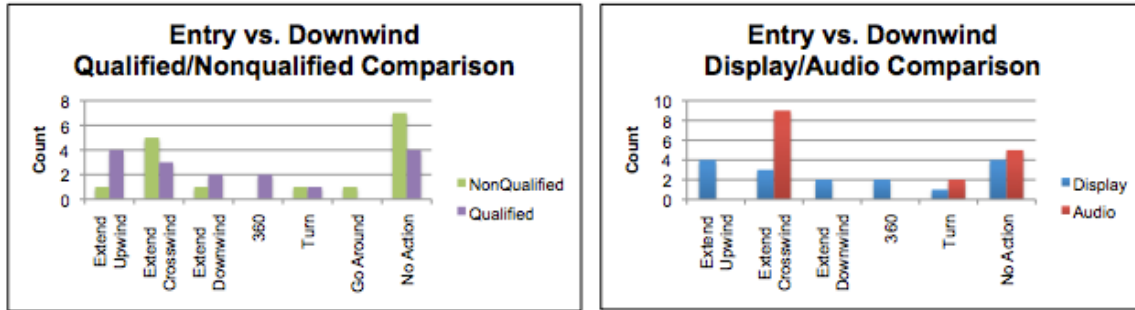
Figure 5-20. Type of Evasive Response for the Entry vs. Downwind Encounter

Overall, the benefit of a visual display of traffic was observed during the study in the enroute cases. Awareness, response time, and miss distance improved when a display was in use as well as when an alert was given. Time of traffic awareness was not different between qualified and non-qualified targets. They were usually identified on the display prior to alert, thus the lack of alert would have less of an effect on awareness of traffic, and so this result is expected. Overall, there was an observed performance benefit when an alert was provided to the pilot. Pilots also generally considered the "LTD" designator to be appropriate in differentiating non-qualified targets. Also, for all of the comparison scenarios, the only unsafe conditions that were encountered occurred because the pilot made a decision not to respond to the traffic alert.

5.2 Performance with Realistic Data Quality

The prior performance analysis was done with ideal data quality; an additional performance analysis was conducted using realistic surveillance data quality. Target data was systematically degraded to a realistic level during the study. Each target was assigned a type of quality from ADS-B, ADS-R, TIS-B1, and TIS-B2. General descriptions of the target quality are provided in Figure 5-21. ADS-B signifies the highest quality target while TIS represents radar targets. TIS-B1 represents a terminal radar target and TIS-B2 represents an enroute radar target. ADS-R targets had similar errors as ADS-B targets, however had a reduced update rate. For each type of target, degradation files were pre-generated for position error, velocity error, altitude error, and update rate. These files were representative of the typical error

for each type of target. The experimental design for this study was very similar to the study using ideal ADS-B data.

ADS-B	Position	Velocity	Altitude	Update Rate
	NACp = 8	NACv = 1	25ft quant.	1s

ADS-R	Position	Velocity	Altitude	Update Rate
	NACp = 8	NACv = 1	100ft quant	5s

TIS-B1	Position	Velocity	Altitude	Update Rate
	NACp = 8	NACv = 1	100ft quant.	6s

TIS-B2	Position	Velocity	Altitude	Update Rate
	NACp = 5	NACv = 1	100ft quant.	12.1s

Figure 5-21. Description of Target Types

5.2.1 Experimental Design

In addition to the validation of the system performance, a between subjects comparison was completed between the participants who experienced ideal quality ADS-B and the participants who experienced realistic quality ADS-B. The scenarios compared are listed below along with their assigned target type. The same equipment was used as was in Section 5.1.1, along with the same methodology and participant instructions.

Scenario	Target Type
Head-On	TIS-B 2
Multiple Intruder	TIS-B 1 & ADS-R
Overtaking Final	TIS-B 1
Opposite Runway	TIS-B 1
Base vs. Final	ADS-B
Entry vs. Downwind	TIS-B 1

Table 5-3. Data Quality Comparison Scenarios and Assigned Data Quality

The participants for this study consisted of 16 general aviation pilots ranging in certification from private pilot to flight instructor as can be seen in Table 5-4. Participants were recruited from flight schools and flying clubs in the greater Boston area.

Total Participant Flight Time (hours)	14674
Mean Total Time (hours)	917
Mean Hours (Past 90 days)	22
Mean Hours (Previous 12 months)	75
Private	9
Private/Instrument	3
Commercial/Instrument	4
ATP	0
CFI(I)/MEI	2

Table 5-4. Participant Experience System Performance Comparison

5.2.2 Results and Conclusions

Table 5-5 summarizes the number of near misses and collisions that occurred during the encounters. In the 2 collision cases in the Overtaking on Final scenario, pilots made a conscience decision to disregard the alert. The other collision case occurred during the head-on scenario with a non-qualified target when using the audio only system. In this collision, the pilot never received annunciation of the threat and failed to acquire the target visually until it was too late. This was a baseline case simulating an aircraft without any traffic alerting or awareness systems. There was

a total of 16 near misses in the ideal data quality cases and 27 near misses observed with realistic data quality.

Scenario	TSAA System	Ideal Data Quality # Near Misses	Realistic Data Quality # Near Misses
Head-On	No TSAA	7 (44%)	3 (19%)*
Head-On	Audio	1 (6%)	5 (31%)
Head-On	Display	0 (0 %)	1 (6%)
Multiple: 3 o'clock	Display	5 (31%)	1 (6%)
Multiple: 12 o'clock	Display	1 (6%)	1 (6%)
Overtaking Final	Display	6 (38%)	8 (50%)**
Base vs. Final	Display	1 (6%)	2 (13%)
Opposite Runway	Display	0 (0%)	1 (6%)
Entry vs Downwind	Audio	2 (13%)	7 (44%)

Table 5-5. Number of Near Misses for Scenarios that Compared Performance with Ideal Data Quality and Realistic Data Quality. (* Denotes Collision Case)

Head-On Encounter

Time of traffic awareness was not significantly different for the head-on encounter between display and audio systems which was consistent with the ideal case. However, as one can see in Figure 5-23, there was a 16.9 second improvement in time of traffic awareness when an alert was provided in the audio system compared to the nonqualified case (z=2.70, p=0.007). The trend was again consistent with the ideal case however there was no significant difference observed in the ideal case.
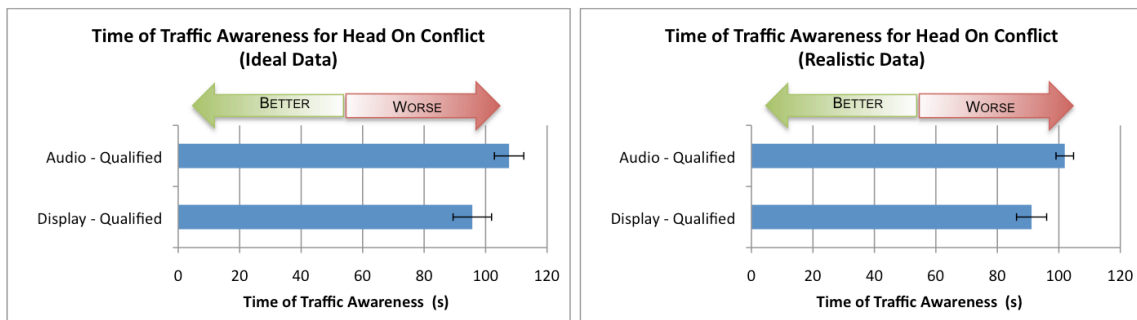
Figure 5-22. Time of Traffic Awareness for Head-On Conflict (Left- Ideal Data Quality, Right- Realistic Data Quality)
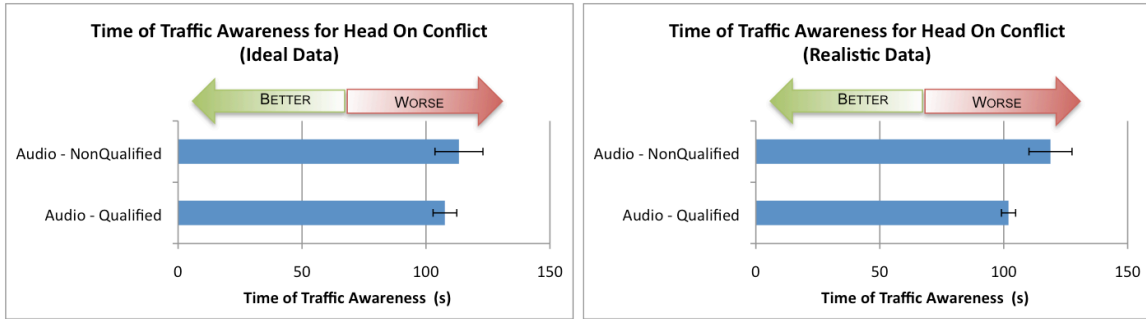
Figure 5-23. Time of Traffic Awareness for Head-On Conflict – Qualified Comparison (Left- Ideal Data Quality, Right- Realistic Data Quality)

As can be seen in Figure 5-24, pilots did take evasive action 21.0 seconds earlier when they were provided with the display, however this difference was not significant. This trend was consistent with performance using ideal data quality. In terms of the qualified/nonqualified comparison in the audio system, Figure 5-25 shows that pilots took action 14.5 seconds earlier when an alert was provided (z=-3.00, p=0.003) and realistic data was used. The trend on time evasive action was again consistent with the ideal case however there was no significant difference observed in the ideal case.
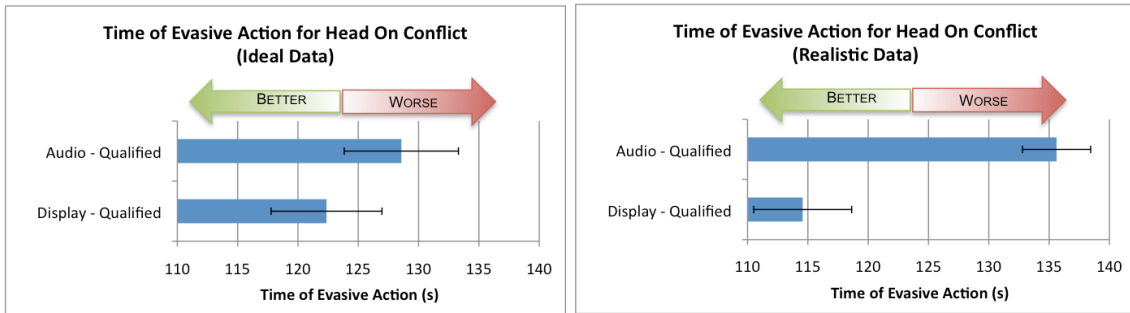
Figure 5-24. Time of Evasive Action for Head-On Conflict (Left- Ideal Data Quality, Right-Realistic Data Quality)
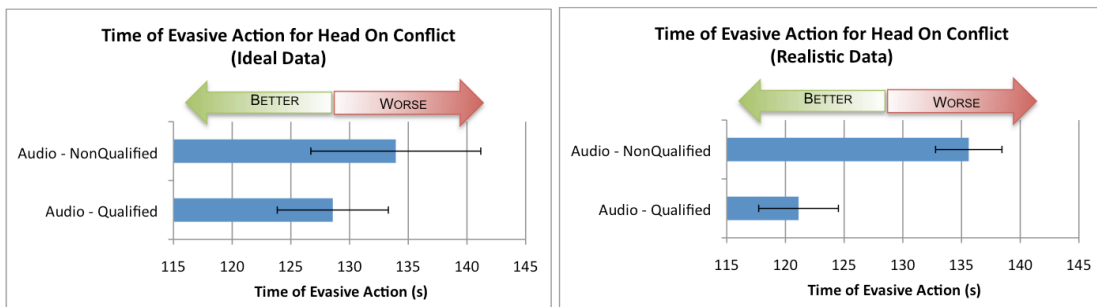
Figure 5-25. Time of Evasive Action for Head-On Conflict – Qualified Comparison (Left- Ideal Data Quality, Right- Realistic Data Quality)

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As can be seen in Figure 5-26, miss distance increased by an average of .34 nm when the display was available for the Head-On conflict (z=2.32, p=0.021). Figure 5-27 shows that there was no significant difference in miss distance between qualified and non-qualified cases. This was consistent with performance using ideal data quality.
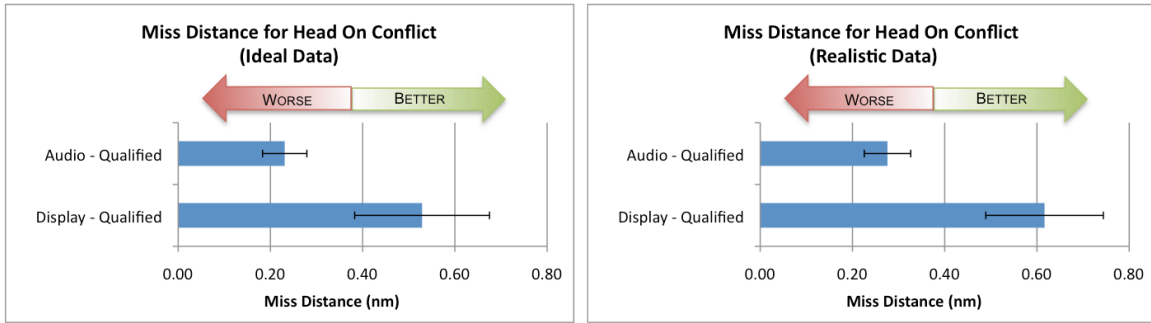
Figure 5-26. Miss Distance for Head-On Conflict (Left- Ideal Data Quality, Right- Realistic Data Quality)
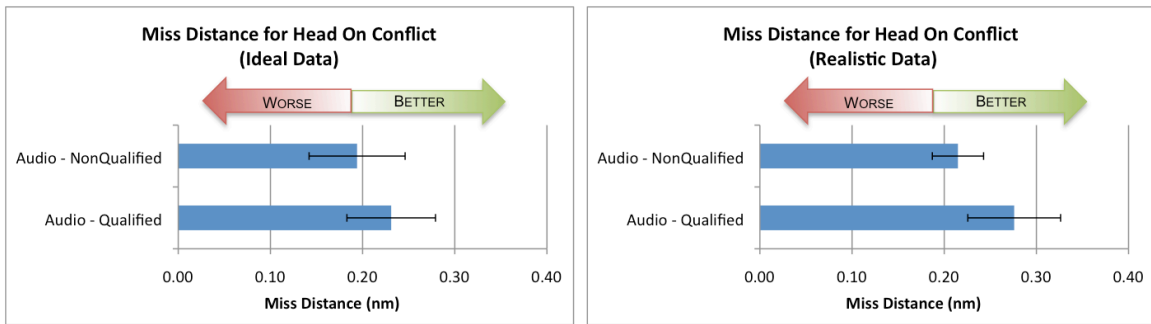
Figure 5-27. Miss Distance for Head-On Conflict – Qualified Comparison (Left- Ideal Data Quality, Right- Realistic Data Quality)

Figure 5-28 shows the type of evasive maneuver. As was observed in Section 5-1 with ideal quality ADS-B, no major differences are seen between qualified and non-qualified encounters. In the display system vs audio system comparison, it can be seen in Figure 5-29 that more pilots turn away from the conflict when using the audio system. This result is intuitive provided that with the display, pilots had more time to assess the situation and could use the display to maintain separation once the target was lost visually.
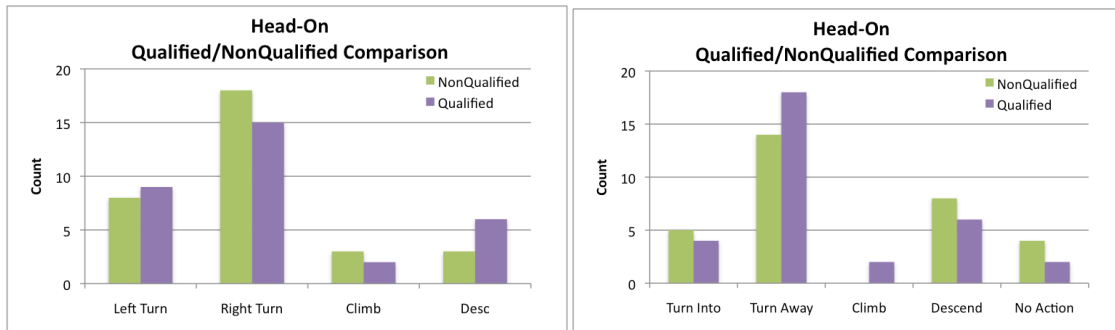
Figure 5-28. Type of Evasive Maneuver for Head-On Conflict (Left- Ideal Data Quality, Right-
Realistic Data Quality)
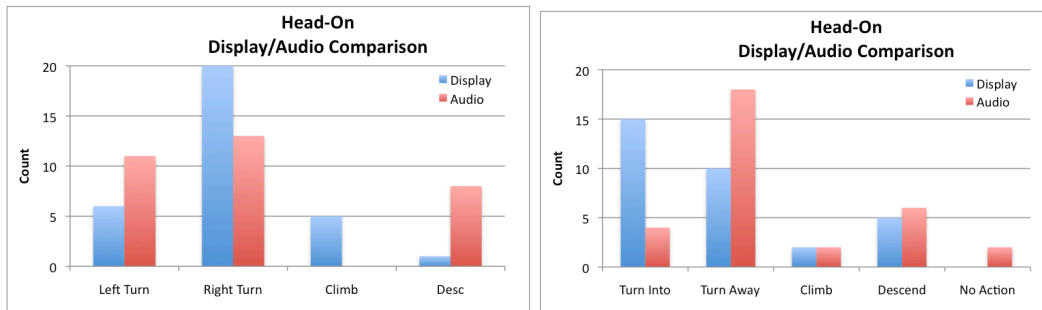
Figure 5-29. Type of Evasive Maneuver for Head-On Conflict (Left- Ideal Data Quality, Right-
Realistic Data Quality)

Overall, the trend of improvement in performance when the CDTI was available
holds when target data is of more realistic data quality for the enroute encounters.
Also, the benefit of the TSAA alerts continues to be observed in a more realistic data
quality environment.

Multiple Intruder Encounter

Performance details for the Multiple Intruder Scenario (Encounter 3 in Section 3-3)
are provided below. Note that all times are relative to the time of first alert.

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	Ideal Data Quality				Realistic Data Quality			
Time of Traffic Awareness	3 o clock: -54s (SD = 34s) 12 o'clock: -5s (SD = 26s)				3 o clock: -61s (SD = 32s) 12 o'clock: -8s (SD = 16s)			
Time of Evasive Action	18s (SD = 15s)				9s (SD=12s)			
Miss Distance	3 o clock: 0.35 nm (SD = 0.36 nm) 12 o'clock: 1.23 nm (SD = 1.44 nm)				3 o clock: 0.42 nm (SD = 0.31 nm) 12 o'clock: 0.84 nm (SD = 0.6 nm)			
Type of Evasive Action	Left Turn	Right Turn	Climb	Descend	Left Turn	Right Turn	Climb	Descend
	6	5	1	4	9	5	1	1
Number of Near Misses	5				2			
Number of Collisions	0				0			

Table 5-6. Performance Details for Multiple Intruder Encounter

During the ideal data quality case, over the shoulder experimenter observations noted that pilots had the tendency to wait until all of the alerts annunciated prior to taking evasive action. This is supported by the average time of 18 seconds that it took for pilots to take evasive action following the first alert. This observation was only observed in a limited number of cases using the degraded data.

Overtaking on Final Encounter

Performance details for the Overtaking on Final Scenario (Encounter 6 in Section 3-3) are provided below. Note that all times are relative to the time of first alert.

	Ideal Data Quality		Realistic Data Quality	
Time of Traffic Awareness	-2.3s (SD=20s)		-3.9s (SD= 10.2s)	
Time of Evasive Action	22.6s (SD=11s)		26.8s (SD=11.0s)	
Miss Distance	0.31 nm (SD =0.29 nm)		0.15 nm (SD = 0.22 nm)	
Type of Evasive Action	Go Around	No Action	Go Around	No Action
	9	6	11	4
Number of Near Misses	6		8	
Number of Collisions	0		2	

Table 5-7. Performance Details for Overtaking on Final Encounter

Time of traffic awareness was 1.5 seconds earlier in the realistic quality data group (z =-2.52, p=0.012). This target was a TIS-B1 target, however, the time of traffic awareness for this encounter was typically the time of first alert as participants generally did not become aware of the traffic prior to the annunciation. Though it is possible that the TIS-B1 quality elicited an alert early, the difference is more likely associated with the traffic generation aspect of the simulator.

Opposite Runway Encounter

Performance details for the Opposite Runway Scenario (Encounter 8 in Section 3-3) are provided below. Note that all times are relative to the time the target first appeared.

	Ideal Data Quality			Realistic Data Quality		
Time of Traffic Awareness	10.3s (SD=9.3s)			12.5s (SD = 10.2s)		
Time of Evasive Action	22.4s (SD = 12s)			26.9s (SD = 11s)		
Miss Distance	0.57 nm (SD=0.43 nm)			0.70 nm (SD = 0.60 nm)		
Type of Evasive Action	Abort Takeoff	Left Turn	Right Turn	Abort Takeoff	Left Turn	Right Turn
	5	2	9	6	4	6
Number of Near Misses	0			1		
Number of Collisions	0			0		

Table 5-8. Performance Details for Opposite Runway Encounter

During the opposite runway encounter, it took an average of 12 seconds (ideal data quality) for pilots to take action after they became aware of traffic. This number is consistent with previous FAA literature highlighting the response time to traffic.

Base vs. Final Encounter

Performance details for the Base vs. Final Scenario (Encounter 4 in Section 3-3) are provided below. Note that all times are referenced to the time the ownship turned downwind.

	Ideal Data Quality	Realistic Data Quality
Time of Traffic Awareness	-54.4s (SD = 39s)	27.8s (SD =44.7s)
Time of Evasive Action	-1.5 s (SD =38s)	68.4s (SD = 40.1s)
Miss Distance	0.74 nm (SD = 0.31 nm)	0.54 nm (SD = 0.37 nm)

Type of Evasive Action	Extend DW	Go Around	No Action	Turn	Climb	Extend DW	Go Around	No Action	Turn	Climb
	12	0	2	1	0	7	6	1	1	1

	Ideal Data Quality	Realistic Data Quality
Number of Near Misses	1	2
Number of Collisions	0	0

Table 5-9. Performance Details for Base vs. Final Encounter

Time of traffic awareness was 82 seconds later in the realistic data quality group (z=3.94, p<0.001). Also, the time of evasive action was 67 seconds later in the realistic data quality group (z=3.82, p=0.001). Recall from Table 5-3 that the Base vs Final encounter was classified as an ADS-B target in the realistic group. Also, the way the encounter evolved, participants rarely observed the target on the display, more readily identifying it visually first. Thus, it is not expected that this strong difference is associated with a small data quality difference. It is unclear why this difference was observed.

Entry vs. Downwind Encounter

Performance details for the Entry vs. Downwind Scenario (Encounter 5 in Section 3-3) are provided below. Note that all times are relative to the time the target first appeared.

	Ideal Data Quality					Realistic Data Quality				
Time of Traffic Awareness	81.4 s (SD =29s)					91.9 s (SD = 13.9s)				
Time of Evasive Action	119 s (SD =53 s)					140.9s (SD=65.3s)				
Miss Distance	0.52 nm (SD =0.32 nm)					0.30 nm (SD = 0.32 nm)				
Type of Evasive Action	Extend Crosswind	Go Around	No Action	Turn	Climb	Extend Crosswind	Go Around	No Action	Turn	Climb
	9	0	5	2	0	3	1	4	4	3
Number of Near Misses	2					7				
Number of Collisions	0					0				

Table 5-10. Performance Details for Entry vs. Downwind Encounter

The time of traffic awareness was 10 seconds later in the realistic quality group (z=3.14, p=0.002). Since pilots did not have a visual display of traffic in this case, it was not believed that the TIS-B1 target was the cause of a significant difference in traffic awareness.

Thus overall, performance was not considered different between ideal quality data and realistic quality data. It was unclear why the three significant differences occurred, but the differences are not believed to be associated with target data quality.

5.3 Overall Performance

Effectiveness of the overall system was analyzed using the scenarios that tested the recommended final design of the TSAA system using the realistic data quality. Near misses were defined as a slant range miss distance of 0.1nm or less. Collisions were defined as slant range miss distances of 0.01 nm or less. Number of near misses and collisions for all of the scenarios that were run using the final TSAA version are presented in the realistic data quality column in Table 5-5. Out of 160 encounters, 34 resulted in near misses (21.3%), and 2 resulted in collisions (1.3%). The TSAA system performed reliably and alerted in all of the cases involving a qualified target. In the 2 collision cases in the Overtaking on Final scenario, pilots made a conscience decision to disregard the alert.

5.4 Summary

Overall, the system functioned as expected. The only unsafe situations that occurred were due to pilot inaction. In some cases, the pilots could anticipate a threatening situation using the CDTI which led to early awareness showing value in the visual display of traffic. Where they did not anticipate a threat, the alert provided awareness to a conflict. It was observed that performance was significantly improved when pilots were provided with alerts and the alerts provided more separation than a situation awareness system without alerts. In general subjective feedback suggested that the display symbology was effective. This holds true for the enroute cases tested using both ideal quality ADS-B and realistic quality ADS-B.

Chapter 6

Effect of Two Levels of Caution Alert

As was described in the system design (Chapter 2), there was an issue identified regarding including two levels of caution alert. There was question as to whether there was a performance difference if the *Reinforced Traffic Caution Alert* was removed from the design. An experiment was designed to test the performance of the system without a *Reinforced Traffic Caution Alert* and compare it to performance with the *Reinforced Traffic Caution Alert* using the human-in-the-loop approach described in Section 3.1. TSAA Version 3.0 was used for this study.

6.1 Experimental Design

This comparison was a within subjects design. Participants experienced two systems: one system included both the *Traffic Caution Alert* and the *Reinforced Traffic Caution Alert* and the other system included only the *Traffic Caution Alert*.

Figure 6-1 provides the test matrix for the variable. Six total encounters were used for comparison. Four of these encounters occurred in the display system, while the other two occurred in the audio system.

COMPARISON 1: PAZ ONLY VS. PAZ WITH UPDATES

PAZ ONLY SYSTEM — PAZ WITH UPDATES SYSTEM

11 Total Encounters (7 display, 4 audio) — 6 Identical Encounters (4 display, 2 audio) — 11 Total Encounters (7 display, 4 audio)
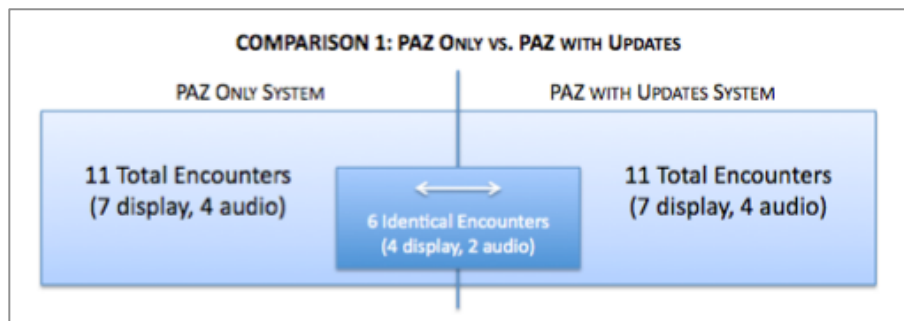
Figure 6-1. Test Matrix for Alert Comparison

Figure 6-2 highlights the encounters which were repeated for the alert comparison. The scenarios were comprised of three enroute encounters and one pattern encounter. In the audio system, only Encounters 1 and 2 were tested.

1.   Head-On (Encounter 1 in Section 3-3)
2.   Vertical High Closure Rate (Encounter 2 in Section 3-3)
3.   Multiple Intruder (Encounter 3 in Section 3-3)
4.   Overtaking on Final (Encounter 6 in Section 3-3)

These were considered corner cases for when the *Reinforced Traffic Caution* could be perceived as useful. A list of all of the encounter scenarios is provided in Figures 6-3 and 6-4.
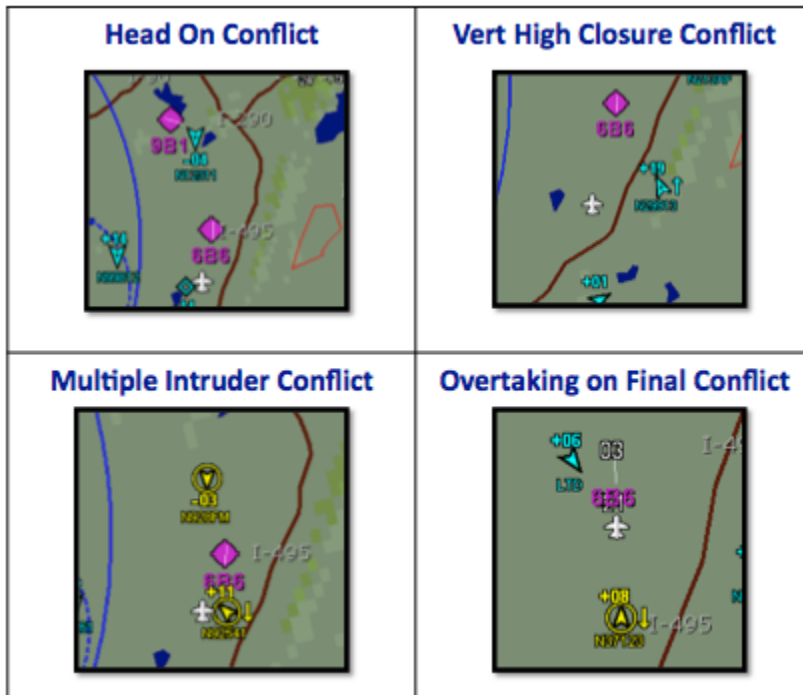
Figure 6-2. Comparison Scenarios
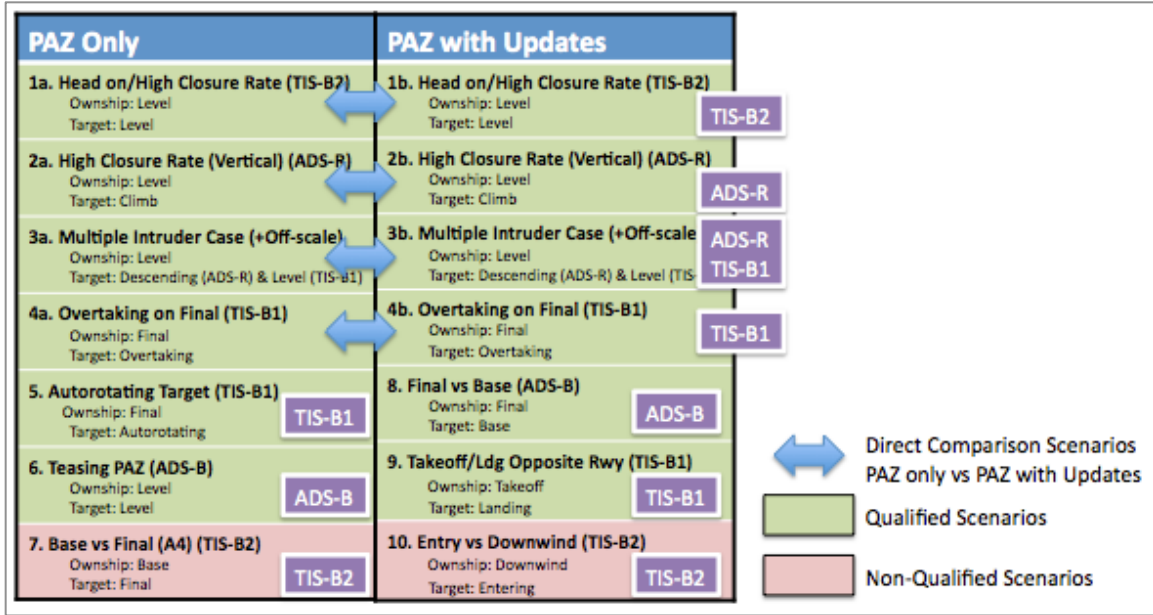
Figure 6-3. Display Scenarios Run for Alert Comparison
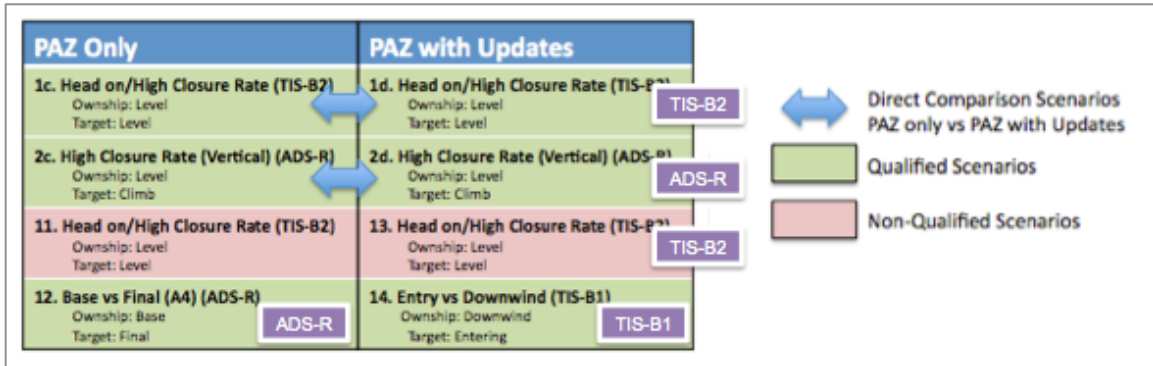
Figure 6-4. Audio Scenarios Run for Alert Comparison

The participants for this study consisted of 16 general aviation pilots ranging in certification from private pilot to airline transport pilot shown in Table 6-1. Participants were recruited from flight schools and flying clubs in the greater Boston area.

Total Participant Flight Time (hours)	14674
Mean Total Time (hours)	917
Mean Hours (Past 90 days)	22
Mean Hours (Previous 12 months)	75
Private	9
Private/Instrument	3
Commercial/Instrument	4
ATP	0
CFI(I)/MEI	2

Table 6-1. Participant Experience for Alert Comparison

6.2 Results and Conclusions

Table 6-2 summarizes the number of near misses and collisions that occurred during the scenarios. There does not appear to be a major difference in performance between the systems that included the *Reinforced Traffic Caution* and the system that did not.

		Without *Reinforced Traffic Caution Alert*	With *Reinforced Traffic Caution Alert*
Scenario	System	# Near Misses	# Near Misses
Head-On	Audio	3 (19%)	5 (31%)
Vertical HCR	Audio	10 (63%)	6 (38%)
Multiple: 3 o'clock	Display	1 (6%)	1 (6%)
Multiple: 12 o'clock	Display	0 (0%)	1 (6%)
Head-On	Display	1 (6%)	1 (6%)
Overtaking on Final	Display	9 (56%)*	8 (50%)**
Vertical HCR	Display	4 (25%)	2 (13%)

Table 6-2. Near Miss and Collision Data for Alert Comparison (* represent one collision occurrence,** represents two collision occurrences)

There were significant differences in terms of reaction time between the two systems that were pronounced in the audio system. In the display system, there were no significant difference in any of the performance measures between the systems with and without the *Reinforced Traffic Caution Alert.*

Head-On Encounter

In the audio system, as is shown in Figure 6-5, pilots reacted to the Head-On conflict on average 7.8 seconds earlier when using the system that included the *Reinforced Traffic Caution* compared to the system that did not include the *Reinforced Traffic Caution* (z=2.05, p=0.040). There was no observed difference in time of traffic awareness or miss distance between the system with and without the *Reinforced Traffic Caution*.
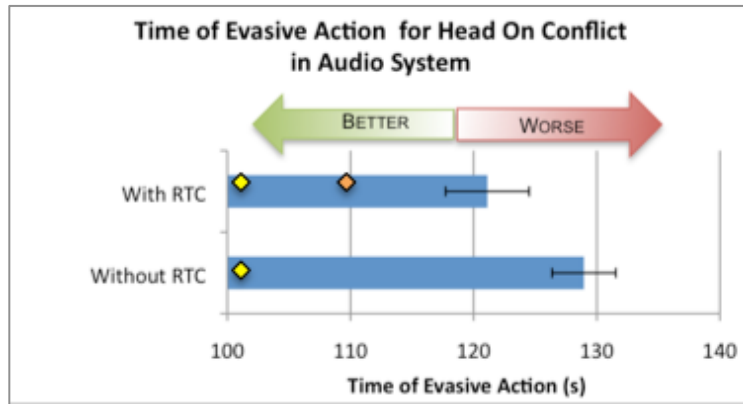
Figure 6-5. Time of Evasive Action for Head-on Conflict in Audio System
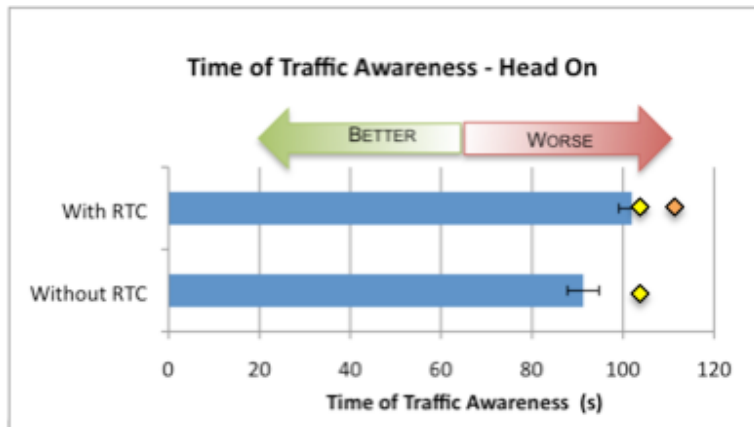
Figure 6-6. Time of Traffic Awareness for Head-on Conflict in Audio System
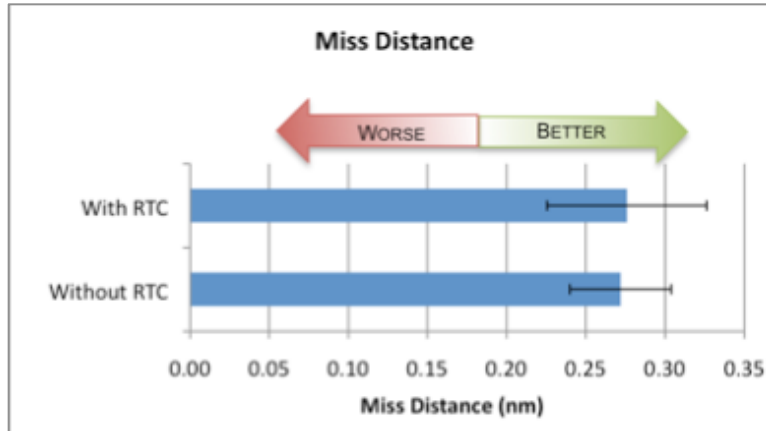
Figure 6-7. Miss Distance for Head-on Conflict in Audio System
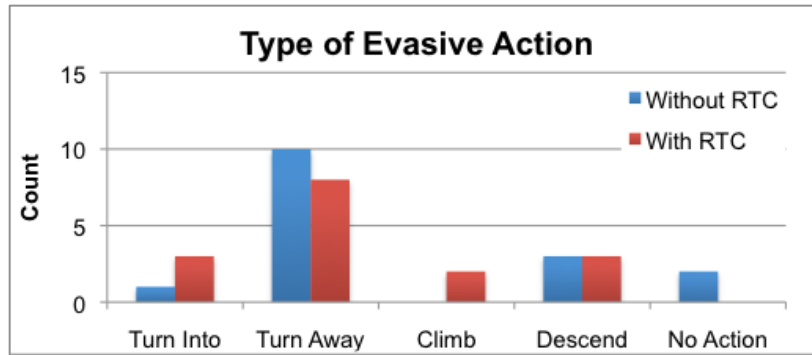
Figure 6-8. Type of Evasive Action for Head-on Conflict in Audio System

In the display system, there were no significant differences in any of the performance measures between the systems with and without the *Reinforced Traffic Caution Alert.*
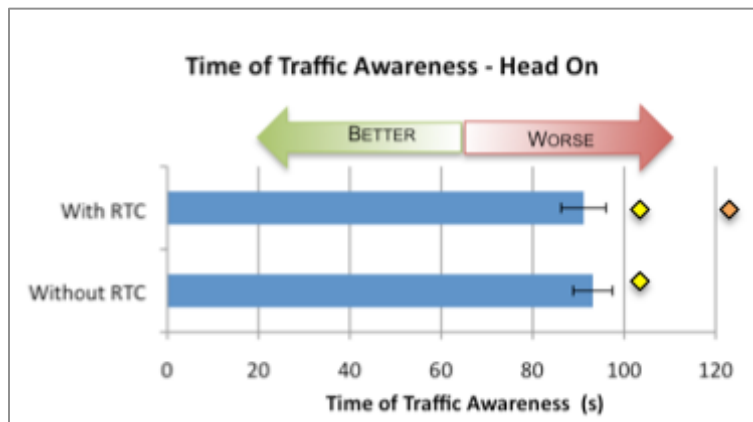
Figure 6-9. Time of Traffic Awareness for Head-on Conflict in Display System

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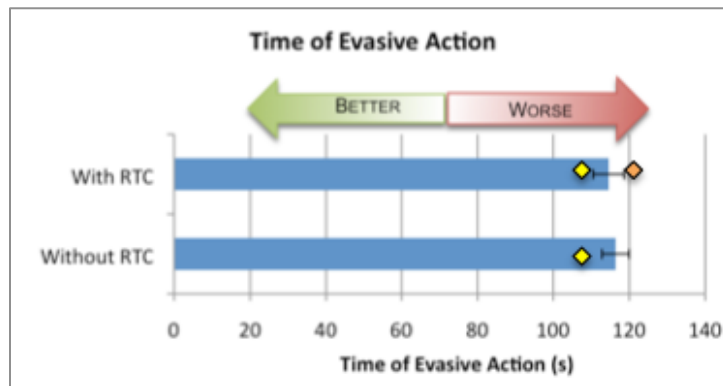
Figure 6-10. Time of Evasive Action for Head-on Conflict in Display System
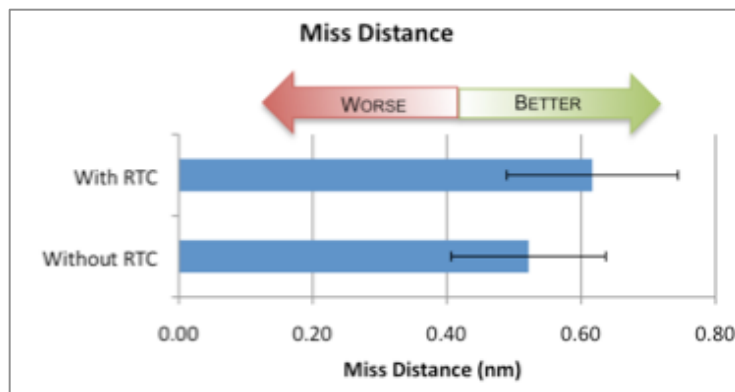
Figure 6-11. Miss Distance for Head-on Conflict in Display System
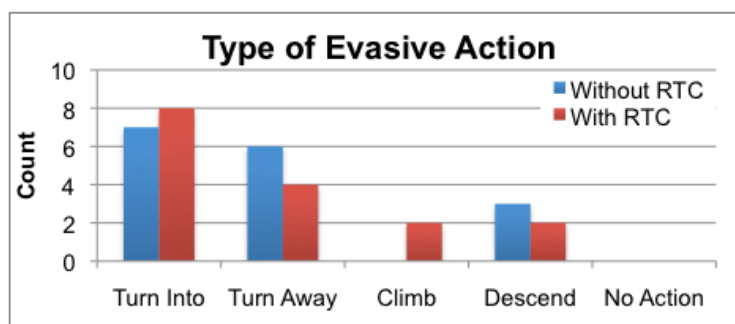
Figure 6-12. Type of Evasive Action for Head-on Conflict in Display System

Vertical High Closure Rate Encounter

During the vertical high closure rate conflict, the same trend was observed in the audio system. Again, no significant difference in awareness time and miss distance

was observed, but a difference in time of evasive response did emerge. As can be seen in Figure 6-13, pilots responded to traffic 8.2 seconds earlier when the *Reinforced Traffic Caution Alert* was included (z=2.09, p=0.037).
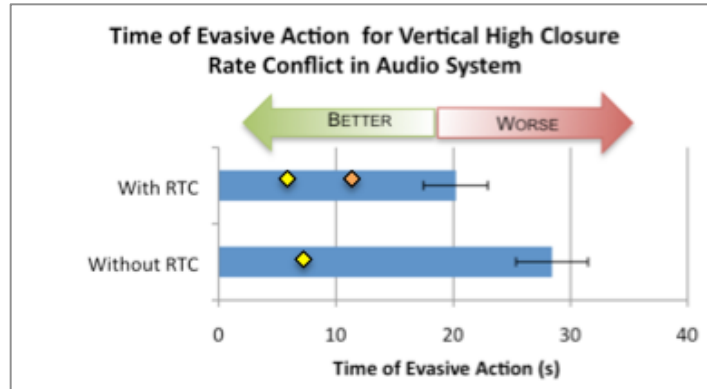
Figure 6-13. Time of Evasive Action for Vertical High Closure Rate Conflict in the Audio System (with respect to the time that the target began descending)
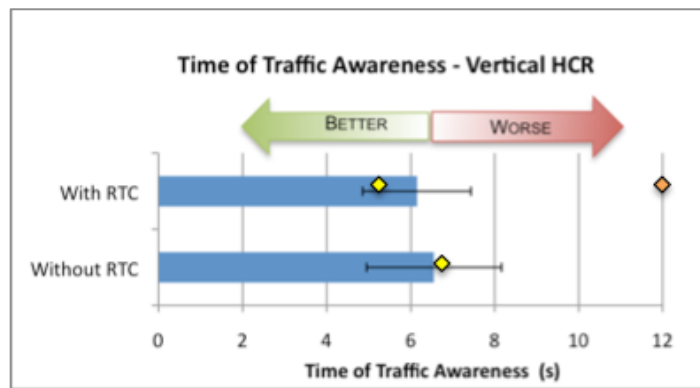
Figure 6-14. Time of Traffic Awareness for Vertical High Closure Rate Conflict in the Audio System (with respect to the time that the target began descending)
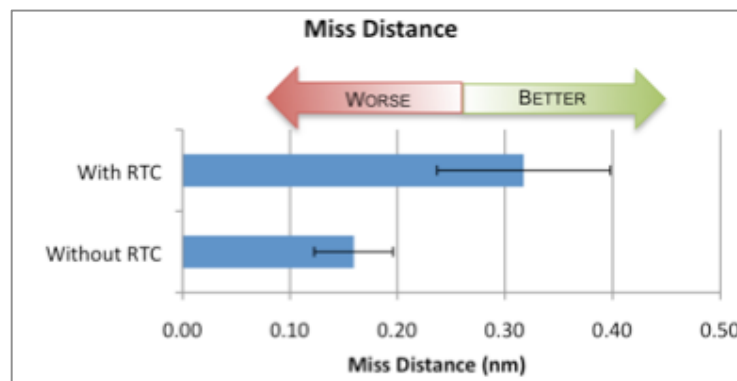
Figure 6-15. Miss Distance for Vertical High Closure Rate Conflict in the Audio System
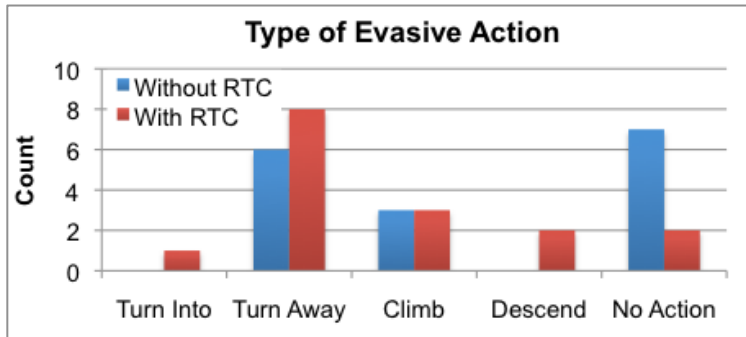
Figure 6-16. Type of Evasive Action for Vertical High Closure Rate Conflict in the Audio System

As mentioned previously, there was no observed difference in performance between the two alert systems in the display based system. This could be due to the added awareness of traffic when the display was in use. There were many occasions in the display system that the pilots reacted prior to the annunciation of a *Reinforced Traffic Caution Alert*. This could account for the lack of difference in the display system.
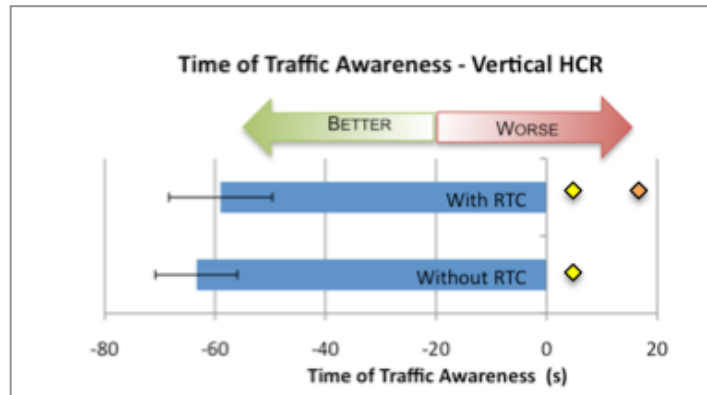
Figure 6-17. Time of Traffic Awareness for Vertical High Closure Rate Conflict in the Display System

Figure 6-18. Time of Evasive Action for Vertical High Closure Rate Conflict in the Display System
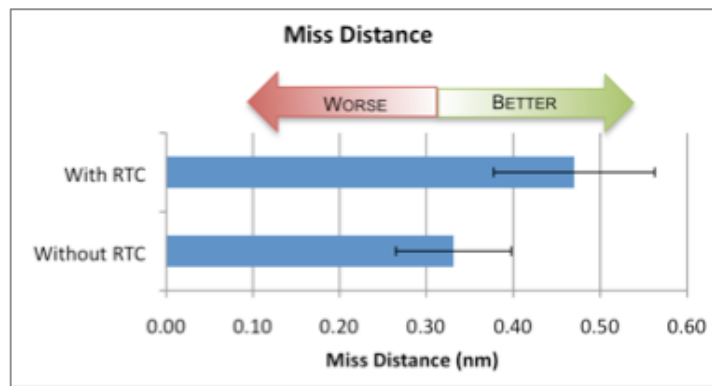
Figure 6-19. Miss Distance for Vertical High Closure Rate Conflict in the Display System
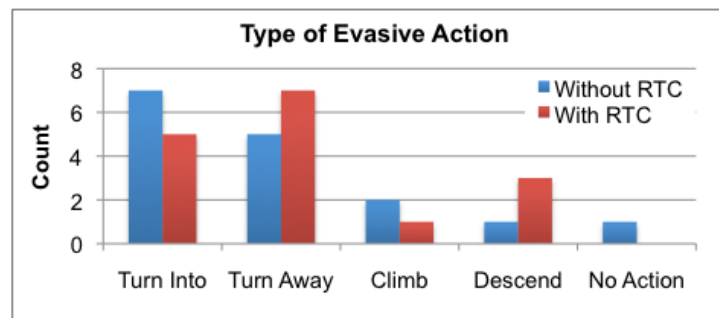
Figure 6-20. Type of Evasive Action for Vertical High Closure Rate Conflict in the Display System

Overtaking on Final Encounter

During the Overtaking on Final conflict, no significant differences were observed for time of traffic awareness, time or type of evasive action, or miss distance. Participants only experienced this conflict in the display based system.
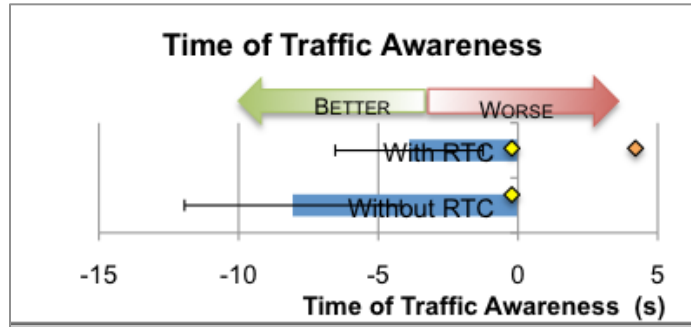
Figure 6-21. Time of Traffic Awareness for Overtaking on Final Conflict in the Display System
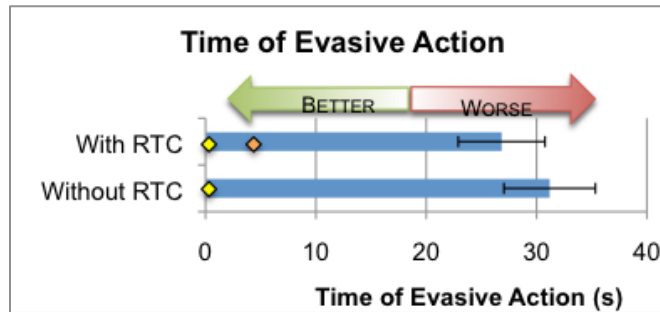
Figure 6-22. Time of Evasive Action for Overtaking on Final Conflict in the Display System
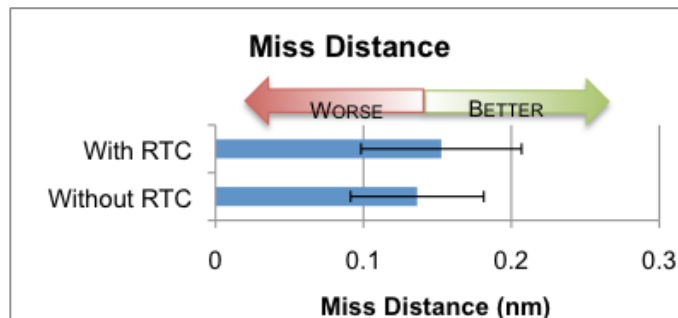
Figure 6-23. Miss Distance for Overtaking on Final Conflict in the Display System
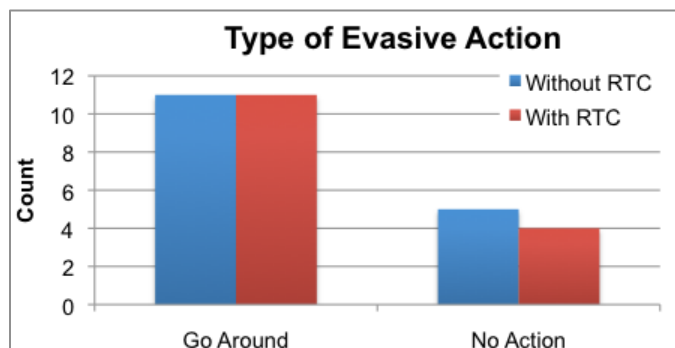
Figure 6-24. Type of Evasive Action for Overtaking on Final Conflict in the Display System

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Multiple Intruder Encounter

During the Multiple Intruder conflict, no significant differences were observed for time of traffic awareness, time or type of evasive action, or miss distance. Participants only experienced this conflict in the display based system.
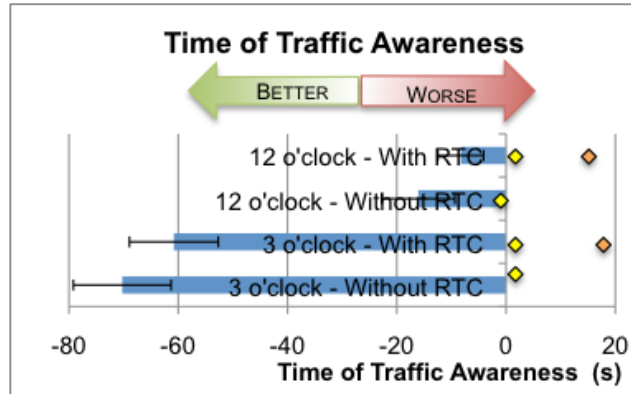
Figure 6-25. Time of Traffic Awareness for Multiple Intruder Conflict in the Display System
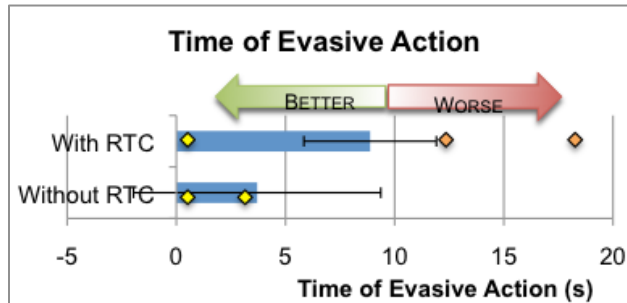
Figure 6-26. Time of Evasive Action for Multiple Intruder Conflict in the Display System
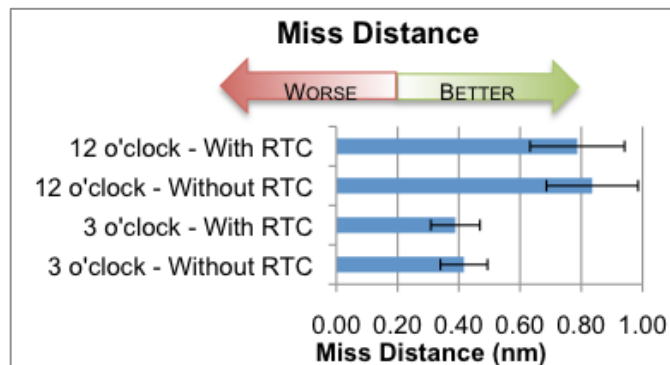
Figure 6-27. Miss Distance for Multiple Intruder Conflict in the Display System
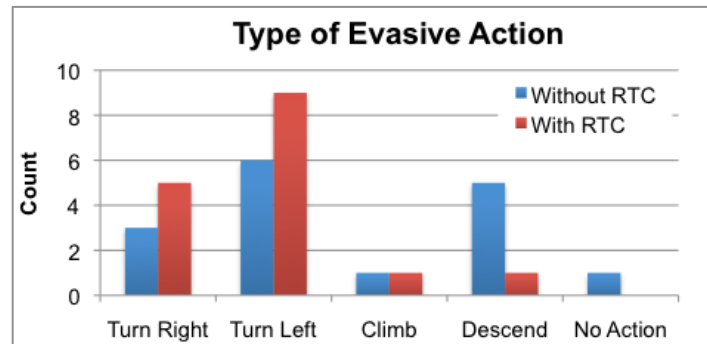
Figure 6-28. Type of Evasive Action for Multiple Intruder Conflict in the Display System

In addition to objective performance, subjective response was also gathered regarding preference to the system including the *Reinforced Traffic Caution Alert* or the system not including the *Reinforced Traffic Caution Alert*. In the audio system, 13/16 (81%) participants preferred the system that included the *Reinforced Traffic Caution Alert*. In the display system, 10/15 (67%) of participants preferred the system that included the *Reinforced Traffic Caution Alert*. 3/16 (19%) of participants in the audio system and 3/15 (20%) of participants in the display system preferred the system without the *Reinforced Traffic Caution Alert*.

Through open-ended feedback on subject preference, there were four main reasons that recurred from participants who preferred the system with *Reinforced Traffic Caution Alert*.

1. The *Reinforced Traffic Caution Alert* provided indication that the conflict was not yet resolved.
2. The *Reinforced Traffic Caution Alert* was attention-getting and served as a "call to action."
3. The *Reinforced Traffic Caution Alert* added information & provided information about closure rate of the target.
4. The *Reinforced Traffic Caution Alert* provided reassurance in the functionality of the system.

The main reasoning for the participants who preferred the system without the *Reinforced Traffic Caution Alert* was due to complaints regarding alerts which annunciated back to back essentially providing no information update, only a higher urgency repeat of the original *Traffic Caution Alert.*

In addition to direct subjective probes, pilots were also presented with trust questions regarding the systems with and without the *Reinforced Traffic Caution Alert.* Figure 6-29 shows trust results for the audio system. It can be seen that 5 out of 6 cases of loss of trust occurred in the system without the *Reinforced Traffic Caution.* When using the display system, Figure 6-30 shows that there were no observed cases of loss of trust in either the single caution or dual caution systems.
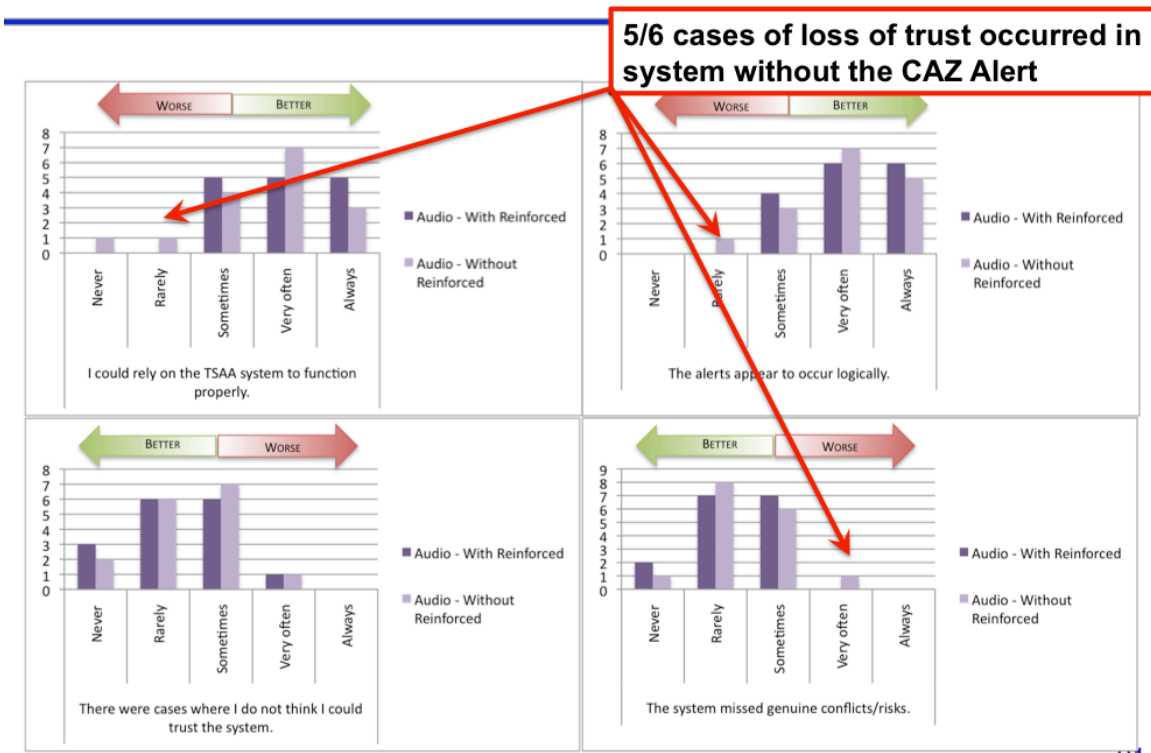
Figure 6-29. Trust Results for Audio System
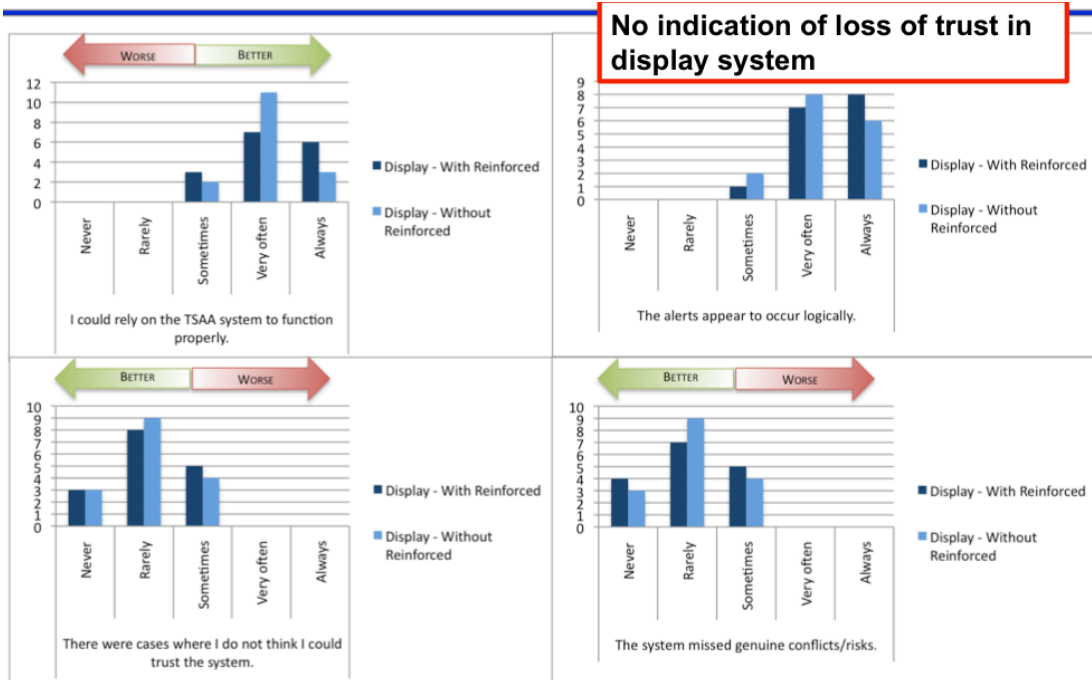
Figure 6-30. Trust Results for Display System

Overall, there was an observed benefit in performance when the *Reinforced Traffic Caution Alert* was used. There was overwhelming preference for the system that included the *Reinforced Traffic Caution Alert*. The concerns highlighted by pilots who preferred the system without the *Reinforced Traffic Caution Alert* could be addressed by either changing the timing of the *Reinforced Traffic Caution Alert* or simply replacing the *Reinforced Traffic Caution Alert* with an information update for traffic. Either of these options would keep the benefits associated with the *Reinforced Traffic Caution Alert* yet address the concerns about the *Reinforced Traffic Caution Alert* as well.

6.3 Summary

A study was designed to evaluate performance with a system that did not include the *Reinforced Traffic Caution* and compared it to a system that included the *Reinforced Traffic Caution Alert*. A performance benefit was observed during the audio system when *Reinforced Traffic Caution Alerts* were annunciated. There was also an overwhelming preference for the system that included the *Reinforced Traffic Caution.* Since there was observed benefit in including a second alert in the design,

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it is recommended that either the *Reinforced Traffic Caution* be maintained or it be replaced with an information update. Decisions must be weighed with the certification concerns for the system with two levels of alert.

Chapter 7

Summary and Conclusions

7.1 Summary

Several recent high profile mid-air collisions highlight the fact that 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) was developed which uses Automatic Dependent Surveillance – Broadcast, a 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 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, an audio based TSAA system was also designed to account for constrained cockpit space and added cost of a MFD.

TSAA system performance & basic usability was tested using human-in-the-loop studies with a total of 50 general aviation pilots. The studies also evaluated a number of design issues in order to provide recommendation for the final TSAA design. The proximate traffic indication was evaluated to determine whether its inclusion caused confusion to the user or whether it aided the pilot in evaluating target threat. Results indicated that pilots who saw the proximate indication identified targets as threats earlier than pilots who did not have the proximate indication. Subjective results indicated no negative perceptions about the use of

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proximate depiction. Due to the benefit in evaluating target threat, proximate traffic was included in the final TSAA design.

The evaluation of non-qualified targets found that retaining directional information when valid was important to the pilot as well as differentiating non-qualified targets from qualified targets. Due to the negative reaction to displaying targets with the non-directional diamond, the LTD designator was used to differentiate non-qualified targets. This designator was deemed appropriate by the pilot users in further studies. The recommendation for the final design is to differentiate non-qualified targets from qualified targets using the "LTD" to designate limited data quality.

The other option evaluated was the inclusion of vertical trend information in the audio callout. Performance was evaluated with and without the information in the audio call to assess benefit. It was found that miss distances significantly increased during a vertical high closure rate encounter when the vertical trend information was included. Due to the observed benefit, the recommendation for final design is to include vertical trend information in the aural alert annunciation.

A study was also designed to evaluate performance with a system that did not include the *Reinforced Traffic Caution* and compare it to a system that included the *Reinforced Traffic Caution Alert*. A performance benefit was observed during the audio system when *Reinforced Traffic Caution Alerts* were annunciated. There was also an overwhelming preference for the system that included the *Reinforced Traffic Caution.* Since there was observed benefit in including a second alert in the design, it is recommended that either the *Reinforced Traffic Caution* be maintained or it be replaced with an information update. Decisions must be weighed with the certification concerns for the system with two levels of alert.

The TSAA system was evaluated for functionality and usability. This research tested the pilot performance with and without alerts 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 the avionics manufacturers.

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7.2 Conclusions

Overall the system appeared to be effective and prevented 98.7% of collisions. TSAA alerted in every case, and the 1.3% of collisions that did occur were due to the pilots' conscience decision to disregard an alert. The system showed benefit in both the audio only and display systems. Performance was significantly improved in the enroute scenarios when a Cockpit Display of Traffic Information (CDTI) was available. In most cases, pilots became aware and responded to traffic earlier when a display was available compared to having aural alerts only. Miss distance also increased. Analysis of the audio only system showed that performance improved when alerts were provided to the pilot when compared to performance without a traffic system for a head-on case highlighting the benefit of TSAA. TSAA system was tested with both ideal ADS-B data and realistic ADS-B and TIS-B data. The performance remained consistent with realistic data quality, highlighting that the TSAA system should function reliably when released into actual flight conditions. Overall, the TSAA system does appear to be a valuable tool for preventing mid-air collisions in general aviation.

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Appendix A:

Human Factors Study 1 Supplementary Material

Appendix A1: Participant Consent Form

CONSENT TO PARTICIPATE IN
NON-BIOMEDICAL RESEARCH

ADS-B Display Configurations with Alerting: Human Factors Study 1

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. Candidate, 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 a flight simulator, 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 vertical profile using a side stick as well as monitor a conflict detection and traffic information display, indicate any traffic issues and select the quadrant where you would scan to visually acquire traffic. The flight tasks will examine flights in the traffic pattern and en route. The study will take approximately 2 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 are low and do not exceed those you would experience using a typical flight simulator or other similar video game.

- **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.

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

Background Questionnaire

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

Please list all of the certificates and ratings you hold.

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

o   Own
o   Rent

o   Fly Professionally (Please Specify)
o   Other (Please Specify)

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

How often do you fly with each of the following traffic systems? Please check the appropriate boxes.

	Never	Rarely	Occasionally	Frequently
TCAS Traffic Collision and Alerting System				
TAS Traffic Advisory System				
TIS Traffic Information System				
ADS-B Based Traffic Display Please Specify: _____				
Other (please Specify) _____				

What is your dominant hand?

o   Right (Right – handed)
o   Left (Left – handed)
o   Both (Ambidextrous)

Which hand do you typically use to manipulate a computer mouse?

o   Right
o   Left

_____

For Experimenter Use Only:

Flight Task	R L
Selection Task	R L

Appendix A3: Background Information Provided to Participants

Appendix A3.1: Background Information for "Proximate" Subject Group

Thank you for participating in the ADS-B Traffic Alerting Display Human Factors Study 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:

You will be testing two different alerting systems. One is a display-based system; the other is an audio only based system. You will be provided training in both of these systems.

In the display-based system, you will be presented with a scenario on a multi-function display (Figure 1) and instructed to fly a flight director profile using a joystick. When you decide that a traffic target may be a threat, you will select the location where you would scan for traffic as well as identify your perceived urgency of the threat. We will measure the times of your selection as well as your performance on the flight task.

In the audio-based system, you will be presented with aural alerts and instructed to fly a flight director profile using a joystick. Upon annunciation of an aural alert, select the location where you would scan for traffic as well as identify your perceived urgency of the threat. We will measure your reaction time as well as your performance on the flight task.

At the end of the experiment, you will be given a subjective evaluation and post-experiment questionnaire to provide feedback on the experiment. The experiment is expected to take about 2.5 hours. You will get opportunities to take short breaks throughout the session.

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

1

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, it calculates the range, altitude, bearing, and closure rate of all aircraft within range. The system can issue two levels of alert: a Traffic Caution Alert and a Reinforced Traffic Caution Alert. Figure 1 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.

The Reinforced Traffic Caution Alert is based on 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. Upon annunciation of the Reinforced Traffic Caution Alert, penetration of the protected area is predicted to occur in 30 seconds or less.

Both the Traffic Caution Alert and the Reinforced Traffic Caution Alert aircraft will be depicted with a caution symbol on the display. (Area 1 in Figure 3) Aural alerts will also annunciate for both alerts including azimuth, range, and altitude information (e.g. "Traffic, 3 o'clock, 2 miles, high"). The Reinforced Traffic Caution Alert will have a higher urgency "Traffic" call compared to the Traffic Caution Alert.

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

Figure 2. Alert Illustration

2

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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. In the display based study you will use two systems. In one system, non-qualified targets will always be depicted with a non-directional diamond ◈ (Area 3 in Figure 3). In the other system, you will have some non-qualified targets depicted as a non-directional diamond ◈ and others depicted as directional targets A (Area 2 in Figure 3) depending on the quality of information.

Display Symbology

Figure 3. Display Symbology

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, high." This specific traffic is 600 feet above you and descending.
2. (N97533) is depicted as non-alert traffic with directionality. This specific traffic is shown 1,600 feet below you and climbing.
3. Non-directional target where directional information is not available. The TSAA system will not annunciate alerts for non-directional targets. This specific traffic is shown 2,300 feet below you and descending.
4. Ground targets. One of the targets shows directionality while the other one does not and is represented with a non-directional diamond.

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5. (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.
6. (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 A3.2: Background Information for "Without Proximate" Subject Group

Thank you for participating in the ADS-B Traffic Alerting Display Human Factors Study 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:

You will be testing two different alerting systems. One is a display-based system; the other is an audio only based system. You will be provided training in both of these systems.

In the display-based system, you will be presented with a scenario on a multi-function display (Figure 1) and instructed to fly a flight director profile using a joystick. When you decide that a traffic target may be a threat, you will select the location where you would scan for traffic as well as identify your perceived urgency of the threat. We will measure the times of your selection as well as your performance on the flight task.

In the audio-based system, you will be presented with aural alerts and instructed to fly a flight director profile using a joystick. Upon annunciation of an aural alert, select the location where you would scan for traffic as well as identify your perceived urgency of the threat. We will measure your reaction time as well as your performance on the flight task.

At the end of the experiment, you will be given a subjective evaluation and post-experiment questionnaire to provide feedback on the experiment. The experiment is expected to take about 2.5 hours. You will get opportunities to take short breaks throughout the session.

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

1

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, it calculates the range, altitude, bearing, and closure rate of all aircraft within range. The system can issue two levels of alert: a Traffic Caution Alert and a Reinforced Traffic Caution Alert. Figure 1 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.

The Reinforced Traffic Caution Alert is based on 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. Upon annunciation of the Reinforced Traffic Caution Alert, penetration of the protected area is predicted to occur in 30 seconds or less.

Both the Traffic Caution Alert and the Reinforced Traffic Caution Alert aircraft will be depicted with a caution symbol on the display. (Area 1 in Figure 3) Aural alerts will also annunciate for both alerts including azimuth, range, and altitude information (e.g. "Traffic, 3 o'clock, 2 miles, high"). The Reinforced Traffic Caution Alert will have a higher urgency "Traffic" call compared to the Traffic Caution Alert.
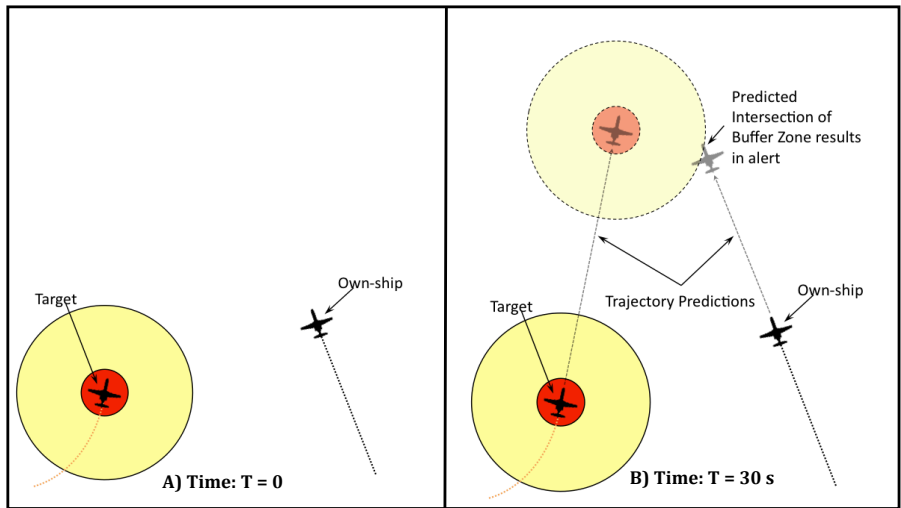

Figure 2. Alert Illustration

2

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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. In the display based study you will use two systems. In one system, non-qualified targets will always be depicted with a non-directional diamond ◇ (Area 3 in Figure 3). In the other system, you will have some non-qualified targets depicted as a non-directional diamond ◆ and others depicted as directional targets A (Area 2 in Figure 3) depending on the quality of information.

Display Symbology

Figure 3. Display Symbology

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, high." This specific traffic is 600 feet above you and descending.
2. (N97533) is depicted as non-alert traffic with directionality. This specific traffic is shown 1,600 feet below you and climbing.
3. Non-directional target where directional information is not available. The TSAA system will not annunciate alerts for non-directional targets. This specific traffic is shown 2,300 feet below you and descending.
4. Ground targets. One of the targets shows directionality while the other one does not and is represented with a non-directional diamond.

3

5. (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

Appendix A4.1. Instructions for Participants in "Proximate" Subject Group

Instructions to participants: Part A

Part A: Display – Based System

You will be presented with a scenario on a multi-function display and instructed to fly a flight director profile using a joystick. When you decide that a traffic target may be a threat, you will select the location where you would scan for traffic as well as identify your perceived urgency of the threat. We will measure the times of your selection as well as your performance on the flight task.

Perceived Urgency Levels

Critical	I will stop talking to ATC and look for traffic.
Important	I will stop entering my flight plan and look for traffic.
Not a Factor	When I have time, I will look for traffic.

During the flight director tracking task, use the joystick to move the aircraft reference symbol. Your goal is to superimpose the aircraft reference symbol onto the flight director steering command bar (purple). This system is only active in pitch. You will receive a score at the end of each scenario reflecting your performance on the tracking task.

You may control range on the TSAA System using the following keyboard inputs:

C	Zoom In
Z	Zoom Out

System A

You will be presented with 8 scenarios for this part of the study. In this system, all non-qualified targets are depicted with a non-directional diamond symbol. You will not get alerts issued on non-qualified targets.

System B

You will be presented with 8 scenarios for this part of the study. In this system, non-directional non-qualified targets are depicted with a non-directional diamond symbol while non-qualified targets with valid directionality are depicted with the basic directional symbol. You will not get alerts issued on non-qualified targets.

	Directional Symbol
	Non – Directional Symbol

Instructions to participants: Part B

Part B: Audio – Based System

You will be presented with aural alerts and instructed to fly a flight director profile using a joystick. Upon annunciation of an aural alert, select the location where you would scan for traffic as well as identify your perceived urgency of the threat. We will measure your reaction time as well as your performance on the flight task.

Perceived Urgency Levels

Critical	I will stop talking to ATC and look for traffic.
Important	I will stop entering my flight plan and look for traffic.
Not a Factor	When I have time, I will look for traffic.

During the flight director tracking task, use the joystick to move the aircraft reference symbol. Your goal is to superimpose the aircraft reference symbol onto the flight director steering command bar (purple). This system is only active in pitch. You will receive a score at the end of each scenario reflecting your performance on the tracking task.

<u>Audio Option 1:</u>

You will be presented with 10 aural alerts for this part of the study. With this option, all alerts occurring within 1 nm will be presented in quarter – mile increments. All alerts occurring above 1 nm will be presented in integer miles.

<u>Audio Option 2:</u>

You will be presented with 10 aural alerts for this part of the study. With this option, all alerts occurring within 1 nm will be called as "Less than one mile." All alerts occurring above 1 nm will be presented in integer miles.

Instructions to participants: Part A

Part A: Display – Based System

You will be presented with a scenario on a multi-function display and instructed to fly a flight director profile using a joystick. When you decide that a traffic target may be a threat, you will select the location where you would scan for traffic as well as identify your perceived urgency of the threat. We will measure the times of your selection as well as your performance on the flight task.

Perceived Urgency Levels

Critical	I will stop talking to ATC and look for traffic.
Important	I will stop entering my flight plan and look for traffic.
Not a Factor	When I have time, I will look for traffic.

During the flight director tracking task, use the joystick to move the aircraft reference symbol. Your goal is to superimpose the aircraft reference symbol onto the flight director steering command bar (purple). This system is only active in pitch. You will receive a score at the end of each scenario reflecting your performance on the tracking task.

You may control range on the TSAA System using the following keyboard inputs:

C	Zoom In
Z	Zoom Out

<u>System A</u>

You will be presented with 8 scenarios for this part of the study. In this system, all non-qualified targets are depicted with a non-directional diamond symbol. You will not get alerts issued on non-qualified targets.

<u>System B</u>

You will be presented with 8 scenarios for this part of the study. In this system, non-directional non-qualified targets are depicted with a non-directional diamond symbol while non-qualified targets with valid directionality are depicted with the basic directional symbol. You will not get alerts issued on non-qualified targets.

	Directional Symbol
	Non – Directional Symbol

Instructions to participants: Part B

Part B: Audio – Based System

You will be presented with aural alerts and instructed to fly a flight director profile using a joystick. Upon annunciation of an aural alert, select the location where you would scan for traffic as well as identify your perceived urgency of the threat. We will measure your reaction time as well as your performance on the flight task.

Perceived Urgency Levels

Critical	I will stop talking to ATC and look for traffic.
Important	I will stop entering my flight plan and look for traffic.
Not a Factor	When I have time, I will look for traffic.

During the flight director tracking task, use the joystick to move the aircraft reference symbol. Your goal is to superimpose the aircraft reference symbol onto the flight director steering command bar (purple). This system is only active in pitch. You will receive a score at the end of each scenario reflecting your performance on the tracking task.

<u>Audio Option 1:</u>

You will be presented with 10 aural alerts for this part of the study. With this option, all alerts occurring within 1 nm will be presented in quarter – mile increments. All alerts occurring above 1 nm will be presented in integer miles.

<u>Audio Option 2:</u>

You will be presented with 10 aural alerts for this part of the study. With this option, all alerts occurring within 1 nm will be called as "Less than one mile." All alerts occurring above 1 nm will be presented in integer miles.

Appendix A5. Subjective Evaluations

Appendix A5.1: Subjective Evaluations for Display Based Test

Subjective Evaluations Part A (1) [Provided after first 8 runs in Display Based Test]

Participant ID # _____

System (A or B): _____

Display Based Test: Subjective Evaluation 1

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 black background? If so, please explain.

   ○ YES   ○ NO

   Explain:

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

   ○ YES   ○ NO

   Explain:

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

   ○ YES   ○ NO

   Explain:

5. Were there any cases where you think you identified the wrong threat? If so, please explain.

○ YES	○ NO

Explain:

6. Could you rely on the TSAA System to function properly?

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

Explain:

7. Did the alerts appear to occur logically?

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

Explain:

8. Were there cases where you do not think you could trust the system?

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

Explain:

9. Does the TSAA System miss genuine conflicts/risks?

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

Explain:

Subjective Evaluation Part A: 2 [Provided after second 8 runs in Part A] (Note: Only difference from part 1 is removal of the question regarding black background readability)

Participant ID # _____

System (A or B): _____

Display Based Test: Subjective Evaluation 2

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. Were there any cases where you think you identified the wrong threat? If so, please explain.

   ○ YES   ○ NO

   Explain:

5. Could you rely on the TSAA System to function properly?

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

Explain:

6. Did the alerts appear to occur logically?

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

Explain:

7. Were there cases where you do not think you could trust the system?

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

Explain:

8. Does the TSAA System miss genuine conflicts/risks?

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

Explain:

Appendix A5.2: Audio-Based System Questionnaire

Participant ID #: _____

<u>Audio – Based System Questionnaire</u>

Which audio option did you prefer? Why?

> Option 1: Quarter-mile increments below 1 nm (or)
> Option 2: "Less than one mile" callout below 1 nm

⚪ Option 1	⚪ Option 2	

Explain:

Can you suggest a better option (different from what was presented today) for reporting range of traffic within 2nm? If so, please describe.

Appendix A5.3: General Usability and Post-Evaluation Questionnaire

Post-Evaluation Questionnaire (For Subjects with Proximate Indication)

Post Evaluation Questionnaire

1. Please describe the different types of alerts in the TSAA system and discuss what they mean.

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

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

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

1

5. How useful did you find the indication of proximate 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

6. If you own an aircraft, please answer question 6a.
   If you typically rent an aircraft, please answer question 6b.

   a. How much would you pay to install a system like this on your airplane?

   ○ Less than $1,000

   ○ $1,000 - $2,000

   ○ $2,000 - $5,000

   ○ $5,000 - $10,000

   ○ $10,000 - $15,000

   ○ $15,000 - $20,000

   ○ More than $20,000

   ○ Would Not Buy

   ○ No Opinion

   b. If you rent, how much more would you pay per hour to have a system like this installed on the airplane you fly?

   ○ $0

   ○ $1 - $5

   ○ $5 - $10

   ○ $10 - $20

   ○ $20 - $30

   ○ $30- $50

   ○ More than $50

   ○ No Opinion

2

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7. Do you have any feedback regarding the experiment?

8. Additional Comments:

Post-Evaluation Questionnaire (For Subjects without Proximate Indication)

Post Evaluation Questionnaire

1. Please describe the different types of alerts in the TSAA system and discuss what they mean.

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

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

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

1

5. If you own an aircraft, please answer question 5a.
   If you typically rent an aircraft, please answer question 5b.

   a. How much would you pay to install a system like this on your airplane?

   - ◯ Less than $1,000
   - ◯ $1,000 - $2,000
   - ◯ $2,000 - $5,000
   - ◯ $5,000 - $10,000
   - ◯ $10,000 - $15,000
   - ◯ $15,000 - $20,000
   - ◯ More than $20,000
   - ◯ Would Not Buy
   - ◯ No Opinion

   b. If you rent, how much more would you pay per hour to have a system like this installed on the airplane you fly?

   - ◯ $0
   - ◯ $1 - $5
   - ◯ $5 - $10
   - ◯ $10 - $20
   - ◯ $20 - $30
   - ◯ $30- $50
   - ◯ More than $50
   - ◯ No Opinion

2

7. Do you have any feedback regarding the experiment?

8. Additional Comments:

3

Appendix B

Human Factors Study 2 Supplementary Material

Appendix B1: Participant Consent Form

CONSENT TO PARTICIPATE IN NON-BIOMEDICAL RESEARCH

ADS-B Display Configurations with Alerting: Human Factors Study 2

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. Candidate, 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 a flight simulator, 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 a fixed base flight simulator as well as monitor a conflict detection and traffic information display, 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 are low and do not exceed those you would experience using a typical flight simulator or other similar video game.

- **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.

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 B2: Background Questionnaire

Background Questionnaire

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

Please list all of the certificates and ratings you hold.

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

o   Own
o   Rent

o   Fly Professionally (Please Specify)
o   Other (Please Specify)

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

How often do you fly with each of the following traffic systems? Please check the appropriate boxes.

	Never	Rarely	Occasionally	Frequently
TCAS Traffic Collision and Alerting System				
TAS Traffic Advisory System				
TIS Traffic Information System				
ADS-B Based Traffic Display Please Specify: _____				
Other (please Specify) _____				

How much experience do you have flying PC-based flight simulators?

○ Never flown one	○ Flown one a few times	○ Own it and fly it regularly

How much experience do you have flying high-level flight simulators?

○ Never flown them	○ Flown them a few times	○ Flown them for training	○ Flown them for extensive training and checkrides

Thank you for participating in the ADS-B Traffic Alerting Display Human Factors Study 2
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:

You will be testing two different alerting systems. One is a display-based system; the other is an audio only based system. You will be provided training in both of these systems.

During the experiment, you will be presented with scenarios on the flight simulator and instructed to fly a flight profile. You will be asked to verbalize any traffic concerns, point with your non-flying hand towards the direction where you would scan for traffic and respond appropriately

At the end of the experiment, you will be given a subjective evaluation and post-experiment questionnaire to provide feedback on the experiment. The experiment is expected to take about 3 hours. You will get opportunities to take short breaks throughout the session.

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. The system can issue two alerts: a Traffic Caution Alert and a Reinforced Traffic Caution Alert. Figure 2 illustrates a top down view of a sample conflict described below.

1

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.

The Reinforced Traffic Caution Alert is based on 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. Upon annunciation of the Reinforced Traffic Caution Alert, penetration of the protected area is predicted to occur in 30 seconds or less.

Both the Traffic Caution Alert and the Reinforced Traffic Caution Alert aircraft will be depicted with a caution symbol on the display. (Area 1 in Figure 3) Aural alerts will also annunciate for both alerts including azimuth, range, and altitude information (e.g. "Traffic, 3 o'clock, 2 miles, high"). The Reinforced Traffic Caution Alert will have a higher urgency "Traffic" call compared to the Traffic Caution Alert. 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.

2

Display Symbology

Figure 3. Display Symbology

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." 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.
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.

3
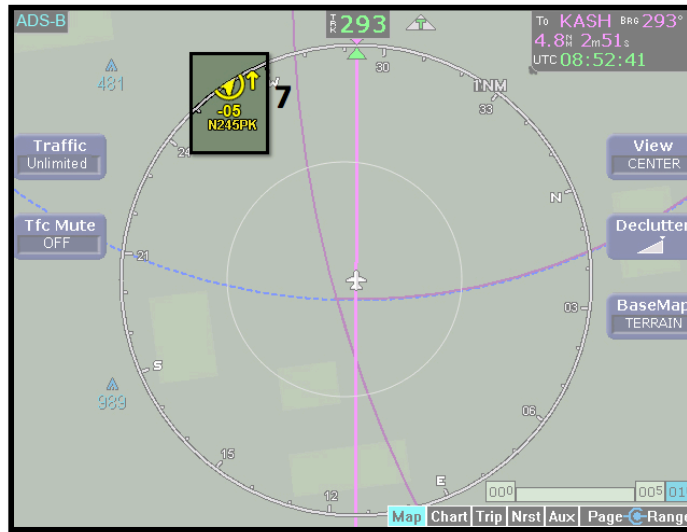
Figure 4. Off-Scale Traffic

Airport Information:

You will be flying a C172SP today out of Minuteman Airfield (6B6). The winds are calm, and runway 21 is in use. Field elevation is 268 feet, and pattern altitude is 1,300 feet. Standard pattern for runway 21 is left traffic.

STOW
MINUTE MAN AIR FIELD   (6B6)   2 N   UTC−5(−4DT)   N42°27.64′ W71°31.07′   NEW YORK
  268   B   S4   **FUEL** 100LL   TPA—See Remarks   NOTAM FILE BDR   L−33C, 34J
  RWY 03–21: H2770X48 (ASPH)   S−12.5   LIRL   IAP
    RWY 03: Hill.   **RWY 21:** REIL. PAPI(P2L)—GA 3.5° TCH 25′.
  Trees.
  RWY 12–30: 1600X70 (TURF–GRVL)
    RWY 12: Trees.   **RWY 30:** Trees.
  AIRPORT REMARKS: Attended 1400–2100Z‡. Tree obstruction in apch,
  primary and transition surfaces Rwy 03 and Rwy 12–30. Upwind
  and crosswind apchs not recommended. Noise abatement
  procedures in effect notify arpt manager 978–897–3933 of
  intention to opr between 0400–1100Z‡. TPA for light acft
  1300(1032). Helicopters use rgt tfc. Rotating bcn OTS
  0400–1200Z‡. ACTIVATE REIL Rwy 21—CTAF.
  COMMUNICATIONS: CTAF/UNICOM 122.8
Ⓡ **BOSTON APP/DEP CON** 124.4
  RADIO AIDS TO NAVIGATION: NOTAM FILE MHT.
    MANCHESTER (L) VOR/DME 114.4   MHT   Chan 91   N42°52.11′
    W71°22.17′   210° 25.3 NM to fld. 471/15W.
    BEDDS NDB (LOM) 332   BE   N42°28.79′ W71°23.32′   275° 5.8
    NM to fld. NOTAM FILE BED.
  COMM/NAV/WEATHER REMARKS: Clnc del thru Bridgeport RADIO (BDR)
  1–866–293–5149.

Figure 5. Airport Information for 6B6

4

Appendix B4: Instructions for Participants

Instructions to Participants

You will be instructed to fly specific flight profiles on the simulator for this experiment. You will be held to private pilot practical test standards for heading, and altitude.

- Assume you have a co-pilot in the plane and verbalize any traffic concerns to him/her
- **Scanning for Traffic**
  - Say "**LOOKING for traffic**" plus the **bearing** . Example. "Looking for traffic at 10 o'clock"
  - Point with your non-flying hand towards the direction you would scan for traffic
  - Turn to look in the direction where you would scan
- **Visual Acquisition**
  - If traffic is not in forward field of view, assume traffic is in sight.
  - If traffic is coming from forward field of view, state **"Traffic in Sight"** when traffic is acquired
- **Respond** to traffic appropriately whenever you deem in necessary.
  - Verbalize any response

You may control range on the TSAA System (Display) using the keyboard:

C	Zoom In
Z	Zoom Out

\

Appendix B5. Subjective Evaluations

Appendix B5.1: Subjective Evaluations for Display Based Test

Display Based Test: Subjective Evaluation

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 black background? If so, please explain.

   ○ YES   ○ NO

   Explain:

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

   ○ YES   ○ NO

   Explain:

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

   ○ YES   ○ NO

   Explain:

5. Did you find that the LTD designating non-qualified targets to be appropriate? If not, can you suggest a better option for depicting non-qualified targets?

   ○ YES   ○ NO

   Explain:

Appendix B5.2: Audio-Based System Questionnaire

<u>Audio Based Test: Subjective Evaluation</u>

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

○ YES	○ NO	
Explain:		

2. Could you rely on the TSAA System to function properly?

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

3. Did the alerts appear to occur logically?

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

4. Were there cases where you **do not** think you could trust the system?

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

5. Does the TSAA System miss genuine conflicts/risks?

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

Appendix B5.3: General Usability and Post-Evaluation Questionnaire

Post Evaluation Questionnaire

(Note: Symbology Pre-Test will be administered here again as a post test)

1. How easy do you think it would be for other pilots to understand the alerting criteria?

    ⭘ Easy with Training

    ⭘ Difficult with Training

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

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

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

5. 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

6. Did you find any of the scenarios to be predictable?

1

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7. If you own an aircraft, please answer question 7A (1 &2).
   If you typically rent an aircraft, please answer question 7B (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

2

8. Do you have any feedback regarding the experiment?

9. Additional Comments:

3

Appendix B6: Symbology Pre-test

1. 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. 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. 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. 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. 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. 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

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

☐

☐

☐

☐

☐

Appendix C

Human Factors Study 3 Supplementary Material

Appendix C1: Participant Consent Form

CONSENT TO PARTICIPATE IN NON-BIOMEDICAL RESEARCH

ADS-B Display Configurations with Alerting: Human Factors Study 3

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. Candidate, 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 a flight simulator, 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 a fixed base flight simulator as well as monitor a conflict detection and traffic information display, 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 are low and do not exceed those you would experience using a typical flight simulator or other similar video game.

- **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.

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 C2: Background Questionnaire

Background Questionnaire

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

Please list all of the certificates and ratings you hold.

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

o Own

o Rent

o Fly Professionally (Please Specify)

o Other (Please Specify)

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

How often do you fly with each of the following traffic systems? Please check the appropriate boxes.

	Never	Rarely	Occasionally	Frequently
TCAS Traffic Collision and Alerting System				
TAS Traffic Advisory System				
TIS Traffic Information System				
ADS-B Based Traffic Display Please Specify: _____				
Other (please Specify) _____				

How much experience do you have flying PC-based flight simulators?

o Never flown one	o Flown one a few times	o Own it and fly it regularly

How much experience do you have flying high-level flight simulators?

o Never flown them	o Flown them a few times	o Flown them for training	o Flown them for extensive training and checkrides

Appendix C3: Background Information

*Thank you for participating in the ADS-B Traffic Alerting Display Human Factors Study 3
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:

You will be testing two different alerting systems. One is a display-based system; the other is an
audio only based system. You will be provided training in both of these systems.

During the experiment, you will be presented with scenarios on the flight simulator and
instructed to fly a flight profile. You will be asked to verbalize any traffic concerns, point with
your non-flying hand towards the direction where you would scan for traffic and respond
appropriately

At the end of the experiment, you will be given a subjective evaluation and post-experiment
questionnaire to provide feedback on the experiment. The experiment is expected to take about
3 hours. You will get opportunities to take short breaks throughout the session.

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. The system can issue two alerts: a Traffic Caution Alert
and a Reinforced Traffic Caution Alert. Figure 2 illustrates a top down view of a sample conflict
described below.

1

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.

The Reinforced Traffic Caution Alert is based on 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. Upon annunciation of the Reinforced Traffic Caution Alert, penetration of the protected area is predicted to occur in 30 seconds or less.

Both the Traffic Caution Alert and the Reinforced Traffic Caution Alert aircraft will be depicted with a caution symbol on the display. (Area 1 in Figure 3) Aural alerts will also annunciate for both alerts including azimuth, range, and altitude information (e.g. "Traffic, 3 o'clock, 2 miles, high"). The Reinforced Traffic Caution Alert will have a higher urgency "Traffic" call compared to the Traffic Caution Alert. 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)
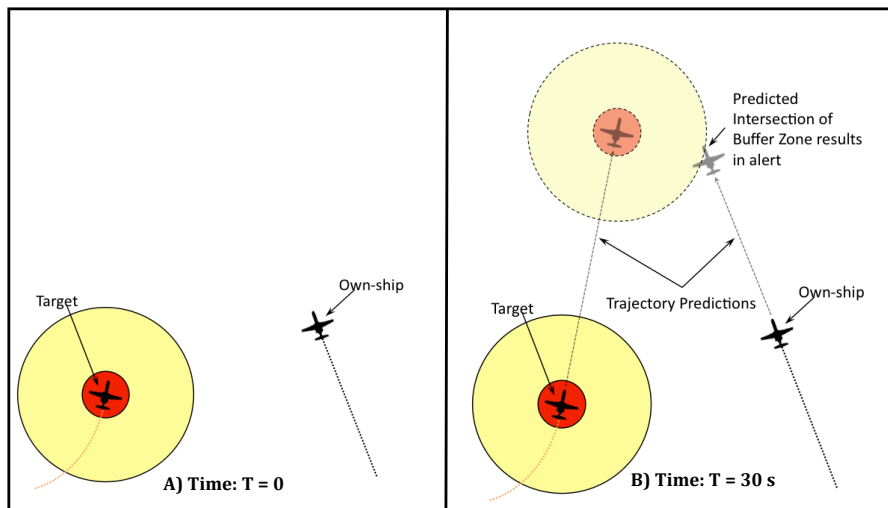

Figure 2. Alert Illustration

During this experiment you will be testing two alerting systems: one including the Reinforced Traffic Caution Alert, and one without the Reinforced Traffic Caution Alert.

2

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.
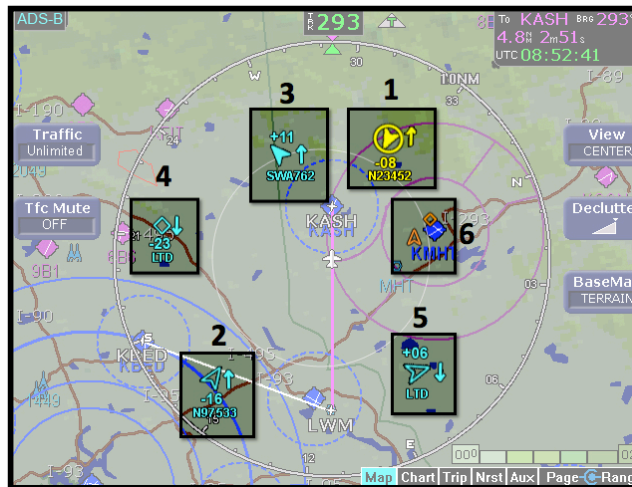
Display Symbology

Figure 3. Display Symbology

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." 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.
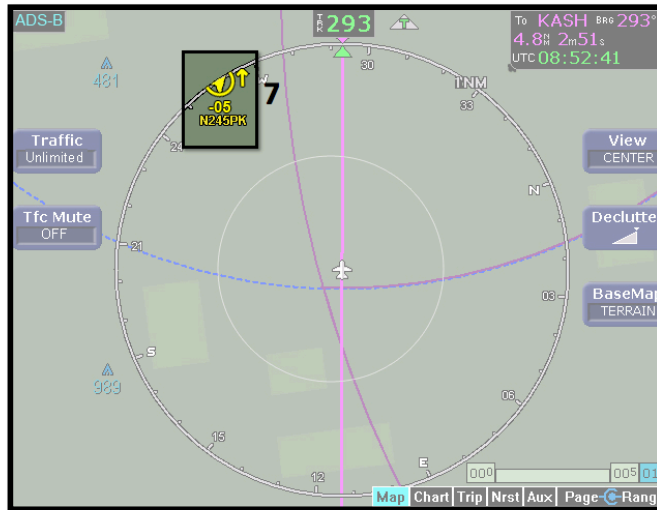
3

Figure 4. Off-Scale Traffic

Airport Information:

You will be flying a C172SP today out of Concord Airport (KCON). The winds are calm, and runway 35 is in use. Field elevation is 342 feet, and pattern altitude is 1,300 feet. Standard pattern for runway 35 is left traffic.

Figure 5. Airport Information for KCON

4

Appendix C4: Instructions to Participants

Instructions to Participants

You will be instructed to fly specific flight profiles on the simulator for this experiment. You will be
held to private pilot practical test standards for heading, and altitude.

- Assume you have a co-pilot in the plane and verbalize any traffic concerns to him/her
- **Scanning for Traffic**
  - o Say "**LOOKING for traffic**" plus the **bearing** . Example. "Looking for traffic at 10
    o'clock"
  - o Point with your non-flying hand towards the direction you would scan for traffic
  - o Turn to look in the direction where you would scan
- **Visual Acquisition**
  - o If traffic is not in forward field of view, assume traffic is in sight.
  - o If traffic is coming from forward field of view, state **"Traffic in Sight"** when traffic is
    acquired
- **Respond** to traffic appropriately whenever you deem in necessary.
  - o Verbalize any response

You may control range on the TSAA System (Display) using the keyboard:

C	Zoom In
Z	Zoom Out

Appendix C5: Subjective Questionnaires

Appendix C5.1: Display-Based System (PAZ Only) Subjective Questionnaire

Test name: HF3: Display - Eval (Not Including Reinforced TCA)

Question 1 of 9

Could you rely on the TSAA System to function properly?

○ **A)** Never
○ **B)** Rarely
○ **C)** Sometimes
○ **D)** Very Often
○ **E)** Always

Question 2 of 9

Please Explain

Question 3 of 9

Did the alerts appear to occur logically?

○ **A)** Never
○ **B)** Rarely
○ **C)** Sometimes
○ **D)** Very Often
○ **E)** Always

Question 4 of 9

Please Explain.

Question 5 of 9

Were there cases where you **do not** think you could trust the alerting system?

○ **A)** Never
○ **B)** Rarely
○ **C)** Sometimes
○ **D)** Very Often
○ **E)** Always

Question 6 of 9

Please Explain.

Question 7 of 9

Does the TSAA System miss genuine conflicts/risks?

○ **A)** Never
○ **B)** Rarely
○ **C)** Sometimes
○ **D)** Very Often
○ **E)** Always

Question 8 of 9

Please Explain.

Question 9 of 9

Out of the 7 scenarios you just experienced, how many times would you have contacted ATC for help in finding traffic or resolving a situation?

○ **A)** Never
○ **B)** Once
○ **C)** Twice
○ **D)** Three times
○ **E)** Four or more times

Appendix C5.2 Audio Based System (PAZ Only) Subjective Questionnaire

Test name: HF3: Audio -Eval (Not Including Reinforced TCA)

Question 1 of 9

Could you rely on the TSAA System to function properly?

- ○ **A)** Never
- ○ **B)** Rarely
- ○ **C)** Sometimes
- ○ **D)** Very Often
- ○ **E)** Always

Question 2 of 9

Please Explain

Question 3 of 9

Did the alerts appear to occur logically?

- ○ **A)** Never
- ○ **B)** Rarely
- ○ **C)** Sometimes
- ○ **D)** Very Often
- ○ **E)** Always

Question 4 of 9

Please Explain.

Question 5 of 9

Were there cases where you **do not** think you could trust the alerting system?

- ○ **A)** Never
- ○ **B)** Rarely
- ○ **C)** Sometimes
- ○ **D)** Very Often
- ○ **E)** Always

Question 6 of 9

Please Explain.

Question 7 of 9

Does the TSAA System miss genuine conflicts/risks?

- ○ **A)** Never
- ○ **B)** Rarely
- ○ **C)** Sometimes
- ○ **D)** Very Often
- ○ **E)** Always

Question 8 of 9

Please Explain.

Question 9 of 9

Out of the 4 scenarios you just experienced, how many times would you have contacted ATC for help in finding traffic or resolving a situation?

- ○ **A)** Never
- ○ **B)** Once
- ○ **C)** Twice
- ○ **D)** Three times
- ○ **E)** Four or more times

Appendix C5.3 Display Based System (PAZ & CAZ) Subjective Questionnaire

Test name: HF3: Display - Eval (Including Reinforced TCA)

Question 1 of 11

Could you rely on the TSAA System to function properly?

○ **A)** Never
○ **B)** Rarely
○ **C)** Sometimes
○ **D)** Very Often
○ **E)** Always

Question 2 of 11

Please Explain

Question 3 of 11

Did the alerts appear to occur logically?

○ **A)** Never
○ **B)** Rarely
○ **C)** Sometimes
○ **D)** Very Often
○ **E)** Always

Question 4 of 11

Please Explain.

Question 5 of 11

Were there cases where you **do not** think you could trust the alerting system?

- ○ **A)** Never
- ○ **B)** Rarely
- ○ **C)** Sometimes
- ○ **D)** Very Often
- ○ **E)** Always

Question 6 of 11

Please Explain.

Question 7 of 11

Does the TSAA System miss genuine conflicts/risks?

- ○ **A)** Never
- ○ **B)** Rarely
- ○ **C)** Sometimes
- ○ **D)** Very Often
- ○ **E)** Always

Question 8 of 11

Please Explain.

Question 9 of 11

What was your perceived difference in urgency between the traffic caution alert & the reinforced traffic caution alert.

○ **A)** Traffic Caution Alert was **much less** urgent than the Reinforced Traffic Caution Alert

○ **B)** Traffic Caution Alert was **slightly less** urgent than the Reinforced Traffic Caution Alert

○ **C)** **No difference** in urgency between Traffic Caution Alert and Reinforced Traffic Caution Alert

○ **D)** Traffic Caution Alert was **slightly more** urgent than the Reinforced Traffic Caution Alert

○ **E)** Traffic Caution Alert was **much more** urgent than the Reinforced Traffic Caution Alert

Question 10 of 11

Please explain why you felt one alert was more urgent than the other, if applicable.

Question 11 of 11

Out of the 7 scenarios you just experienced, how many times would you have contacted ATC for help in finding traffic or resolving a situation?

○ **A)** Never

○ **B)** Once

○ **C)** Twice

○ **D)** Three times

○ **E)** Four or more times

Appendix C5.4 Audio Based System (PAZ & CAZ) Subjective Questionnaire

Test name: HF3: Audio -Eval (Including Reinforced TCA)

Question 1 of 11

Could you rely on the TSAA System to function properly?

○ **A)** Never
○ **B)** Rarely
○ **C)** Sometimes
○ **D)** Very Often
○ **E)** Always

Question 2 of 11

Please Explain

Question 3 of 11

Did the alerts appear to occur logically?

○ **A)** Never
○ **B)** Rarely
○ **C)** Sometimes
○ **D)** Very Often
○ **E)** Always

Question 4 of 11

Please Explain.

Question 5 of 11

Were there cases where you **do not** think you could trust the alerting system?

○ **A)** Never
○ **B)** Rarely
○ **C)** Sometimes
○ **D)** Very Often
○ **E)** Always

Question 6 of 11

Please Explain.

Question 7 of 11

Does the TSAA System miss genuine conflicts/risks?

○ **A)** Never
○ **B)** Rarely
○ **C)** Sometimes
○ **D)** Very Often
○ **E)** Always

Question 8 of 11

Please Explain.

What was your perceived difference in urgency between the traffic caution alert & the reinforced traffic caution alert.

- ○ **A)** Traffic Caution Alert was **much less** urgent than the Reinforced Traffic Caution Alert
- ○ **B)** Traffic Caution Alert was **slightly less** urgent than the Reinforced Traffic Caution Alert
- ○ **C)** **No difference** in urgency between Traffic Caution Alert and Reinforced Traffic Caution Alert
- ○ **D)** Traffic Caution Alert was **slightly more** urgent than the Reinforced Traffic Caution Alert
- ○ **E)** Traffic Caution Alert was **much more** urgent than the Reinforced Traffic Caution Alert

Question 10 of 11

Please explain why you felt one alert was more urgent than the other, if applicable.

Question 11 of 11

Out of the 4 scenarios you just experienced, how many times would you have contacted ATC for help in finding traffic or resolving a situation?

- ○ **A)** Never
- ○ **B)** Once
- ○ **C)** Twice
- ○ **D)** Three times
- ○ **E)** Four or more times

Appendix C5.5 Display Final Subjective Evaluation

Test name: HF3: Display - Eval Final

Question 1 of 14

Did you experience any problems using the alerting system?

○ **A)** Yes

○ **B)** No

Question 2 of 14

If you experienced any problems, please explain.

Question 3 of 14

Were there problems reading the traffic symbology on the **map** background?

○ **A)** Yes

○ **B)** No

Question 4 of 14

If there were problems reading the traffic symbology, please explain.

Question 5 of 14

Were there any problems reading the traffic symbology on the **black** background?

○ **A)** Yes

○ **B)** No

Question 6 of 14

If there were problems reading the symbology, please explain.

Question 7 of 14

Was display clutter a problem?

○ **A)** Yes

○ **B)** No

Question 8 of 14

If display clutter was a problem, please explain.

Question 9 of 14

Were there any cases where you think you identified the wrong threat?

○ **A)** Yes

○ **B)** No

Question 10 of 14

If so, please explain.

Question 11 of 14

Did you find the LTD designating non-qualified targets to be appropriate?

○ **A)** Yes

○ **B)** No

Question 12 of 14

Can you suggest a better option for depicting non-qualified targets?

Question 13 of 14

Out of the two systems you experienced using the display, which did you prefer?

○ **A)** Alerting system **with** Reinforced Traffic Caution Alert

○ **B)** Alerting system **without** Reinforced Traffic Caution Alert

○ **C)** No preference

Question 14 of 14

Please explain the reasoning behind your preference.

Appendix C5.6 Audio Based System Final Subjective Evaluation

Test name: HF3: Audio - Eval Final

Select multiple choice answers with a cross or tick:

○ Only select one answer

☐ Select multiple answers

Question 1 of 4

Did you experience any problems using the alerting system?

○ **A)** Yes

○ **B)** No

Question 2 of 4

If you experienced any problems, please explain.

Question 3 of 4

Out of the two systems you experienced using the display, which did you prefer?

○ **A)** Alerting system **with** Reinforced Traffic Caution Alert

○ **B)** Alerting system **without** Reinforced Traffic Caution Alert

○ **C)** No preference

Question 4 of 4

Please explain the reasoning behind your preference.

Appendix C5.7 Post Evaluation Questionnaire

Test name: Post Evaluation 3

Question 1 of 17

What was the **best** feature of the TSAA System?

Question 2 of 17

What was the **worst** feature of the TSAA System?

Question 3 of 17

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

Question 4 of 17

How easy do you think it would be for other pilots to understand the alerting criteria?

- ○ **A)** Easy with Training
- ○ **B)** Difficult with Training

Question 5 of 17

Were there cases where an alert was annunciated, but you thought it was unnecessary?

- ○ **A)** Never
- ○ **B)** Rarely
- ○ **C)** Sometimes
- ○ **D)** Very Often
- ○ **E)** Always

Question 6 of 17

Please Explain

Question 7 of 17

How useful did you find the indication of proximate (nearby airborne) traffic?

- ○ **A)** Always helped me identify the threat
- ○ **B)** Sometimes helped me identify the threat.
- ○ **C)** Did not help **nor** hinder me in identifying the threat.
- ○ **D)** Sometimes made it more difficult to identify the threat.
- ○ **E)** Always made it more difficult to identify the threat.

Question 8 of 17

Did you find any of the scenarios to be predictable? (i.e. could you predict which aircraft would come into conflict with you?)

Question 9 of 17

Were there cases where you thought what you saw out of the window was **different** than what was shown on the display (or annunciated in the aural callout)?

- ○ **A)** Never
- ○ **B)** Rarely
- ○ **C)** Sometimes
- ○ **D)** Very Often
- ○ **E)** Always

Question 10 of 17

Please explain.

Question 11 of 17

If you own an aircraft, how much would you pay to install an MFD **and** ADS-B alerting system like this on your airplane?

- A) Less than $1,000
- B) $1,000 - $1,999
- C) $2,000 - $4,999
- D) $5,000 - $9,999
- E) $10,000 - $14,999
- F) $15,000 - $19,999
- G) More than $19,999
- H) Would not buy
- I) No Opinion
- J) Do not own an aircraft

Question 12 of 17

If you own an aircraft, how much would you pay to add the ADS-B traffic alerting **onto an existing** Multi-Function Display for your airplane?

- A) Less than $1,000
- B) $1,000 - $1,999
- C) $2,000 - $4,999
- D) $5,000 - $9,999
- E) $10,000 - $14,999
- F) $15,000 - $19,999
- G) More than $19,999
- H) Would Not Buy
- I) No Opinion
- J) Do not own an aircraft

Question 13 of 17

If you rent aircraft, 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?

- A) $0
- B) $1 -$4
- C) $5 - $9
- D) $10 - $19
- E) $20 - $29
- F) $30 - $49
- G) More than $49
- H) No Opinion
- I) Do not rent aircraft

Question 14 of 17

If you rent aircraft, 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?

- A) $0
- B) $1 - $4
- C) $5 - $9
- D) $10 - $19
- E) $20 - $29
- F) $30 - $49
- G) More than $49
- H) No Opinion
- I) Do not rent aircraft

Question 15 of 17

Please rank the importance of each piece of information in the audio call (from most important to least important).

Example:

"Traffic, 3 o'clock, high, 2 miles, descending"

Bearing   Relative   Range   Vertical Trend
           Altitude
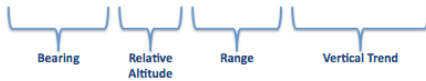
Question 16 of 17

Do you have any feedback regarding the experiment?

Question 17 of 17

Additional Comments:

Appendix C6: Symbology Pre-test

1. 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. 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. 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. 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. 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. 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

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

☐

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Appendix D

Encounter Performance

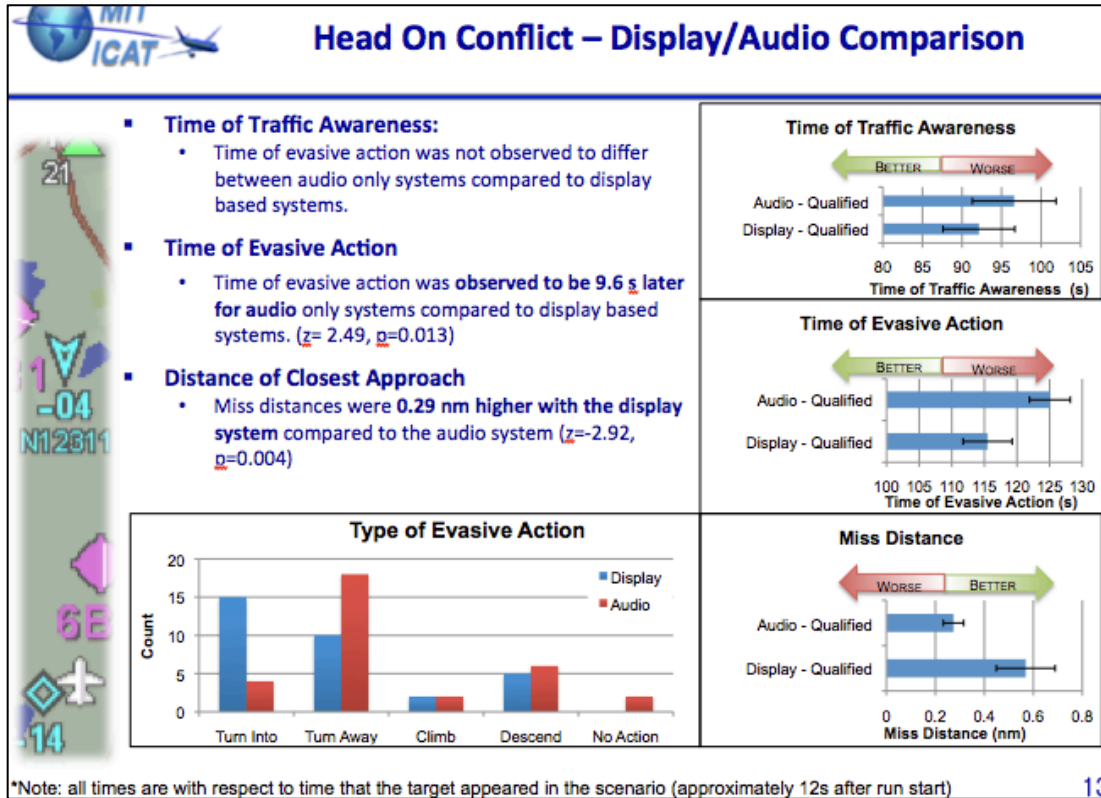Appendix D1: Head-On High Closure Rate Encounter

Appendix D1.1: Performance with ideal ADS-B
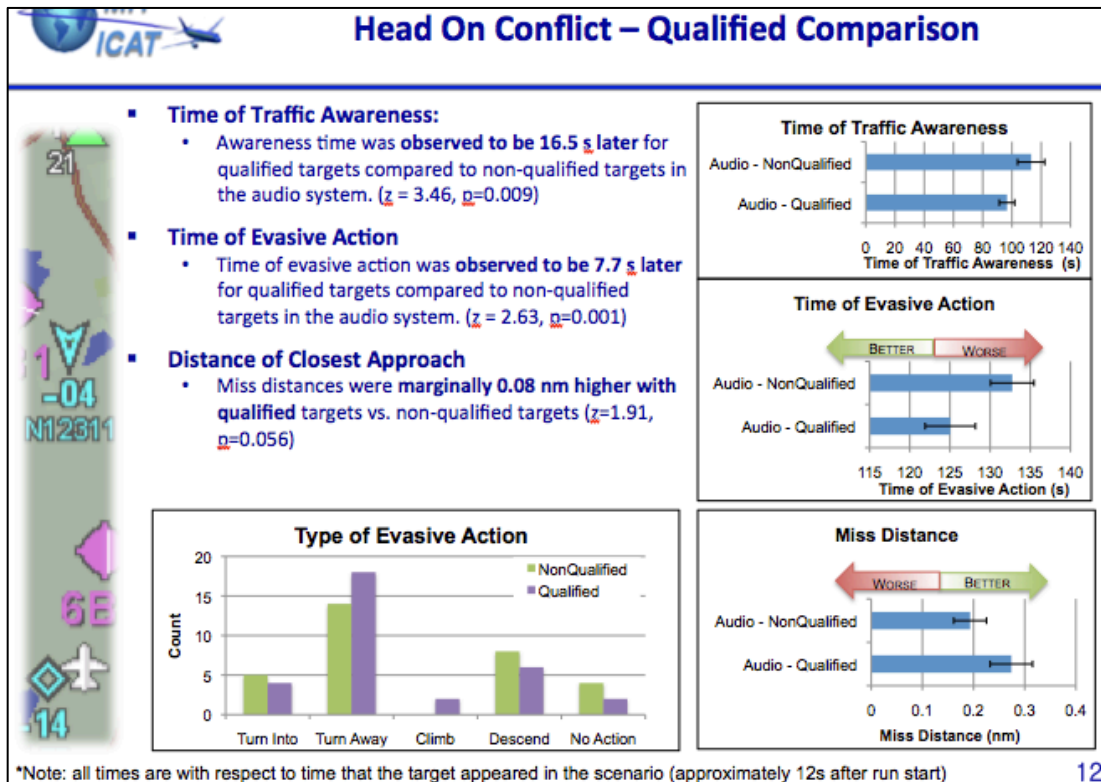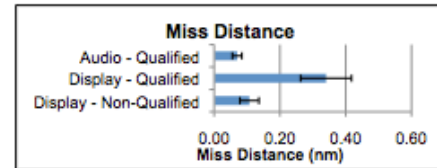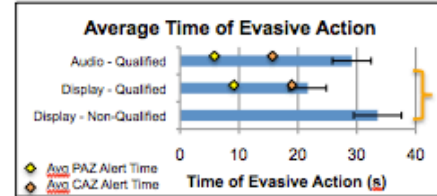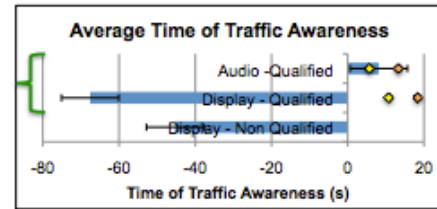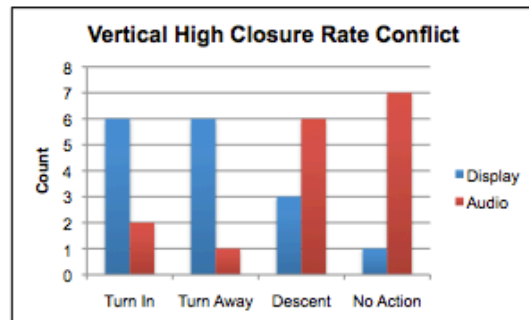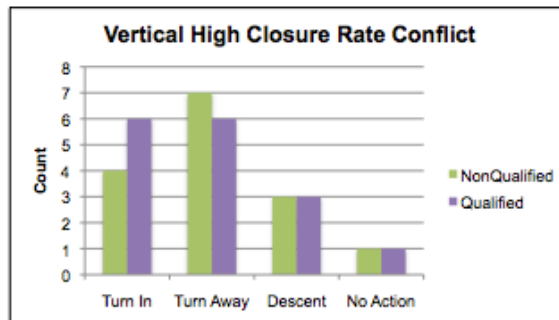
- **Time of Traffic Awareness:**
  - No observed difference in traffic awareness time between qualified and nonqualified targets
  - Awareness time was **observed to be later** for audio only systems compared to display based systems for the head on scenario. ($z = -2.057$, $p=0.040$)
- **Time of Evasive Action**
  - No observed difference in time of evasive action between qualified and nonqualified targets
  - Time of evasive action was **observed to be later** for audio only systems compared to display based systems for the head on scenario. ($z= -2.356$, $p=0.018$)
- **Time between Awareness and Evasive Action**
  - No observed difference between qualified and non-qualified targets.
  - No observed difference between audio and display based systems
- **Distance of Closest Approach**
  - Miss distances were **higher with qualified** targets vs. non-qualified targets ($z=-2.185$, $p=0.029$)
  - Miss distances were **higher using the display** vs audio systems. ($z=2.94$, $p=0.003$)

*Note: all times are with respect to time that the target appeared in the scenario (approximately 12s after run start)

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Average Time of Traffic Awareness

Audio Based System
Display Based System

0 20 40 60 80 100 120 140
Time of Traffic Awareness (s)

Average Time of Evasive Action for

Audio Based System
Display Based System

110 120 130 140
Time of Evasive Action (s)

Miss Distance for Head On Conflict

Qualified
Non-Qualified
Audio System
Display System

0.00 0.20 0.40 0.60 0.80
Miss Distance (nm)

◇ Avg PAZ Alert Time
◇ Avg CAZ Alert Time

Type of Evasive Action

	Left Turn	Right Turn	Climb	Descent
Non-Qualified	8	18	3	3
Qualified	9	15	2	6

- No apparent major difference in distribution of type of evasive action between qualified and non-qualified targets

	Left Turn	Right Turn	Climb	Descent
Display	6	20	5	1
Audio	11	13	0	8

- Slight difference in the distribution of type of evasive action between the display system and audio only system

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Appendix D1.2: Performance with realistic data quality

Appendix D2: Vertical High Closure Rate Encounter

Appendix D2.1: Performance with ideal ADS-B

- **Time of Traffic Awareness:**
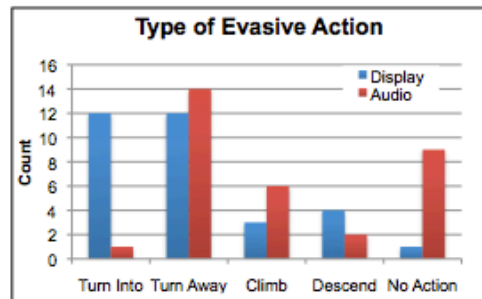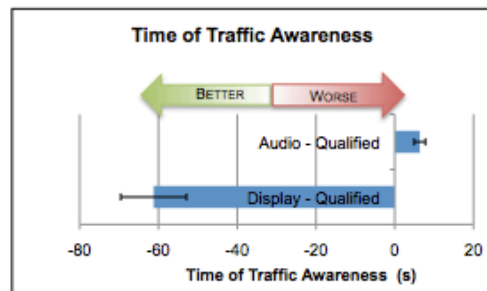 - No observed difference in traffic awareness time between qualified and nonqualified targets
  - Awareness time was **observed to be later for audio** only systems compared to display based systems. (F = 26.7 , p<0.001)

- **Time of Evasive Action**
  - There was **observed difference** in time of evasive action between qualified and nonqualified targets (z=-2.102, p=0.036)
  - Time of evasive action was not observed to differ between audio only systems compared to display based systems. (z=-1.864, p=0.062)

- **Time between Awareness and Evasive Action**
  - No observed difference between qualified and non-qualified targets.
  - The time between awareness and action **was longer during the display based system** (z =-3.465, p=0.001).

- **Distance of Closest Approach**
  - Miss distances were **higher with qualified** targets vs. non-qualified targets (z=-2.741, p=0.006)
  - Miss distances were **higher using the display** vs audio systems. (z=3.411, p=0.001)

*Note: all times are with respect to time that target began descending

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Type of Evasive Maneuver

- Note the increase in number of participants who chose not to take action against the traffic when only given audio cues.

- Could indicate value in providing vertical trend information (climbing/descending) in the audio call

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- **Time of Traffic Awareness:**
  - Awareness time was **observed to be later for audio** only systems compared to display based systems. (z=5.26, p<0.001)

- **Time of Evasive Action**
  - Time of evasive action was not observed to differ between audio only systems compared to display based systems.

- **Distance of Closest Approach**
  - There was no observed difference in miss distance between audio and display systems

Time of Traffic Awareness

BETTER   WORSE

Audio - Qualified

Display - Qualified

-80   -60   -40   -20   0   20

Time of Traffic Awareness (s)

Type of Evasive Action

Display
Audio

16
14
12
10
8
6
4
2
0

Count

Turn Into   Turn Away   Climb   Descend   No Action

+19

N29913

*Note: all times are with respect to time that target began descending

14

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Appendix D3: Multiple Intruder Encounter

Appendix D3.1: Performance with ideal ADS-B

- **There was some confusion on the multiple alerts because of the rapid consecutive alerts**
  - Participants tended to wait until after the audio completed before taking action (Average time of evasive action was 18s after time of first alert)
  - Based on observations of the safety pilot, no unsafe conditions occurred during this scenario

Time of Traffic Awareness	3 o'clock - Of the conflicts where alerts annunciated and participants were aware of the traffic, awareness time was 54.1 seconds before time of first alert. (SD=34s) 12 o'clock - Of the conflicts where alerts annunciated and participants were aware of the traffic, awareness time was 5.1 seconds before time of first alert. (SD=26s)
Time of Visual Acquisition	• 8/16 participants visually acquired 12 o'clock traffic • Average time of visual acquisition was 7.1s after the time of first alert (SD=31)
Time of Evasive Action	• 3 participants maneuvered before any alert was issued • Of the remaining participants, evasive action was taken on average **18s after time of first alert (SD=15s)**
Time between Awareness and Evasive Action	3 o'clock - It took on average 65s (SD=28s) to take evasive action once the participants became aware of the traffic. 12 o'clock - It took on average 20.5 s (SD=41s) to take evasive action once the participants became aware of the traffic.

Type of Evasive Action	Left Turn	Right Turn	Climb	Descend
	6	5	1	4

Closest Approach Distance	3 o'clock = 0.35nm (SD: 0.36nm), 12 o'clock = 1.23nm (SD: 1.44nm)

PAZ (3 o'clock): Annun 10/16 cases 3.4s (SD 5.1s)

CAZ (3 o'clock): Annun 1/16 cases 10s

PAZ (12 o'clock): Annun 13/16 cases 7.2s (SD 10.3s)

CAZ (12 o'clock): Annun 9/16 cases 12.9s (SD 5.2s)

*Note: all times relative to the time of first alert

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Appendix D3.2: Performance with realistic data quality

- **Time of Traffic Awareness:**
  - No observed difference in traffic awareness time between systems with or without Reinforced Traffic Caution

- **Time of Evasive Action**
  - No observed difference in time of evasive action time between systems with or without Reinforced Traffic Caution

- **Time between Awareness and Evasive Action**
  - No observed difference between systems with or without Reinforced Traffic Caution

- **Distance of Closest Approach**
  - No observed difference in miss distance between systems with or without Reinforced Traffic Caution
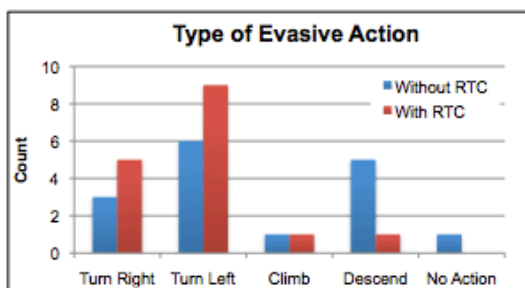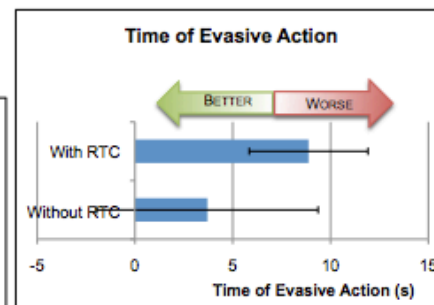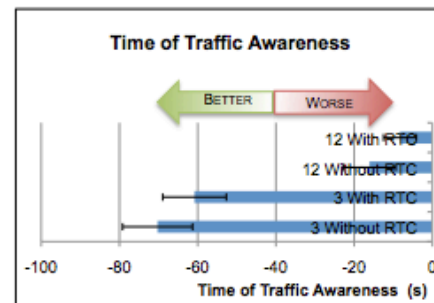
*Note: all times relative to the time of first alert

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Appendix D4: Base vs. Final Encounter

Appendix D4.1: Performance with ideal ADS-B

- **Time of Traffic Awareness:**
  - No observed difference in traffic awareness time between qualified and nonqualified targets
  - Awareness time was not different between audio only systems compared to display based system ($p=0.080$)

- **Time of Evasive Action**
  - No observed difference between qualified and nonqualified targets
  - No observed difference between audio only systems and display based systems.

- **Time between Awareness and Evasive Action**
  - No observed difference between qualified and non-qualified targets.
  - No observed difference between display and audio systems ($z =-1.655$, $p=0.098$).

- **Distance of Closest Approach**
  - No observed difference in miss distance between qualified and nonqualified targets
  - No observed difference in miss distance between display and audio systems.
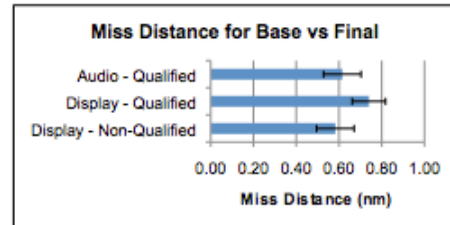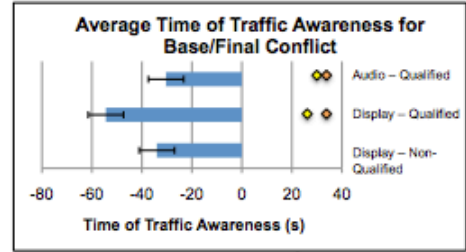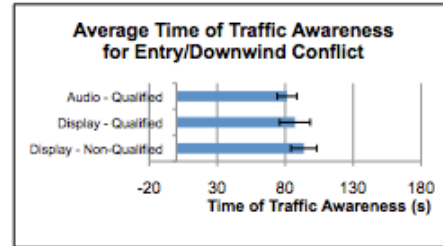

*Note: all times are with respect to time that the target was abeam the departure end of the runway on downwind.
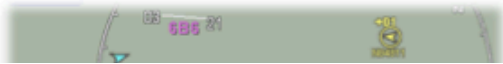
Type of Evasive Maneuver
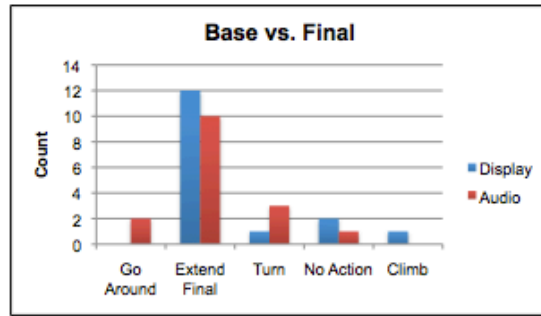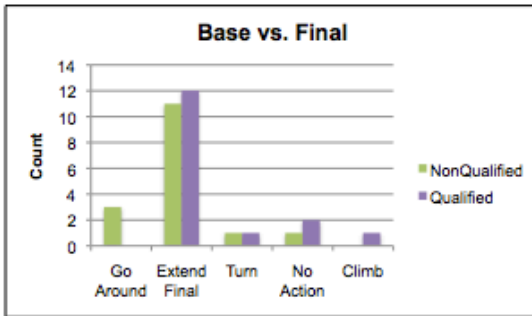
- No major differences in types of evasive maneuver between either comparison.

- This is expected due to the nature of this conflict. Participants tended to visually acquire traffic upon their turn to downwind and elected to continue their downwind upon reaching abeam the numbers

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Appendix D4.2: Performance with realistic data quality

Base vs. Final Conflict - Display

- **TSAA performed as expected**
  - Based on observations of the safety pilot, 1 unsafe condition occurred due to pilot inaction

Time of Traffic Awareness	Participants became aware of traffic approximately 27.8s after the ownship turned downwind. (SD=44.7s)					
Time of Visual Acquisition	7/16 participants visually acquired traffic Average time of visual acquisition was 0.4 s before the ownship turned downwind (SD=19.6s)					
Time of Evasive Action	Average time of evasive action was 68.4s (SD= 40.1s) after the ownship turned downwind					
Time between Awareness and Evasive Action	It took on average 35.3s to take evasive action once the participant became aware of the target (SD=32s)					
Type of Evasive Action	Extend DW	Go Around	Short Approach	No Action	Turn	Climb
	7	6	0	1	1	1
Closest Approach Distance	0.54 nm (SD = 0.36s) *Slant Range Distance					

PAZ:
Annun 9/16 cases
84.5s (SD 8.2s)

CAZ:
Annun 5/16 cases
90.6s (SD 11.0s)

*Note: all times are with respect to time that the target was a beam the departure end of the runway on downwind.   18

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Appendix D5: Entry vs. Downwind Encounter

Appendix D5.1: Performance with ideal ADS-B

Time of Traffic Awareness:
- No observed difference in traffic awareness time between qualified and nonqualified targets
- There was no observed difference between audio only systems compared to the display based system

Time of Evasive Action
- No observed difference between qualified and nonqualified targets
- No observed difference between audio only systems and display based systems.

Time between Awareness and Evasive Action
- No observed difference between qualified and non-qualified targets.
- No observed difference between display and audio system.

Distance of Closest Approach
- Miss distances were **higher with qualified** targets vs. non-qualified targets (z=-1.989, p=0.047)
- There was no observed difference between display and audio systems.

Average Time of Traffic Awareness for Entry/Downwind Conflict
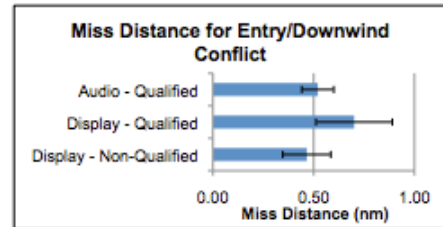
◆ Avg PAZ Alert Time
◆ Avg CAZ Alert Time

Miss Distance for Entry/Downwind Conflict

*Note: all times are with respect to time that the target appeared in the scenario (approximately 12s after run start)

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Type of Evasive Maneuver

Entry vs. Downwind
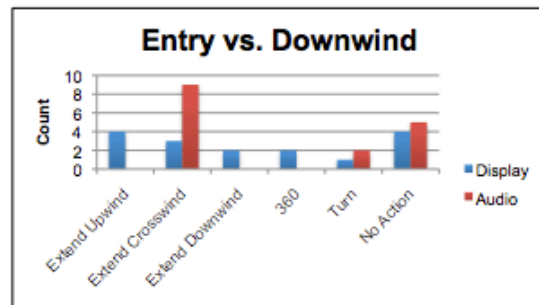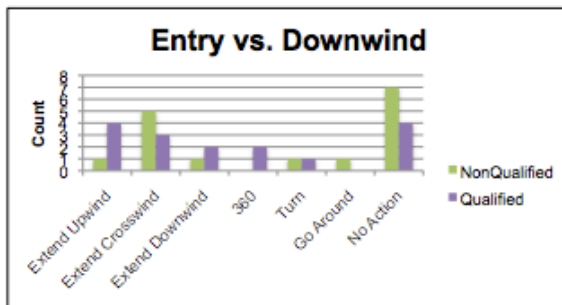
Entry vs. Downwind

- No major differences in types of evasive maneuver between qualified and non-qualified.

- With the display system, participants sometimes elected to extend upwind based on the graphical display of traffic.

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Appendix D5.2: Performance with realistic data quality
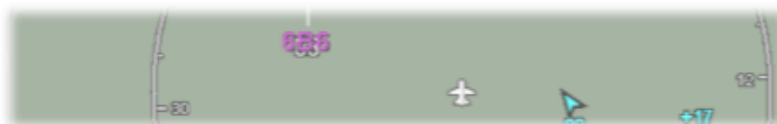
Entry vs. Downwind - Audio

- **TSAA performed as expected**
  - Based on observations of the safety pilot, 1 unsafe condition occurred due to pilot inaction

Time of Traffic Awareness	Participants became aware of traffic approximately 91.9s after the target appeared (SD=13.9s)
Time of Visual Acquisition	7/16 participants visually acquired traffic Average time of visual acquisition was 126 s after the target appeared (SD=77.4s)
Time of Evasive Action	Average time of evasive action was 140.9 s (SD= 65.3 s) after the target appeared
Time between Awareness and Evasive Action	It took on average 49s to take evasive action once the participant became aware of the target (SD=56.2s)

Type of Evasive Action	Extend Crosswind	Turn	Climb	Go Around	No Action
	3	4	3	1	4

Closest Approach Distance	0.30 nm (SD = 0.34s) *Slant Range Distance

PAZ:
Annun 11/16 cases
98.5s (SD 12s)

CAZ:
Annun 7/16 cases
142s (SD 55.8s)

*Note: all times relative to the time that target first appeared in scenario

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Appendix D6: Overtaking on Final Encounter

Appendix D6.1: Performance with ideal ADS-B

Appendix D6.2: Performance with realistic data quality

Appendix D7: Autorotating Helicopter Encounter

Appendix D7.1: Performance with ideal ADS-B

- **TSAA performed as expected**
  - 1 case when alerts did not annunciate because encounter was completely avoided
  - Based on observations of the safety pilot, 5 unsafe conditions occurred during this scenario due to pilot inaction. (Could be attributed to simulator effect)
- **Time of evasive action was 11.7s after time of first alert (consistent with previous literature on response time to traffic)**

Time of Traffic Awareness	Participants became aware of the traffic either soon after takeoff or within a few seconds of the alert annunciating. (Mean= -149s, SD= 102s)		
Time of Visual Acquisition	• 12/16 participants visually acquired traffic • Average 4.6s after time of first alert (SD=12s)		
Time of Evasive Action	Of those who received an alert AND chose to take evasive action, action was taken on average 11.7s after the time of first alert (SD=9.9s)		
Time between Awareness and Evasive Action	Of those who received an alert AND chose to take evasive action, action was taken on average 193s after the participant became aware of the traffic (SD=72s) .		
Type of Evasive Action	**Go Around**	**Right Turn**	**No Action**
	10	1	5
Closest Approach Distance	0.11 nm (SD = 0.08nm) *Slant Range Distance		

PAZ:
Annun 15/16 cases
0s (SD 0s)

CAZ:
Annun 15/16 cases
8.1s (SD 5.2s)

*Note: all times relative to the time of first alert

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Appendix D7.2: Performance with realistic data quality

- **TSAA performed as expected**
  - Based on observations of the safety pilot, 4 unsafe conditions occurred during this scenario due to pilot inaction. (Could be attributed to simulator effect)

Time of Traffic Awareness	Participants became aware of the traffic either soon after takeoff or within a few seconds of the alert annunciating. (Mean= -124s, SD= 113s)			
Time of Visual Acquisition	• 13/16 participants visually acquired traffic • Average 4.1s after time of first alert (SD=13.8s)			
Time of Evasive Action	Of those who received an alert AND chose to take evasive action, action was taken on average 23.0s after the time of first alert (SD=11.9s)			
Time between Awareness and Evasive Action	Of those who received an alert AND chose to take evasive action, action was taken on average 147s after the participant became aware of the traffic (SD=114s) .			
Type of Evasive Action	**Go Around**	**Left Turn**	**Right Turn**	**No Action**
	8	2	2	4
Closest Approach Distance	0.12 nm (SD = 0.11nm) *Slant Range Distance			

PAZ:
Annun 15/16 cases
0s (SD 0s)

CAZ:
(NOT APPLICABLE)

*Note: all times relative to the time of first alert

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Appendix D8: Opposite Runway Encounter

Appendix D8.1: Performance with ideal ADS-B

- **TSAA performed as expected**
  - 3 cases where pilots aborted takeoff before alert annunciated
  - Based on observations of the safety pilot, no unsafe conditions occurred during this scenario
- **It took on average 12 seconds to take evasive action once the participant became aware of the target. (Consistent with previous literature on response time to traffic)**

Time of Traffic Awareness	Participants became aware of traffic approximately 10.3s after it appeared. (SD=9.3s)		
Time of Visual Acquisition	15/16 participants visually acquired traffic Average time of visual acquisition was 10s after the target appeared (SD=10s)		
Time of Evasive Action	Average time of evasive action was 22.4s (SD=12s) after the target appeared		
Time between Awareness and Evasive Action	It took on average **12s to take evasive action** once the participant became aware of the target (SD=6.9s)		
Type of Evasive Action	**Abort Takeoff**	**Right Turn**	**Left Turn**
	5	9	2
Closest Approach Distance	0.57 nm (SD = 0.43s) *Slant Range Distance		

PAZ: Annun 13/16 cases 21.4s (SD 4.8s)

CAZ: Annun 2/16 cases 48.7s (SD 2s)

*Note: all times relative to the time that target first appeared in scenario

20

Appendix D8.2: Performance with realistic data quality

- **TSAA performed as expected**
  - 6 cases where pilots aborted takeoff before alert annunciated
  - Based on observations of the safety pilot, no unsafe conditions occurred during this scenario
- **It took on average 14.4 seconds to take evasive action once the participant became aware of the target. (Consistent with previous literature on response time to traffic)**

Time of Traffic Awareness	Participants became aware of traffic approximately 12.5s after it appeared. (SD=10.2s)		
Time of Visual Acquisition	13/16 participants visually acquired traffic Average time of visual acquisition was 11.3 s after the target appeared (SD=11s)		
Time of Evasive Action	Average time of evasive action was 26.9s (SD=11s) after the target appeared		
Time between Awareness and Evasive Action	It took on average 14.4s to take evasive action once the participant became aware of the target (SD=8.2s)		
Type of Evasive Action	**Abort Takeoff**	**Right Turn**	**Left Turn**
	6	4	6
Closest Approach Distance	0.70 nm (SD = 0.58s) *Slant Range Distance		

PAZ: Annun 10/16 cases 23.9s (SD 4.6s)

CAZ: Annun 7/16 cases 48.2s (SD 6.2s)

*Note: all times relative to the time that target first appeared in scenario

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Appendix D9: Teasing PAZ Encounter

Appendix D9.1: Performance with ideal ADS-B

- **TSAA performed as expected**
    - Based on observations of the safety pilot, no unsafe conditions occurred during this scenario

Time of Traffic Awareness	Participants became aware of traffic approximately 54.9s after the target appeared (SD=42s)
Time of Visual Acquisition	Visual acquisition not possible
Time of Evasive Action	Of the participants who chose to take action, action was taken on average 135s (SD=71s) after the time the target first appeared.
Time between Awareness and Evasive Action	It took on average 94s (SD=61s) for participants to take action after they became aware of the traffic.

Type of Evasive Action				
	Turn Left	Climb	Descend	No Action
	4	2	3	7

Closest Approach Distance	1.14 nm (SD = 0.32nm) *Slant Range Distance

PAZ:
Annun 14/16 cases
150s (SD 57s)

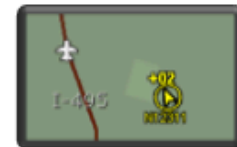**CAZ:**
Annun 3/16 cases
199s (SD 5.6s)

*Note: all times relative to the time that target first appeared in scenario

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Appendix D9.2: Performance with realistic data quality

- **TSAA performed as expected**
    - Based on observations of the safety pilot, no unsafe conditions occurred during this scenario

Time of Traffic Awareness	Participants became aware of traffic approximately 30.5s after the target appeared (SD=23.4s)
Time of Visual Acquisition	Visual acquisition not possible
Time of Evasive Action	Of the participants who chose to take action, action was taken on average 14.4s (SD=3.7s) after the time the target first appeared.
Time between Awareness and Evasive Action	It took on average 10.0 s (SD=5.0s) for participants to take action after they became aware of the traffic.

Type of Evasive Action			
	Turn	Descend	No Action
	7	2	6

Closest Approach Distance	3.1 nm (SD = 2.7nm) *Slant Range Distance

PAZ:
Annun 15/16 cases
40.9s (SD 30.2s)

CAZ:
(Not Applicable)

*Note: all times relative to the time that target first appeared in scenario
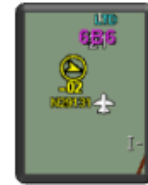
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Appendix D10: Extended Final Encounter

Appendix D10.1: Performance with ideal ADS-B

- **TSAA performed as expected**
  - Based on observations of the safety pilot, 1 unsafe conditions occurred during this scenario due to pilot inaction

Time of Traffic Awareness	Participants became aware of traffic on average 33.7s before the target turned base. (SD=30s)
Time of Visual Acquisition	• 11/16 participants visually acquired traffic • Average time of visual acquisition was 10.9s before the target turned base. (SD=38s)
Time of Evasive Action	Of the participants who chose to take action, action was taken on average 37s (SD=25s) after the time the target turned base
Time between Awareness and Evasive Action	It took on average 71s (SD=30s) for participants to take action after they became aware of the traffic.
Type of Evasive Action	see table below
Closest Approach Distance	0.74 nm (SD = 0.50nm) *Slant Range Distance

Go Around	360 in pattern	Right Turn	Left Turn	No Action
4	5	4	1	1

PAZ:
Annun 11/16 cases
26.5s (SD 44s)

CAZ:
Annun 6/16 cases
38.5s (SD 6.1s)

*Note: all times relative to the time that target turned base turn

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Appendix D10.2: Performance with realistic quality data and non-qualified target

- **TSAA performed as expected**
  - Based on observations of the safety pilot, 2 unsafe conditions occurred during this scenario due to pilot inaction

Time of Traffic Awareness	Participants became aware of traffic on average 60.6s before the target turned base. (SD=30.3s)
Time of Visual Acquisition	• 6/14 participants visually acquired traffic • Average time of visual acquisition was 7.2s after the target turned base. (SD=76.9s)
Time of Evasive Action	Of the participants who chose to take action, action was taken on average 4.4s (SD 18.7s) before the time the target turned base
Time between Awareness and Evasive Action	It took on average 61.3s (SD=37.3s) for participants to take action after they became aware of the traffic.
Type of Evasive Action	see table below
Closest Approach Distance	0.58 nm (SD = 0.38nm) *Slant Range Distance

Go Around	360 in pattern	Right Turn	Left Turn	No Action
6	2	3	1	2

PAZ:
(Not Applicable)

CAZ:
(Not Applicable)

*Note: all times relative to the time that target turned base turn

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Appendix E:

Audio Range Resolution Analysis

With the greater quality data available with ADS-B, it became possible to provide higher resolution range within 2nm than the standard one-mile resolution used currently by ATC. Various resolution options were considered and rated based on syllable count, compatibility with standard phraseology, and position uncertainty. Range unit options included maintaining the range unit of miles or introducing the range unit of feet within a certain range. Ultimately the option of using feet as a range unit was discarded due to greater position uncertainty and interference with current ATC standards ("feet" traditionally a unit of altitude) [8]. In terms of resolution of miles to be tested, syllable count analysis was completed for integer mile, decimal mile, quarter mile, and half mile increments (Figure E1). An option was also tested that annunciated in quarter miles up to 1 nm, half miles up to 2 nm, and integer miles above 2 nm. Average syllable counts are listed in Table E1. Overall, the quarter mile option had the lowest average syllable count when averaged over one mile and two miles.
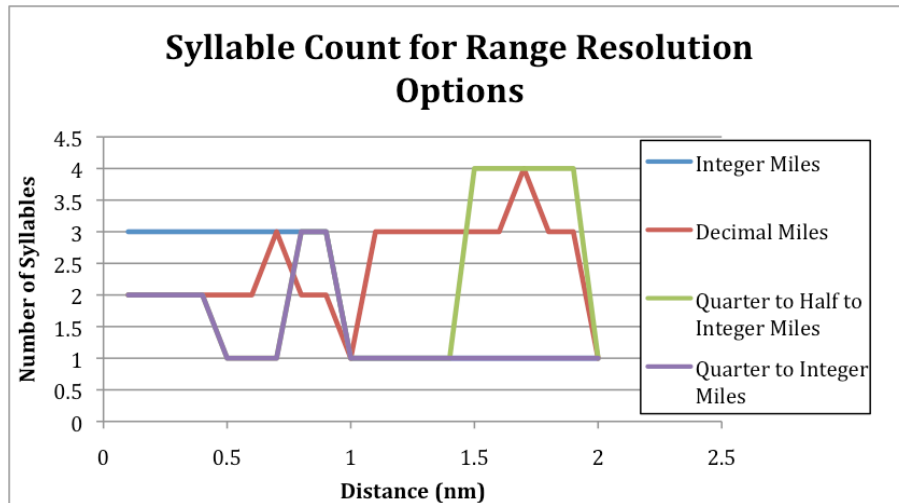

Figure E1. Syllable Count Analysis for Range Resolution Options

Average Syllable Count		
	2 nm	**1 nm**
Integer Miles (all times)	1.9	2.8
Decimal Miles (within 2 nm)	2.45	2
Quarter (within 1 nm) to Half (between 1 and 2 nm) to Integer (above 1 nm)	2.15	1.8
Quarter (within 1 nm) to Integer (above 1 nm)	1.4	1.8

Table E1. Average Syllable Count for Range Resolution Options

Therefore, the quarter mile option was tested against the existing one mile integer option in an experiment to determine any detriment or benefit in added range resolution in the audio call.

Experimental Design

Audio range resolution was a within subjects design. The quarter mile option calls range in quarter mile increments below 1 nm and integer miles above 1nm. For example a call for traffic at 3 o'clock, quarter mile would annunciate as "Traffic, three o'clock, same altitude, quarter mile."

The one mile option calls "less than one mile" below 1 nm and integer miles above 1nm. Subjects were provided with examples of each option prior to their runs. Using the same example highlighted above, the call would annunciate as "Traffic, three o'clock, same altitude, less than one mile."

For this test, the Playback Method (Chapter 3.2) was used, however, for the audio system test, only the side task and data system were operating. Prerecorded audio traffic callouts were presented and the subject was expected to perform the scan selection and urgency selection based solely on the audio call. The traffic callouts and timing of callouts were embedded into the Matlab script so time of the stimulus presentation and selection were automatically synced.

During the audio system test, the participant was presented with aural alerts and instructed to fly a flight director profile using a joystick. Upon annunciation of an aural alert, the subject selected the quadrant where he would scan for traffic as well as identified his perceived urgency of the threat. Participants received training on both options (quarter mile vs. one mile resolution) prior to data collection runs. Training consisted of a description of each option as well as an audio example of each option.

The audio callouts for the audio based system are listed in Tables E2 and E3. Table E2 shows the calls for Option 1 with quarter mile resolution. Table E3 shows the calls for Option 2 with one mile resolution. Table E2 and E3 scenarios had azimuths transposed, however alert type and altitude were identical. The scenarios were randomized for each option.

The options were counterbalanced for Part B of the study. The systems will be counterbalanced where half of the subjects were presented with Option 1 first, while the other half were presented with Option 2 first. Also, the scenarios in Option 2 were run in reverse order of the scenarios in Option 1. The callouts in Option 1 and Option 2 had opposite azimuths to mitigate recognition. The alerts occurred non-periodically throughout a time period of five minutes for each option.

Scenario #	Alert Type	Traffic Alert Call
1	PAZ	"Traffic, 12 o'clock, low, quarter mile"
2	PAZ	"Traffic, 9 o'clock, same altitude, half mile"
3	PAZ	"Traffic, 5 o'clock, high, three quarter mile"
4	**CAZ**	"**Traffic**, 2 o'clock, high, quarter mile,"
5	**CAZ**	"**Traffic,** 11 o'clock, low, half mile"
6	**CAZ**	"**Traffic,** 3 o'clock, same altitude, three quarter mile"
7	**CAZ**	"**Traffic**, 1 o'clock, same altitude, one mile"
8	PAZ	"Traffic, 8 o'clock, low, two miles"
9	**CAZ**	"**Traffic**, 10 o'clock, high, three miles,"
10	PAZ	"Traffic, 4 o'clock, high, one mile"

Table E2. Alerts for Option 1: Quarter Mile Range Resolution (below 1 nm). Note: Bold "Traffic" in table refers to increase in prosodic urgency.

Scenario #	Alert Type	Traffic Alert Call
1a	PAZ	"Traffic, 12 o'clock, low, less then one mile"
2a	PAZ	"Traffic, 3 o'clock, same altitude, less then one mile"
3a	PAZ	"Traffic, 7 o'clock, high, less then one mile"
4a	**CAZ**	"**Traffic**, 10 o'clock, high, less then one mile"
5a	**CAZ**	"**Traffic,** 1 o'clock, low, less then one mile"
6a	**CAZ**	"**Traffic,** 9 o'clock, same altitude, less then one mile"
7a	**CAZ**	"**Traffic**, 11 o'clock, same altitude, one mile"
8a	PAZ	"Traffic, 4 o'clock, low, two miles"
9a	**CAZ**	"**Traffic**, 2 o'clock, high, three miles"
10a	PAZ	"Traffic, 8 o'clock, high, one mile"

Table E3. Alerts for Option 2: "Less than one mile" Range Call Below 1 nm. Note: Bold "Traffic" in table refers to increase in prosodic urgency.

Results and Conclusions

There was no observed difference in reaction time between the two range resolution options (Figure E2).
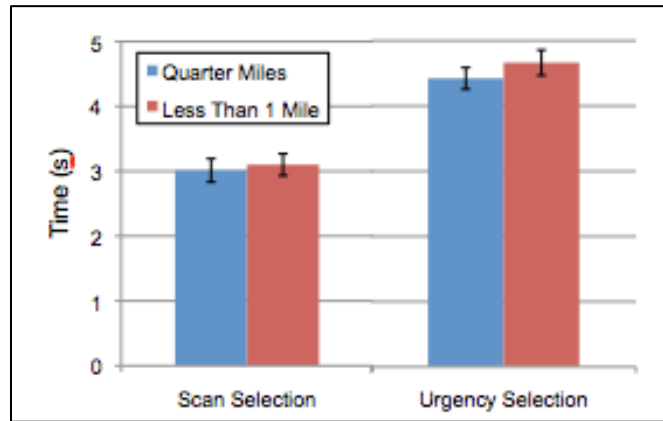

Figure E2. Reaction time for two range resolution options.

Subjective response to preference between the audio options yielded split preference. Half of the participants preferred the quarter mile resolution due to the increase in information and ability to gauge closure rate. The other half of the participants preferred the one mile resolution highlighting three main reasons.

1. Concern about the fractional miles being meaningful
2. Ability to hear the word "less" & immediately gauge that the aircraft is in proximity
3. Ambiguity between 3 mile and 3-quarter mile call

Due to primarily the ambiguity between 3 and ¾ mile and the lack of performance difference between the two options, it was recommended to maintain one mile resolution for all audio callouts. This is consistent with current practice for air traffic control traffic callouts.

Appendix F:

Prosodic Urgency Analysis

As was discussed in Chapter 2.2.2, prosodic urgency was chosen to differentiate the CAZ and PAZ alerts to the user. There was some concern in the community whether the difference in prosodic urgency was an effective differentiator. In the span of the three human factors studies that were completed, there were two analyses that addressed questions about prosodic urgency.

The first analysis resulted from the audio system test described in Appendix E. Prosodic urgency for the "traffic" call was simulated using a higher urgency female recorded voice. When reaction time between CAZ and PAZ alerts was compared, the CAZ response time was 0.86s faster than the PAZ response time for the scan selection (Figure F1). This was also true in the urgency selection with a difference of 0.71s. This difference indicates that prosodic urgency may be an effective differentiator between the CAZ and the PAZ alerts. Many pilots report not noticing a difference in prosodic urgency between the CAZ and PAZ calls, however the objective data suggests that the benefit to reaction time may have been a subconscious response to the implied urgency of the CAZ call.
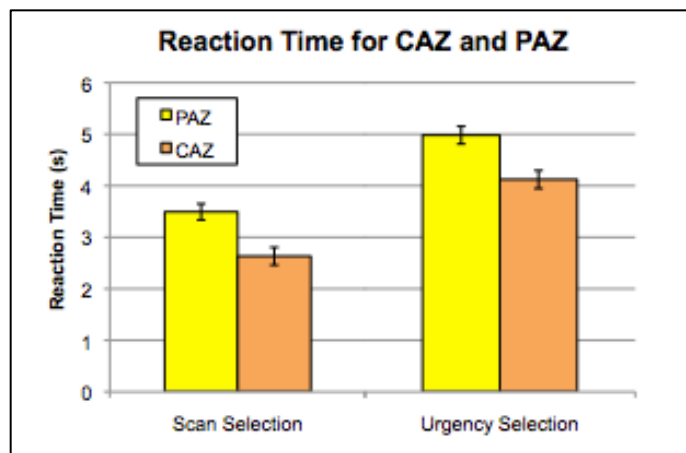

Figure F1. Reaction time for CAZ and PAZ alerts.

The second analysis was conducted during the third human factors study where pilots were subjectively probed about how different the CAZ and PAZ urgencies were perceived to be. In this case, prosodic urgency effect was achieved by changing the following parameters in the audio call.

1. The CAZ call was progressively amplified.
   a. Traffic and bearing was 10 dB higher than the PAZ call
   b. Altitude was 8 dB higher than the PAZ call
   c. Range was 6 dB higher than the PAZ call
2. Speed of CAZ call was 15% higher than speed of the PAZ call.
3. Pitch was decreased to counteract pitch increase from speed increase.

The question presented to the pilots is shown in Figure F2 along with the distribution of responses. The bell curve shape of the distribution indicates that pilots cannot easily distinguish the difference in prosodic urgency between the PAZ and CAZ. If pilots could more easily distinguish the difference, the curve would become skewed to the left.
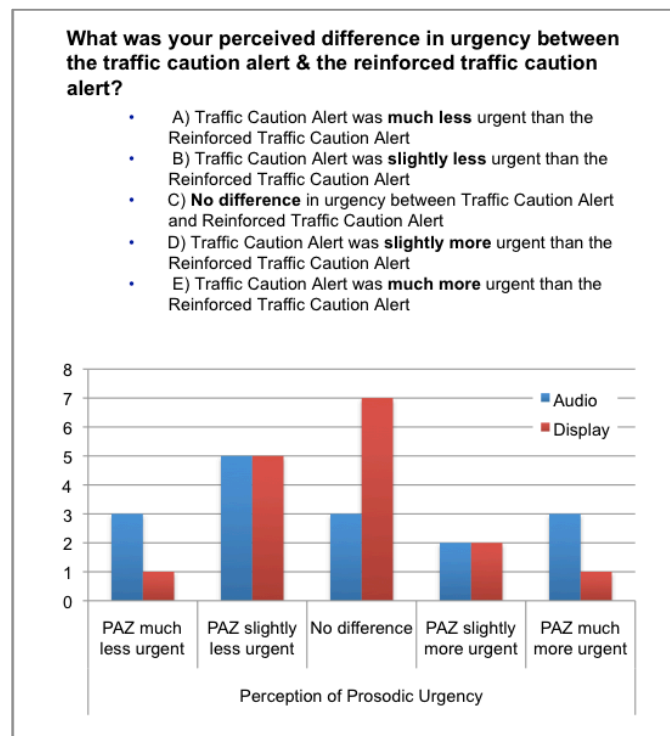
Appendix G

Traffic Pattern Description (FAA AIM 4-3-3) [15]
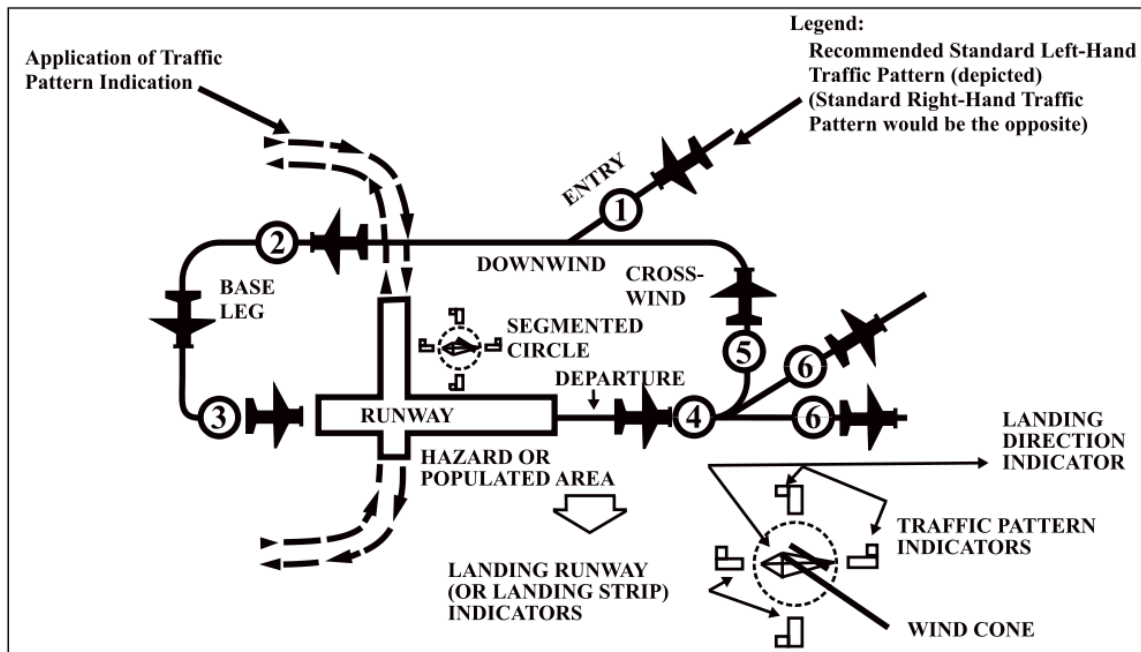
EXAMPLE-
Key to traffic pattern operations

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.*