NASA/TP–2016-219172

Conducting Safe and Efficient Airport Surface Operations in a NextGen Environment

Denise R. Jones, Lawrence J. Prinzel III, Randall E. Bailey, and Jarvis J. Arthur III
Langley Research Center, Hampton, Virginia

James R. Barnes
Booz Allen Hamilton Engineering Services, LLC, Hampton, Virginia

March 2016

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NTRS Registered and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counter-part of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at http://www.sti.nasa.gov

- E-mail your question to help@sti.nasa.gov

- Phone the NASA STI Information Desk at 757-864-9658

- Write to:
  NASA STI Information Desk
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/TP–2016-219172

Conducting Safe and Efficient Airport Surface Operations in a NextGen Environment

Denise R. Jones, Lawrence J. Prinzel III, Randall E. Bailey, and Jarvis J. Arthur III
Langley Research Center, Hampton, Virginia

James R. Barnes
Booz Allen Hamilton Engineering Services, LLC, Hampton, Virginia

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

March 2016

Available from:

NASA STI Program / Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199
Fax: 757-864-6500

Table of Contents

Acronyms and Symbols

μ	Mean
σ	Standard Deviation
AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance-Broadcast
AFE	Above Field Elevation
AGL	Above Ground Level
AMM	Airport Moving Map
ANOVA	Analysis of Variance
ASDE-X	Airport Surface Detection Equipment Model X
ATC	Air Traffic Control
ATSA-SURF	Airborne Traffic Situational Awareness for Surface Operations
CD&R	Conflict Detection & Resolution
CG	Center-of-Gravity
CPA	Closest Point of Approach
EFB	Electronic Flight Bag
EPU	Estimated Position Uncertainty
ETA	Estimated Time-of-Arrival
FAA	Federal Aviation Administration
F	F-ratio, variance ratio
FY	Fiscal Year
GPM	Geographic Position Marker
GPS	Global Positioning System
GS	Ground Speed
HUD	Head-Up Display
IA	Indications and Alerts
KMEM	Memphis International Airport
MANOVA	Multivariate Analysis of Variance
N/A	Not Applicable
NACp	Navigation Accuracy Category for Position
NASA	National Aeronautics and Space Administration
ND	Navigation Display
NextGen	Next Generation Air Transportation System
nm	Nautical Miles
NTSB	National Transportation Safety Board
OTW	Out-the-Window
p	Probability of occurrence of an event
PFD	Primary Flight Display
RAAS	Runway Awareness and Advisory System
RFD	Research Flight Deck
RSI	Runway Status Indication
RTA	Required Time-of-Arrival
RTCA, Inc.	Radio Technical Commission for Aeronautics
RTO	Rejected Takeoff
SART	Situation Awareness Rating Technique
SD	Standard Deviation
SOP	Standard Operating Procedure
SPR	Safety, Performance and Interoperability Requirements
STBO	Surface Trajectory-Based Operations
SURF IA	Enhanced Traffic Situational Awareness on the Airport Surface with Indications and Alerts
TI	Traffic Indication
TLX	Task Load Index

1 Abstract

The Next Generation Air Transportation System (NextGen) vision proposes many revolutionary operational concepts, such as surface trajectory-based operations (STBO) and technologies, including display of traffic information and movements, airport moving maps (AMM), and proactive alerts of runway incursions and surface traffic conflicts, to deliver an overall increase in system capacity and safety. A piloted simulation study was conducted at the National Aeronautics and Space Administration (NASA) Langley Research Center to evaluate the ability of a flight crew to conduct safe and efficient airport surface operations while utilizing an AMM. Position accuracy of traffic was varied, and the effect of traffic position accuracy on airport conflict detection and resolution (CD&R) capability was measured. Another goal was to evaluate the crew's ability to safely conduct STBO by assessing the impact of providing traffic intent information, CD&R system capability, and the display of STBO guidance to the flight crew on both head-down and head-up displays (HUD). Nominal scenarios and off-nominal conflict scenarios were conducted using 12 airline crews operating in a simulated Memphis International Airport terminal environment. The data suggest that all traffic should be shown on the airport moving map, whether qualified or unqualified, and conflict detection and resolution technologies provide significant safety benefits. Despite the presence of traffic information on the map, collisions or near-collisions still occurred; when indications or alerts were generated in these same scenarios, the incidents were averted. During the STBO testing, the flight crews met their required time-of-arrival at route end within 10 seconds on 98 percent of the trials, well within the acceptable performance bounds of 15 seconds. Traffic intent information was found to be useful in determining the intent of conflicting traffic, with graphical presentation preferred. The CD&R system was only minimally effective during STBO because the prevailing visibility was sufficient for visual detection of conflicting traffic. Overall, the pilots indicated STBO increased general situation awareness but also negatively impacted workload, reduced the ability to watch for other traffic, and increased head-down time.

2 Introduction

The Next Generation Air Transportation System (NextGen) vision transforms the air transportation system to meet the projected growth in aircraft operations expected in the 2025 time-frame (1.4 to 3 times current levels [JPDO, 2010]) in a safe, efficient, and reliable manner. NextGen is envisioned to remove many constraints of the current air transportation system, support a wider range of operations, and deliver an overall increase in system capacity and safety. Emerging NextGen operational concepts [JPDO, 2010], such as trajectory-based airborne and surface operations, equivalent visual operations, and high-density arrival and departure operations, represent a revolutionary approach to air traffic management; as a result, a dramatic shift in the tasks, roles, and responsibilities for the flight deck are required to ensure a safe, sustainable air transportation system. A net-centric infrastructure is envisioned, enabling a safe and efficient airport surface environment by providing the information necessary to improve flight deck and ground vehicle situation awareness through display of ground traffic, airport moving maps (AMM), and proactive alerts of runway incursions and surface traffic conflicts.

Surface Trajectory-Based Operations (STBO) is a NextGen operational concept aimed at improving the efficiency and safety of surface operations at high-density airports. Surface movement management tools will utilize improved surveillance, environmental and operational conditions, and other information to sequence aircraft for departure, issue conflict-free time-based taxi routes, monitor taxi conformance, and revise taxi plans as necessary. The optimized three-dimensional (lateral, longitudinal, and time) taxi routes are intended to be transmitted through data communication protocols and displayed to the flight crew on a flight deck surface movement display. Although STBO is intended to eliminate surface traffic conflicts, on-board conflict detection and resolution (CD&R) systems will provide an additional protective safety layer for NextGen operations in the event that tactical or strategic situation awareness is not sufficient or when human errors or blunders occur.

The National Aeronautics and Space Administration (NASA) has developed a CD&R concept that leverages advances in flight deck displays and technologies to promote enhanced surface and airborne traffic awareness with associated flight deck alerting concepts for safety assurance. These concepts employ continual ownship and traffic data monitoring and algorithms to detect potential conflicts on the runway and during taxi operations for aircraft and surface vehicles. NASA has also conducted initial research on ground-based CD&R for air traffic control (ATC) STBO decision support tools [Cheng et al., 2011a; Cheng et al., 2011b; and Montoya et al, 2013] and the integration of ground- and flight deck-based CD&R for STBO [Cheng et al., 2012].

A high-fidelity full-motion piloted simulation experiment was conducted as a two part study to evaluate flight deck concepts. The objectives of Part 1 were to evaluate the ability of a flight crew to conduct safe and efficient airport surface operations while utilizing an AMM. Horizontal position accuracy of the traffic was varied, and the effect of traffic position accuracy on CD&R capability was measured. The evaluation included approach, departure, and runway incursion scenarios and two AMM conditions. The objectives of Part 2 were to evaluate the crew's ability to safely conduct STBO by assessing the impact of providing traffic intent information, flight deck-based CD&R system capability, and the display of STBO guidance to the flight crew on both head-down and head-up displays (HUD). Evaluations were conducted during STBO taxi operations from the ramp to the departure runway utilizing two AMM conditions, a HUD or no HUD, and airport traffic with various levels of horizontal position accuracy. This paper describes the experimental systems, method, and quantitative and qualitative results.

3 Background

Research and technologies relevant to the current simulation study are discussed below. These relevant technologies are airport moving maps, STBO, and surface CD&R.

3.1 Airport Moving Maps

The Commercial Aviation Safety Team (cooperative government-industry initiative) recommended the use of AMMs as a highly effective safety enhancement to reduce the risk of runway incursions. A detailed analysis of surface accident and mitigation strategies concluded that flight deck AMMs are essential to the prevention of surface accidents and incidents [Boucek, 2002]. Research has supported the conclusion that situation awareness is substantially enhanced by the presence of an electronic display that, as a minimum, depicts ownship position. For example, research found that 17% of low-visibility and night taxi trials resulted in navigation errors that were mitigated by the use of AMMs [Hooey and Foyle, 2006]. The National Transportation Safety Board (NTSB) has recommended the adoption of AMM displays [NTSB, 2007] and they are standard equipage on most new commercial transport aircraft. Although AMMs may be displayed on forward flight deck displays, the most common location is on EFBs.

According to the Federal Aviation Administration's (FAA's) Advisory Circular (AC) 120-76A [FAA, 2014a], an EFB is an electronic display system intended primarily for cockpit/flight deck or cabin use. EFB devices can be subdivided into three different classes [FAA, 2014a]:

- Class 1 EFB: Portable commercial-off-the-shelf computer system used for aircraft operations, such as flight crew laptops, which are not inter-connected with ship systems and do not require certification;
- Class 2 EFB: Portable and typically commercial-off-the-shelf-based systems connected to the aircraft during normal operations which do require minimal certification (e.g., power supply); and
- Class 3 EFB: Fully installed equipment that requires formal certification.

The FAA specifies requirements for the approval of the AMM function [FAA, 2003 and RTCA, 2003a]. Originally, AMM applications showing ownship position were limited to Class 3 EFB devices but, in 2007, the FAA reversed course and certified Class 2 EFBs to depict ownship location on the airport surface [FAA, 2007a]. As a consequence, electronic AMMs for surface operations can vary significantly in the level of detail (e.g., airport surface information elements depicted) and functionality available.

The simplest AMM may consist of ownship position superimposed on a geo-referenced electronic airport diagram. The airport attributes depicted will be identical to what is presented on a paper chart. This map may be non-interactive; functionality, if any, will be limited, e.g., zooming may be available, but more complicated features such as de-cluttering may not be available.

More complex AMM displays are constructed from a database that contains positional data describing the location of airport attributes. The database information is collected through a detailed survey that maps the location of these attributes. AMMs constructed from a database vary in the detail with which the airport is depicted and in the functionality available. Common display elements depicted include ownship position, runways, runway labels, taxiways, taxiway labels, non-movement areas, and buildings. Common functions include zooming, displaying traffic, and de-cluttering. Features such as surface navigation guidance with the display of a taxi route and auto-zoom are currently not certifiable [FAA, 2007a] and AMMs are limited to display of ownship position.

Although the FAA has included the use of traffic displays for surface operations in the mid-term NextGen vision, the depiction of surface traffic on the AMM is not currently allowed. However, RTCA DO-289 [RTCA, 2003b] specifies the requirements for positional accuracies (described below) required for depiction of ownship and traffic position for Aircraft Surveillance Applications. The document specifies the requirements for traffic display elements that include, at a minimum: AMM database, ownship and traffic symbols, positioning information, heading, and traffic status (e.g., airborne). Also, RTCA DO-322 [RTCA, 2010a] provides the minimum operational, safety, and performance requirements (SPR) for the implementation of enhanced Airborne Traffic Situational Awareness for Surface Operations (ATSA-SURF).

The Navigation Accuracy Category for Position (NACp) describes the accuracy of positional information. NACp values range from 0 to 11 [RTCA, 2002]. The NACp categories of 8 and higher are listed in Table 1 with their associated horizontal Estimated Position Uncertainty (EPU) values, since only NACp values of 8 and higher were used for this study. Both DO-289 and DO-322 define the minimum requirement for horizontal position accuracy for depiction of ground traffic on an AMM to be at least 30 m within 95% containment bounds, equivalent to NACp 9.

Table 1. NACp Horizontal Accuracy Bound.

NACp	95% Horizontal Accuracy – Estimated Position Uncertainty (EPU)
8	EPU < 92.6 m (0.05 nm, 305.6 ft)
9	EPU < 30 m (99 ft)
10	EPU < 10 m (33 ft)
11	EPU < 3 m (9.9 ft)

The FAA has issued an Automatic Dependent Surveillance – Broadcast (ADS-B) Out Final Rule to support ATC service [FAA, 2010] which includes performance standards. The rule states that EPU of the reported position must be less than 0.05 nm, which is equivalent to NACp 8. This positional surveillance accuracy is not sufficient to support the depiction of traffic information on an AMM display, per DO-322, although possible risk mitigation strategies have been proposed (e.g., RTCA DO-322, Appendix D) [RTCA, 2010a] that may increase the traffic position reporting for otherwise unqualified traffic (e.g., NACp < 9) through, for example, the comparison of traffic position with runway and taxiway location; ground sensor positional data; known ionospheric status; use of multilateration, Traffic Information Service – Broadcast (TIS-B), Wide Area Augmentation System (WAAS)/Satellite-based Augmentation System (SBAS), and Local Area Augmentation System (LAAS)/Ground Based Augmentation System

(GBAS); and dual-frequency Global Positioning System (GPS). RTCA DO-338 [RTCA, 2012] provides an excellent overview of these mitigations for qualification of ADS-B Out rule compliance (NACp = 8) targets for surface surveillance. Ownship horizontal dilution of precision, requalification of surface features, and multilateration were identified as the best candidates based on cost and implementation timeframe and since LAAS and dual-frequency GPS are considered unlikely to be fielded.

Despite concerns regarding the use of the ADS-B Out with NACp 8 accuracy to enable successful and safe surface surveillance, major aircraft manufacturers (i.e., Boeing and Airbus) have announced intentions to use traffic displays beyond the presentation of ownship only information to yield the theorized benefits that should accrue with greater situation awareness of low altitude (i.e., below 1000 feet (ft) above ground level) and surface traffic. Boeing's approach includes added features on "crew awareness of taxi route, airport traffic, runway status, and runway traffic conflicts" in the 2011 – 2018+ timeframe [Clark and Trampus, 2011]. Airbus Onboard Airport Navigation System (OANS) technology brochure describes functions including, "moving map capability with A/C position overlay", significant "interactivity" features (e.g., search functions), and integration with other Airbus surface safety technologies including, "Brake to Vacate", "Runway Proximity Advisory", datalink loading of ATC path/clearances, ADS-B traffic display, and "threat detection information" [Airbus, 2015].

3.2 Surface Trajectory-Based Operations

Delays due to surface congestion, such as aircraft waiting to cross active runways, are often cited as being responsible for the largest delay costs in the U.S. airspace system [Glass and Gawdiak, 1997; Williams et al., 2006]. Surface congestion delays may result from various causes but often are due to limited resources, such as available runways and taxiways. Airport capacity is typically measured in terms of runway throughput for arrival and departure operations. Often, controllers attempt to maximize runway capacity through queuing strategies that line up multiple aircraft at a departure runway end to minimize departure slot losses. Similarly, controllers apply arrival strategies that minimize runway occupancy and runway crossing times. The FAA Airport Benefit-Cost Analysis Guidance [FAA, 1999] captured the delay costs associated with inefficient surface operations and identified that movement area delays are due predominately to departure and runway crossing queuing. Movement area delays can be increased due to lack of push-back time prediction and timing uncertainties for taxi operations, such as speed control, clearance and hand-off, and hazard avoidance (e.g., stop-and-go for avoidance of ground vehicles). Weather and airport expansion have exacerbated the issue because of delays caused by gate access, de-icing operations, and longer taxi times from new runways. Predictions of decreased intervals between arriving and departing traffic because of proposed technologies in the NextGen system will allow more aircraft per unit time in the terminal maneuvering area (e.g., Prevot et al., 2012). A logical prescription to the issues identified above would be to better effectively control surface operations to emulate the timing precision witnessed in airborne operations (i.e., required/controlled time-of-arrival). The STBO concept has been proposed to effectively achieve time-based precision surface movements to optimize the available airport surface and maximize the number of aircraft that could safely conduct gate-to-departure and arrival-to-gate operations [JPDO, 2011]. Mid-term [FAA, 2009a and RTCA, 2011] and far-term [Hooey et al., 2014] STBO concepts have been proposed.

The FAA established the STBO to conduct research on airport time-based surface operations. To achieve the goals of the project, it was observed that changes in procedures would be required, as well as advances in automation aids and collaboration between the flight deck and controllers. For example, local data exchange [Brinton and Atkins, 2008] may be required to share flight readiness information and collaborative decision-making between airline coordinators (Airline Operation Centers); flight dispatch; tower controllers; and flight crews (including between aircraft) that would enable the precise pre-planned runway schedules and coordination necessary to ensure safe and efficient movements. Advantages include reduced engine operation and environmental impacts, less surface taxi time, more efficient routings, and avoidance of surface congestion, particularly during peak times. Through ground-based communication, navigation and surveillance, and STBO automation aids, the sequence of aircraft movements can be more tightly controlled. However, to fully realize the benefits, flight deck technological aids are also expected to be needed. An example is the use of digital taxi clearances [Baxley et al., 2010] that may facilitate needed taxi conformance monitoring [Diffenderfer and Morgan, 2011] and mitigation of potential runway/taxiway incursions and other hazards (e.g., taxi to wrong runway) that have been predicted with the potential future increase in number of movements on limited available concrete [Funk et al., 2008]. The use of STBO is likely to fundamentally change the roles and responsibilities of controllers and flight crews [Verma et al., 2007] and how aircraft taxi compared to current surface operations.

Surface traffic management systems for Air Traffic Control (ATC) are an enabling technology for STBO. These systems are primarily designed to support airport configuration management, runway assignment, scheduling and sequencing, taxi routing, and conformance monitoring. Extensive work has been conducted to define the concept of use for these technologies [Ashley et al., 2011; Diffenderfer and Morgan, 2010; and Morgan, 2010] and human-in-the-loop testing has been reported [McGarry and Kerns, 2010; Stelzer, 2010; Stelzer and Stanley, 2011; and Stelzer et al, 2011]. The Spot and Runway Departure Advisor is a surface management system developed by NASA that aids tower controllers in maintaining efficient airport surface operations by providing specific optimized timing and sequencing information for each departing aircraft (metering at spots, runway departure point, and active runway crossing intersections). Use of this advisor will result in reduced taxi times, departure queues, runway crossing wait times, fuel burn, and environmental emissions [Hoang et al., 2014; Hoang et al., 2011; Jung et al., 2011; and Jung et al., 2010].

A key component of the NextGen STBO vision is the generation of conflict-free time-based taxi clearances to enable precise departure times and limited simultaneous runway occupancy [JPDO, 2010b]. These taxi route clearances will likely be sent directly to the flight deck [Diffenderfer and Morgan, 2010]. STBO flight deck research has focused primarily on information display requirements for presentation of automated STBO taxi clearances to the crew and the ability of the crew to comply with the STBO clearances [Williams et al., 2006; Foyle et al., 2009; Prinzel et al., 2009; Shelton et al., 2009; Cheng et al., 2009; and Foyle et al., 2011]. For STBO to be successful, it was concluded that an advanced flight deck display would be needed [Foyle et al., 2009; Bakowski et al., 2011; and Foyle et al., 2011]. Advances in flight deck avionics and displays have great potential to provide graphical depiction of the taxi route, including waypoints, hold-short points, and target time and speed indicators [Cheng et al., 2008; Shelton et al., 2009; Williams et al., 2006]. To prevent excessive head-down time, STBO guidance may need to be shown on a HUD or head-worn display [Bakowski et al., 2011; Shelton et al., 2009; and Foyle et al., 2011].

The move toward STBO surface operations has significant implications for surface safety and pushes the need for CD&R capability beyond the current runway incursion focus to include all surface operations. Although the safety impact of following STBO taxi clearances has not been determined, non-conformance to these clearances could result in unintentional taxi conflicts. In these instances, taxi CD&R capability becomes critical. Initial research has been conducted on ground-based CD&R for ATC STBO decision support [Cheng et al., 2011a; Cheng et al., 2011b; and Montoya et al, 2013] and on the integration of ground-based and flight deck-based CD&R for STBO [Cheng et al., 2012].

3.3 Surface CD&R

The worst aviation accident on record resulted in 583 fatalities and was caused by a runway incursion when two fully loaded 747 airplanes operating in low visibility collided on a runway at Tenerife airport in 1977. Airport surface safety, including runway incursion prevention, is a serious concern of the NTSB [NTSB, 2012], FAA, and NASA. The FAA is committed to reducing the severity, number, and rate of runway incursions by implementing a combination of guidance, education, outreach, training, technology, infrastructure, and risk identification and mitigation initiatives [FAA, 2011]. Progress has been made in reducing the number of serious incursions, from a high of 67 in Fiscal Year (FY) 2000 to 6 in FY 2010;

however, that number is again on the rise with 18 serious incursions in FY 2012. The rate of all incursions has risen steadily over recent years – from a rate of 12.3 incursions per million operations in FY 2005 to a rate of 22.7 incursions per million operations in FY 2012 [FAA, 2011; FAA, 2007b; FAA, 2009b; and FAA 2012]. Without proactive counter-measures, the increase in air traffic forecast under NextGen could potentially result in corresponding increases in runway incursion accidents.

Numerous efforts have been launched by the FAA, industry, and others to reduce the frequency of runway incursions and the risk of runway collisions to meet the recommendations put forth by the NTSB [NTSB, 2000]. These solutions include EFB with AMM, Airport Surface Detection Equipment Model X (ASDE-X), Low Cost Ground Surveillance, Airport Movement Area Safety System; Final Approach Runway Occupancy Signal; Runway Status Lights; enhanced controller training; airport surface operations advisory circulars; improved airport signs, markings, and lighting; improved pilot education, training, and awareness; and revised pilot/controller communications phraseology. These efforts target improved awareness and enhanced surveillance.

Currently, no system is available (either ground or aircraft-based) that directly provides the flight deck with alerts of potential runway conflicts with other traffic. However, some flight deck-based situation awareness systems exist, including:

- An aircraft-based SmartRunway/Runway Awareness and Advisory System (RAAS) was developed by Honeywell International Inc. [Honeywell, 2013]. RAAS uses GPS position data and a database to provide aural and graphical advisories that supplement flight crew awareness of ownship position during ground operations and on approach to landing. RAAS does not, however, provide alerts of runway incursion conflicts with other traffic.
- SafeRoute™, developed by Aviation Communication & Surveillance Systems, an L3 Communications and Thales Company, provides the pilot with an electronic map of the airport surface on an electronic flight bag, showing ownship and other aircraft positions. The system will also indicate when a runway is occupied by highlighting the runway on the display [ACSS, 2014]. SafeRoute™ does not, however, detect and alert for conflicts between aircraft and vehicles.

NASA- and FAA-sponsored research has also been conducted by Honeywell Aerospace and SAAB Sensis Corp. to transmit ASDE-X runway incursion alerts (optimized for ATC) to the flight deck [Hughes, 2007]. Additional research is needed to determine both the effectiveness of providing the ATC-optimized ASDE-X alerts to the flight crew and the data link requirements.

Working cooperatively with NASA, Era Corporation, a SRA International, Inc. subsidiary, developed a CD&R system, known as PathProx™, that detects potential runway conflicts and generates alerts for display to the flight crew [Cassell et al., 2003]. PathProx™ does not include the cockpit display device and is not commercially available at this time.

A CD&R concept was developed by NASA to address airport surface safety in commercial, business, and general aviation sectors [Jones et al., 2001; Jones, 2002; Jones, 2005; Jones and Prinzel, 2006; Jones et al., 2009; Jones et al., 2010; Jones et al., 2012a, and Jones et al., 2012b]. The concept utilizes flight deck displays and technologies for enhanced surface and airborne traffic awareness with flight deck alerting concepts for safety assurance during approach, landing, and surface (runway and taxiway) operations.

The Enhanced Traffic Situational Awareness on the Airport Surface with Indications and Alerts (SURF IA) application has been established by RTCA to reduce the likelihood and severity of runway incursions and collisions. A SURF IA SPR [RTCA, 2010b] has been developed to increase flight crew situation awareness of the runway environment and facilitate an appropriate and timely response to potential conflict situations. As part of this effort, the FAA sponsored flight demonstrations, conducted by Aviation Communication and Surveillance Systems [ACSS, 2010] and Honeywell [Honeywell, 2010], to show the feasibility of implementing this technology. NASA research was integrated into this effort.

4 System Description

This section describes the experimental hardware and simulation elements used for this study, including the simulation facility, flight deck displays, air traffic control simulation, CD&R system, and surveillance data.

4.1 Simulation Environment

This research was conducted in the Research Flight Deck (RFD) simulator at NASA Langley Research Center (Figure 1) which is a high-fidelity, six degrees-of-freedom motion-based (Figure 2) large commercial aircraft simulator with full-mission capability and advanced glass flight deck displays. Operations were conducted at the Memphis International (KMEM) airport. The out-the-window (OTW) scene included realistic taxiways and runways with appropriate markings, airport lighting, and other aircraft in simulated visibility conditions and provided approximately 20/40 visual acuity with a collimated 200 degree horizontal by 40 degree vertical field of view at 26 pixels per degree resolution. All standard audio call-outs were issued.

The RFD is equipped with dual 46 degree horizontal x 34.5 degree vertical field-of-view commercial HUDs with 1400 x 1050 display resolution and greater than 4,000 foot lamberts display brightness; however, only the HUD located on the left or captain's side was utilized.

As shown in Figure 1, the simulator had four large main instrument panel displays referred to as: (left to right) pilot's Primary Flight Display (PFD), pilot's Navigation Display (ND), co-pilot's ND, and co-pilot's PFD. Each display panel had a 13.25 inch x 10.5 inch viewable area at 1280 x 1024 resolution.

Two EFBs were installed. Each provided a display resolution of 1024 x 768 pixels over a 10.4 inch diagonal area. The EFBs were mounted outboard of the PFDs and were used as the flight crew's interface for the AMM, charts, checklists, and ATC data-link communications. The EFBs were located within the pilot's primary field-of-view as per the FAA AC 25-11A [FAA, 2007c].

Figure 1. RFD Simulator Cockpit Configuration and Displays.

Figure 2. RFD Simulator on Motion Platform.

4.2 Flight Deck Displays

The PFD, ND, and HUD formats mimicked current state-of-the-art production aircraft. Additions were made to accommodate study objectives.

4.2.1 Primary Flight Display

The PFD included an ATC message area on the outboard portion of the panel showing incoming and outgoing ATC data-link communications in textual format, when required by test conditions (Figure 3). Incoming messages were color-coded green while outgoing messages were white. All messages were time-stamped.

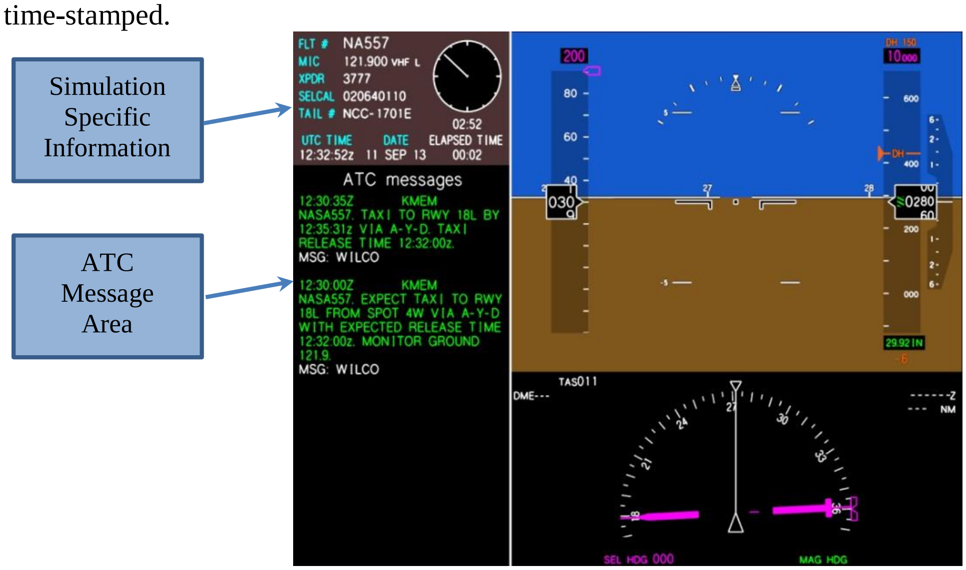


Figure 3. Captain’s Primary Flight Display.

4.2.2 Navigation Display

The ND was split, showing a half-screen navigational display and half-screen Engine Indication and Caution Alerting System (Figure 4).

Figure 4. Captain's Navigation Display.

4.2.3 Head-Up Display

The HUD was only used during taxi operations when test conditions required. Standard on-ground HUD symbology was used in declutter mode (Figure 5). Note that ground speed was displayed in the lower left.

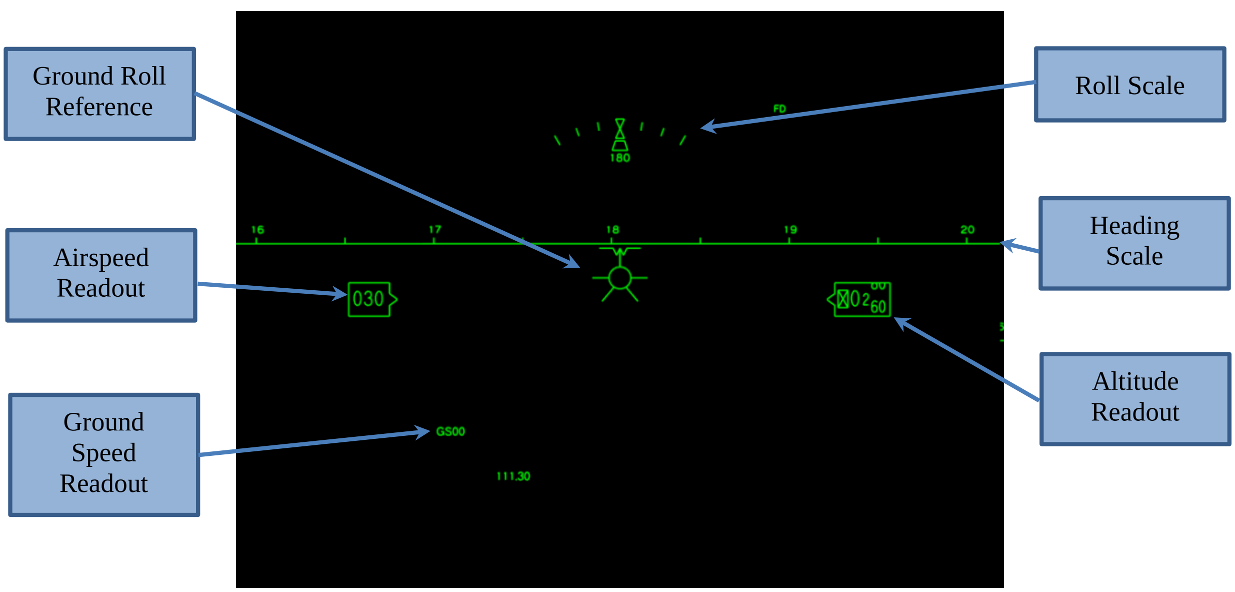


Figure 5. Head-Up Display Symbology.

4.2.4 Electronic Flight Bag Display

The EFB was used for communications, charts, checklists, and AMM. Test subjects interacted with the EFB through either a bezel button or touch screen interface. The main menu selections are shown in Figure 6.

The communications function (comm) was used to display and respond to ATC data-link messages (Figure 7). An incoming ATC message was displayed in green on the EFB and also on the PFD. Once the message was acknowledged, the message color changed to white on the EFB and an acknowledgement message (e.g., 'WILCO') was displayed on the PFD.

The charts function provided the ability to display arrival, approach, departure, and airport charts (Figure 8). Pan/zoom (full page, half of the diagram, one fourth of the diagram) capability was provided.

The checklists function provided the capability to display all aircraft checklists. The checklists available were Taxi, Before Takeoff, After Takeoff, Cruise, Descent, Before Landing, After Landing, and Parking. The evaluation pilots were requested to use these checklists during operations.

The AMM (moving map) was only displayed on the EFB. Range control for the AMM was selectable at 0.4 nautical miles (nm), 0.8 nm, 1.6 nm, or 3.2 nm and was selected through a knob on the center isle stand. The basic AMM display (Figure 9) included an airport layout showing runways, taxiways, and buildings. Surface (tan) and airborne (cyan) traffic icons were shown along with ownship position (white chevron). The AMM used a KMEM airport geographic database developed to RTCA standards [RTCA, 2001]. In this document, all figures of the AMM are shown without the surrounding EFB bezel button structure. Specific AMM configurations used for the study are provided in the Test Method section below.

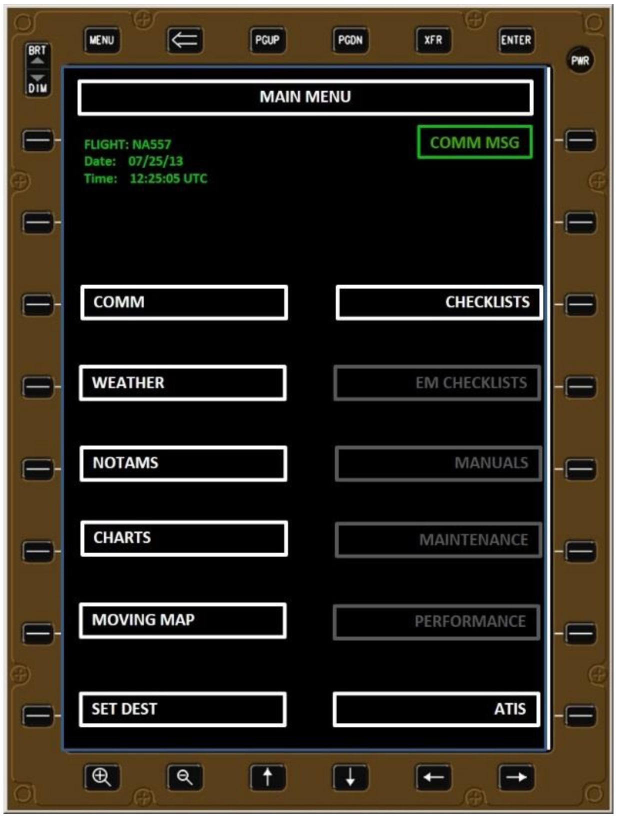


Figure 6. Main Menu Page on EFB.

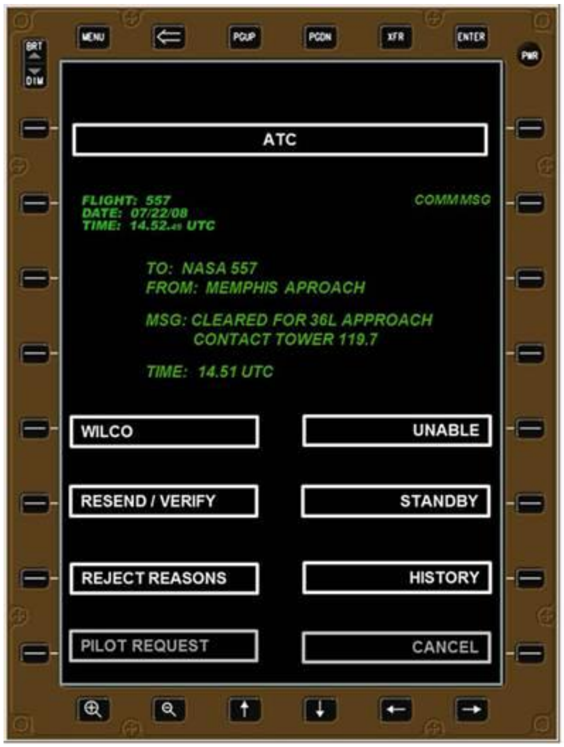


Figure 7. ATC Communications Page on EFB.

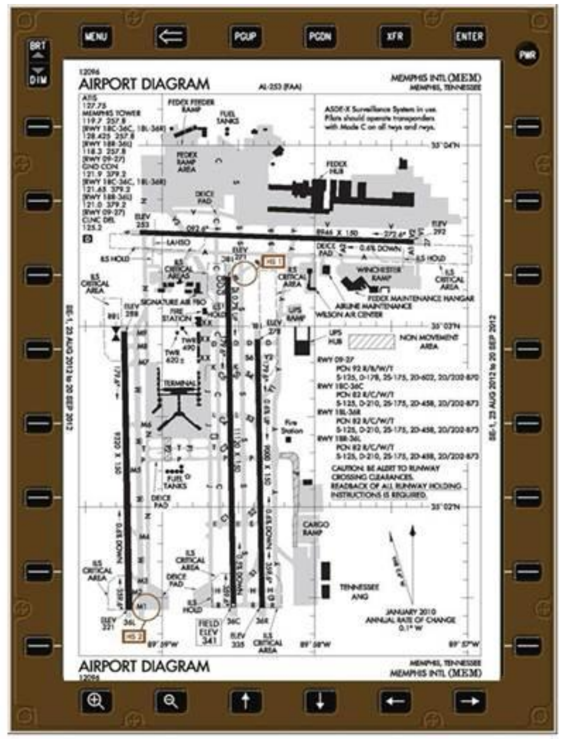


Figure 8. Airport Diagram Shown on EFB.

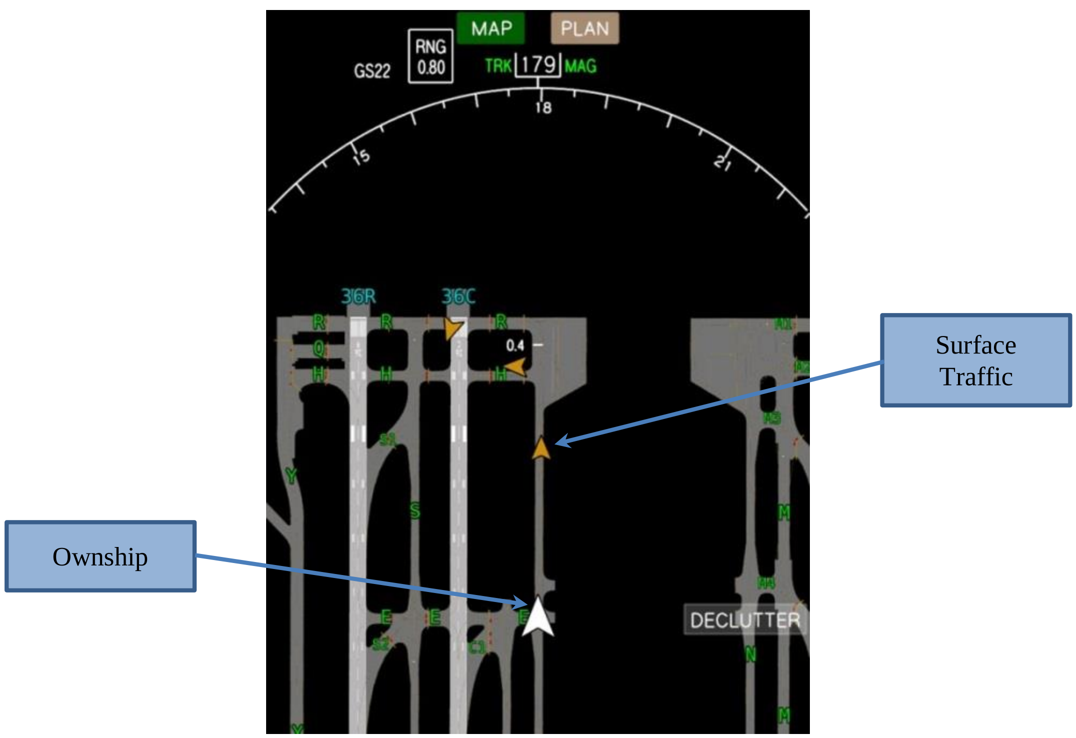


Figure 9. Basic Airport Moving Map Display.

4.3 Air Traffic Control Simulation

ATC instructions and other aircraft requests and replies were simulated via a speech generation system to increase the fidelity of the simulation and provide normal pilot workload demands. The messages were played through the intercom or through the flight deck speaker system when the ownship and simulated traffic reached specified locations or timings to coincide with the scenario task. The subject pilots were asked to provide radio replies as per normal operating procedures. Human back-up was present if additional or unscripted communication or clarification was necessary.

4.4 Conflict Detection and Resolution

A CD&R system was active during the testing. This system was developed based on SURF IA specifications [RTCA, 2010b] and NASA CD&R research. SURF IA specifications were used to develop the runway conflict detection portion of the CD&R system used for this testing.

4.4.1 SURF IA

SURF IA identifies potential runway conflicts that involve aircraft or vehicles in the airport maneuvering area, within 3 nm of the runway threshold and up to 1,000 ft above field elevation (AFE), and generates both indications and alerts for display to the flight crew. SURF IA utilizes traffic surveillance information obtained from ADS-B-In and generates indications and alerts based on the aircraft/vehicle states during same runway, very closely spaced parallel runway, and intersecting runway operating configurations. Six types of aircraft operational states are defined: (1) taxiing on a taxiway toward a hold line or stopped at a hold line; (2) entering or crossing a runway (not lined up with runway); (3) takeoff; (4) approach; (5) after landing roll-out on runway (e.g., less than or equal to 40 knots (kts)); and (6) stopped or taxiing along a runway. To prevent inappropriate crew responses during departure, indications and alerts are inhibited above 80 kts ground speed (GS). The SURF IA application does not currently address taxiway or low altitude air-to-air conflicts, directive alerting, and is not intended for use on helicopters or vehicles.

4.4.2 NASA CD&R Research

NASA CD&R research has included development of algorithms to identify potential traffic conflicts at low altitudes near the airport, on the runway, and during taxi operations for multiple classes of aircraft and surface vehicles [Otero et al, 2013]. Since SURF IA does not currently include specifications for taxi conflicts, NASA research specific to taxi conflict detection was used to develop the taxi conflict detection portion of the CD&R system used for this testing.

The NASA taxi conflict monitor was designed to detect and alert for ground taxi conflicts in the airport movement area by computing distances between the ownship and traffic, closing speeds, time to closest point of approach and other parameters to determine if criteria and thresholds are met for issuing alerts. Indications are not currently generated for taxi conflict situations.

4.4.3 Indications and Alerts

Indications and alerts (IAs) notify the flight crew of potentially hazardous situations. Criteria for issuing IAs are defined in [RTCA, 2010b and Otero et al, 2013]].

Indications were intended to generate pilot awareness and situation assessment by highlighting the runway and traffic status as relevant to ownship operations. Indications identified operational conditions that were generally normal, yet relevant for runway safety and could be a precursor to a non-normal situation. Only visual annunciations were required and used for indications. Indications were only issued for runway conflict situations. Two types of indications were utilized.

A *traffic indication* (TI) highlighted a potential runway traffic collision/hazard that could emerge in the immediate future. TIs were intended to increase the flight crews' awareness of the relevant runway traffic. The flight crew could proceed with the intended operation after a brief assessment of the situation and if appropriately cleared. A TI was displayed on the AMM (Figure 10) as an enlarged traffic symbol for the relevant traffic surrounded by a dashed circle in the same color as the traffic symbol and an identification tag that showed flight identification and ground speed in knots. A status message ("Traffic") was displayed at the bottom of the surface map along with the estimated distance to the traffic in nautical miles until below 0.1 nm (600 ft), then displayed in feet.

A *runway status indication* (RSI) identified whether the runway that the ownship was approaching or using was in-use or occupied by other traffic and was not suitable for entering, takeoff, or landing. Before proceeding, the crew should ensure they had the appropriate clearance and the indicated traffic was not a factor. An RSI was displayed on the AMM (Figure 11) in the same manner as a TI with the addition of a solid blue line outlining the relevant runway.

Figure 10. Traffic Indication.

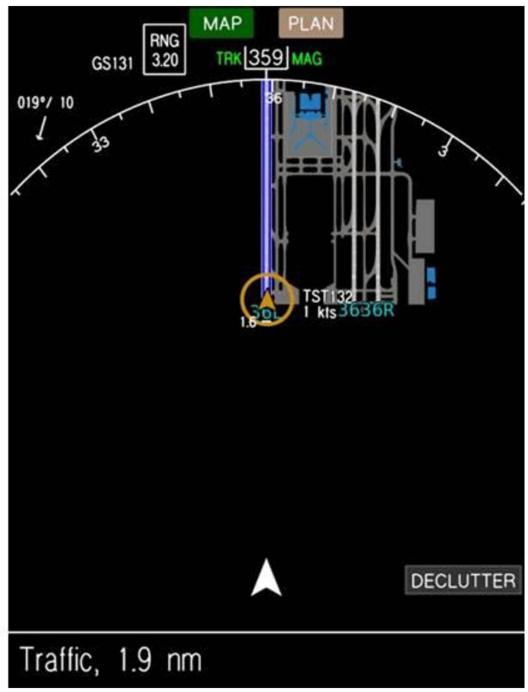


Figure 11. Runway Status Indication.

Alerts identified potential collision hazards which require immediate flight crew awareness and may require timely action or response to avoid a collision. Alerts had priority over indications. Auditory and visual annunciations were required for alerts. Alerts were issued for both runway and taxi conflict situations. A two-level alerting scheme was utilized.

Caution alerts were generated for conditions that required immediate flight crew awareness and subsequent flight crew response. A caution alert was displayed on the AMM (Figure 12) as an enlarged yellow traffic symbol surrounded by a yellow circle for the relevant traffic, an identification tag that showed flight identification and ground speed in knots, and a yellow line around the relevant runway, if applicable. An alert message ("Caution, Traffic") was displayed at the bottom of the surface map in yellow text along with the estimated distance to the traffic. An audible annunciation was also made ("Caution, Traffic, Caution, Traffic").

Warning alerts were issued for conditions that required immediate flight crew awareness and immediate flight crew response. Warning alerts could occur without preceding caution alerts. A warning alert was displayed in the same manner on the AMM as a caution alert, except the warning was associated with the color red, a square was used to surround the traffic symbol, and the alert message was "Warning, Traffic" (Figure 13).

An off-scale traffic symbol was pegged on the edge of the display in the direction of traffic if the traffic was outside of the AMM viewing area when an IA was generated (Figure 14).

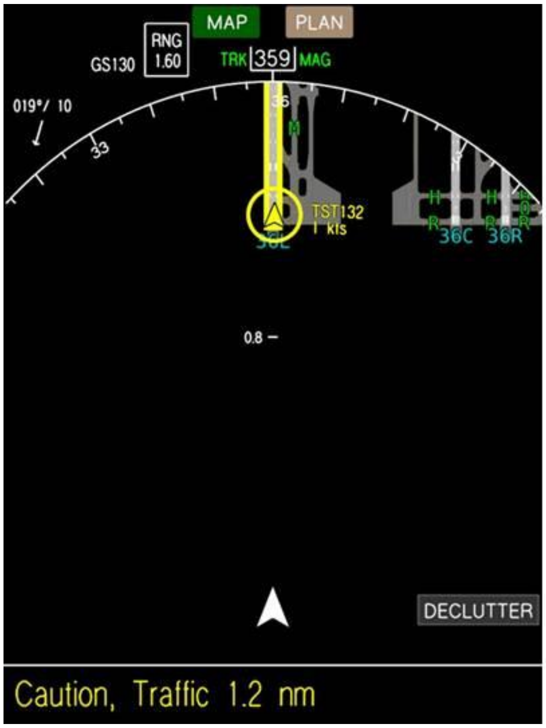


Figure 12. Caution Alert.

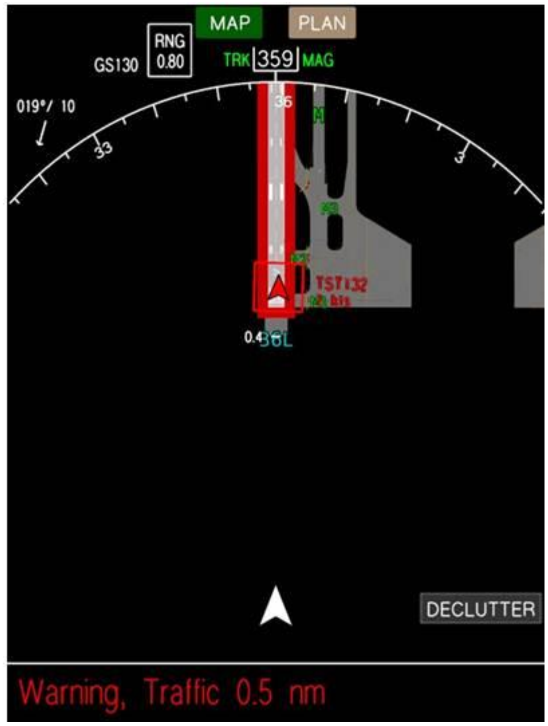


Figure 13. Warning Alert.

Figure 14. Off-Scale Traffic Symbol Displayed During Runway Status Indication.

4.5 Surveillance Data

The quality and accuracy of reported traffic surveillance data are critical to the integrity of the AMM traffic displays and the CD&R capability. The traffic position accuracy was simulated as dependent upon the GPS measurement errors. A Gauss-Markov process modeled the time correlation between successive position measurement errors [Mohleji and Wang, 2010]. It was assumed that ADS-B would be used as the means for transmitting (ADS-B Out) and receiving (ADS-B In) these GPS-based aircraft surveillance data. Although ADS-B transmission qualities and effects were not modeled for this study, the traffic positional data was updated at one hertz to simulate ADS-B transmission rates. Latency effects, transmission line-of-sight, bandwidth blockage, and vertical position accuracy were not modeled since the focus of the study was evaluating the effects of position accuracy (NACp).

The SURF IA SPR has proposed horizontal position accuracy requirements [RTCA, 2010b] for the SURF IA function. Through analysis, the SPR identified that to meet safety requirements, horizontal position accuracy when on the airport surface needs to be at least 10 m within 95% containment bounds (NACp 10) to allow indications and alerts to be issued for traffic at virtually all airports in the National Airspace System.

The NACp position accuracy requirements specified in the ADS-B Out Final Rule (see Background section), ATSA-SURF requirements for display of traffic on an AMM (see Background section), and SURF IA requirements for issuing IAs are shown in Table 2. To span these accuracy requirements, traffic position accuracy equivalent to NACp 8, 9, 10, and 11 levels were used for this study. Truth data, with no accuracy errors, was also recorded. The accuracy levels (e.g. NACp 8, NACp 9, etc.) were controlled for individual traffic. For each test trial, every aircraft was assigned a position accuracy level. This NACp assignment remained consistent for each crew; however, there was some variability in position accuracy since the values could fluctuate within the NACp horizontal accuracy bound (Table 1). Traffic transmitting horizontal position accuracy equivalent to NACp 8 definitions was considered unqualified traffic. Traffic transmitting position accuracy equivalent to NACp 9 and higher was considered qualified traffic (qualified for the ATSA-SURF function).

Table 2. NACp Accuracy Requirements.

NACp	ADS-B Out Final Rule	Display Per DO-322 (ATSA-SURF)	IAs Per DO-323 (SURF IA)
8	Yes	No	No
9	Yes	Yes	No
10	Yes	Yes	Yes
11	Yes	Yes	Yes

5 Test Method

The testing was conducted in two phases, Part 1 and Part 2, as described below.

5.1 Evaluation Pilots

Twenty-four commercial pilots from four airlines served as participants for the research. The test subjects were paired by airline and role (Captain, First Officer) to ensure crew coordination and cohesion with regard to terminal and surface standard operational procedures. All pilots held an Airline Transport Pilot rating. The Captains had an average of over 17,000 flight hours with 25 years of commercial experience. The First Officers had an average of over 13,000 flight hours with 20 years of commercial experience.

5.2 Part 1 Testing

The objectives of the Part 1 testing were to evaluate the ability of a subject crew to conduct safe and efficient airport surface operations while utilizing an AMM. The AMM displayed traffic of various position accuracies, which also affected traffic density on the AMM. The effect of traffic position accuracy on CD&R capability was also measured. The evaluation included approach, departure, and runway incursion scenarios and two AMM conditions. Part 1 testing was conducted prior to Part 2 testing.

5.2.1 Part 1 AMM Display Conditions

Two AMM display conditions were chosen to evaluate the effects of displaying only qualified traffic on an AMM (Map A condition) versus displaying all airport traffic on an AMM (Map B condition).

The *Map A condition* consisted of the basic AMM format displaying qualified traffic only (traffic reporting a horizontal position accuracy of NACp 9 and higher) (Figure 15). As a result, the locations of some of the airport traffic (those reporting horizontal position accuracy of NACp 8) were not displayed. The only method of acquiring the NACp 8 reporting traffic was visually, OTW.

The *Map B condition* consisted of the basic AMM format displaying both qualified and unqualified traffic (traffic reporting a horizontal position accuracy of NACp 8) (Figure 16); therefore, all airport traffic was displayed on the AMM. As position accuracy decreased, the location of traffic symbols could vary from the traffic's actual location. For example, the traffic symbol for an aircraft transmitting a position accuracy of NACp 8 could be displayed 305 ft or more (see Table 1) from the aircraft's actual location, giving a potentially misleading indication of the traffic's location.

The traffic position accuracy (NACp level) was not indicated to the crew through methods such as different AMM icon shapes or colors to limit the number of evaluation parameters.

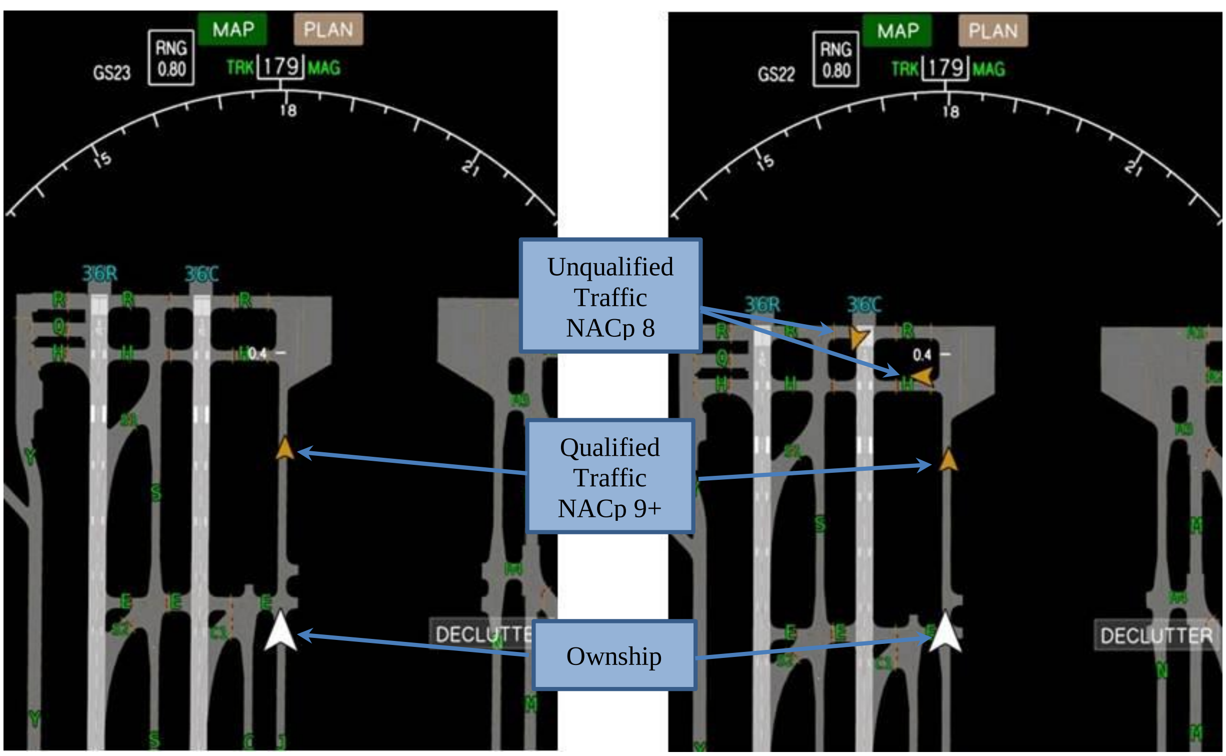


Figure 15. Map A Display Condition. **Figure 16. Map B Display Condition.**

5.2.2 Part 1 Test Matrix

A total of ten trials (eight nominal, two off-nominal) were experienced by each crew. All trials were conducted in daytime 1,800 ft visibility. ATC clearances were provided verbally via the voice generation system; data-link was not used. The HUD was not utilized. The full test matrix is shown in Appendix A.

Nominal trials evaluated the effect of displaying traffic transmitting various position accuracies on the AMM during airport surface operations. Traffic was transmitting position accuracy ranges from NACp 8 to NACp 11. Two AMM conditions (Map A and Map B) were evaluated across subjects during two approach and two departure scenarios (Appendix B), for a total of eight nominal trials. There were 12 to 14 non-conflicting traffic aircraft per nominal trial, with three to five of those aircraft transmitting NACp 8 accuracy (not visible on Map A)

For the approach scenarios, the ownship was initialized in landing configuration approximately 5 nm from the runway threshold (normal position of the final approach fix) for a standard auto-land approach. After landing and roll-out, the aircraft was to exit the runway and taxi to the ramp via the designated taxi route. The trial terminated when the aircraft entered the ramp area. For the departure scenarios, the subject crew began taxi from the ramp, taxied to the departure runway via the designated taxi route, and executed a takeoff after receiving the appropriate clearance. The trial terminated once the aircraft reached approximately 1,000 ft AFE. The pilots were requested to maintain a standard taxi speed of 15 kts whenever feasible for both the approach and departure scenarios.

Off-nominal trials were conducted between subjects to evaluate the potential safety implications of traffic position accuracy on airport surface CD&R capability. Each crew completed two off-nominal trials as Test Runs 6 and 10 of ten trials. There were 12 or 13 non-conflicting traffic aircraft per off-nominal trial, with two of those aircraft transmitting NACp 8 accuracy (not visible on Map A).

For six of the crews, the objective was to evaluate the impact of displaying qualified versus unqualified traffic on the AMM during conflict situations. These crews were given a taxi crossing and departure conflict scenario (see below for description), using either Map A or B display condition (Table 3). The conflict traffic was transmitting NACp 8 position accuracy for all these trials; therefore, IAs were not issued. When using Map A, the conflict traffic was not displayed on the AMM and could only be seen OTW. When using Map B, the conflict traffic was displayed on the AMM, albeit with NACp of 8 accuracy, and could also be seen OTW.

For the other six crews, the objective of the off-nominal trials was to evaluate the impact of receiving versus not receiving IAs for traffic displayed on the AMM during conflict situations. These crews were given a taxi crossing and departure conflict scenario using the Map A display condition. The conflict traffic was transmitting either NACp 9 or NACp 10 position accuracy (Table 4) and, therefore, was always displayed on the AMM. Per SURF-IA specifications, IAs were not issued for traffic transmitting NACp 9 position accuracy, but were issued for traffic transmitting NACp 10 position accuracy.

Table 3. Part 1 Off-Nominal Group 1 Test Conditions.

Crew	Scenario	Map Condition	Conflict Traffic Accuracy
1, 5, 9	Taxi Crossing	A	8
	Departure	B	8
3, 7, 11	Taxi Crossing	B	8
	Departure	A	8

Table 4. Part 1 Off-Nominal Group 2 Test Conditions.

Crew	Scenario	Map Condition	Conflict Traffic Accuracy
2, 6, 10	Taxi Crossing	A	9
	Departure	A	10
4, 8, 12	Taxi Crossing	A	10
	Departure	A	9

5.2.3 Part 1 Conflict Scenarios

Two conflict scenarios were utilized. Every effort was made to produce similar timings; however, a certain amount of variability was naturally introduced due to the maneuvering conducted by the pilot (e.g., taxi speed).

5.2.3.1 Taxi Crossing Conflict Scenario

An approach and departure flow was simulated. Traffic approached Runway 36C (three aircraft) (Figure 17, green route) and Runway 36L (three aircraft) (Figure 17, orange route), spaced 5 nm apart and staggered between runways. This traffic landed, exited the runway, and taxied to the terminal via the routes shown in Figure 17. There was a departure flow (four aircraft) using Runway 36R via the blue colored route shown in Figure 17. The traffic held at Runway 36C until after an aircraft landed, then crossed to Runway 36R for departure approximately every three minutes. One aircraft would cross Runway 36C after every other arrival, for a rate of one departure for every two arrivals. Three other static aircraft were placed in the ramp area to add interest to the scenario.

At the beginning of this scenario, the ownship was parked on the ramp near Taxiway M6 facing Taxiway N. The flight crew was cleared to taxi to Runway 36C via Taxiways N, P, S, and R (Figure 17, magenta route), holding short of Runway 36C. As the ownship approached the Runway 36C hold line, an aircraft was landing on the runway. The subject crew was cleared to cross Runway 36C when the landing traffic was approximately 8,000 ft away.

This scenario tested the incursion situation where an aircraft taxis across a runway even though another aircraft is landing on the same runway. In this case, the subject crew was given an erroneous clearance to cross the runway, resulting in a potential collision unless action was taken.

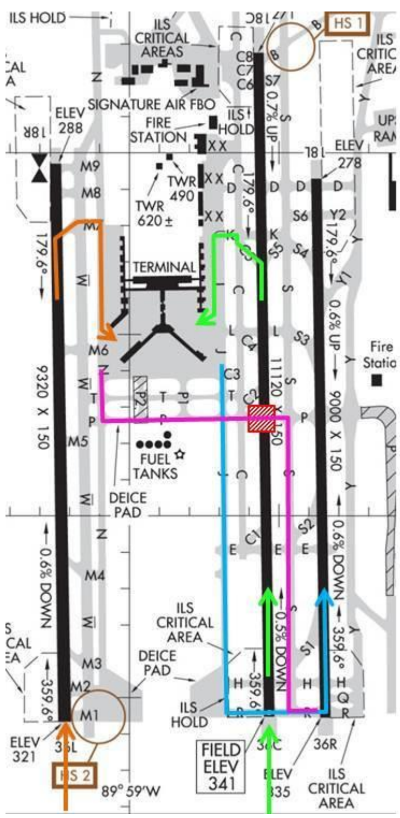


Figure 17. Part 1 Conflict Scenario, Taxi Crossing.

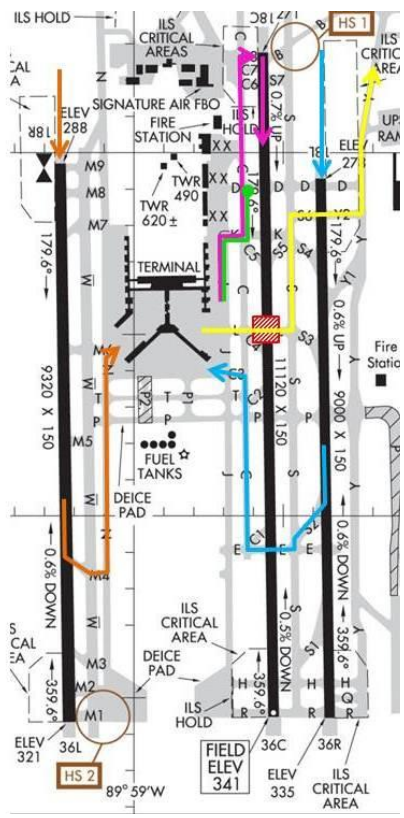


Figure 18. Part 1 Conflict Scenario, Departure.

5.2.3.2 Departure Conflict Scenario

A southern approach and departure flow was simulated. Traffic approached Runway 18R (three aircraft) (Figure 18, orange route) and Runway 18L (four aircraft) (Figure 18, blue route), spaced 5 nm apart and staggered between runways. This traffic landed, exited the runway, and taxied to the terminal via the routes shown in Figure 18. There was a departure flow (three aircraft) using Runway 18C via the magenta colored route shown in Figure 18. The traffic would depart approximately every three minutes, for a rate of one departure for every two arrivals.

One aircraft taxied from the ramp via the green route shown in Figure 18 and held short of Runway 18C at Taxiway D. This aircraft was intended to be a distraction for the subject crew. Two other static aircraft were placed in strategic locations (Runway 18C hold lines) to add interest to the scenario.

At the beginning of this scenario, the ownship was parked on the ramp facing Taxiway J. The flight crew was cleared to taxi to Runway 18C via Taxiways J, K, C, and C8 (Figure 18, magenta route), holding short of Runway 18C. As the ownship was cleared and taxied onto the runway, another aircraft taxied from the ramp (Figure 18, yellow route) and held short of Runway 18C at Taxiway L. As the ownship began its departure roll, the aircraft holding on Taxiway L crossed the runway in front of the ownship. Taxiway L is 4,500 ft from the Runway 18C threshold, providing enough time for the departure aircraft to stop if necessary.

This scenario tested the incursion situation where an aircraft taxis across a runway in front of a departing aircraft. The traffic for this scenario, instead of holding short, taxied across Runway 18C without clearance as the ownship began its departure.

5.2.4 Part 1 Procedure

Prior to the testing phase, each test subject participated in a briefing and simulator training session. The training included general simulator characteristics and specific items and procedures related to Part 1 testing, such as Map Conditions A and B, traffic position accuracy, and CD&R capability.

During the training for the CD&R capability, the flight crews were trained to abort if a warning alert was generated during departure, go-around if a warning alert was generated on approach, and stop if a warning alert was generated during taxi. They were not required to take evasive action when an indication or caution alert was issued.

Before each trial, the flight crew was briefed on the run conditions, e.g., approach or departure, visibility, winds, display condition in use, and ATC radio frequencies. The case order list is shown in Appendix C.

The test runs were documented via audio, video, and digital data recordings, and post-run and post-test questionnaires (see Appendices G, H, and J).

5.3 Part 2 Testing

The objectives of the Part 2 testing were to evaluate the ability to safely conduct STBO by assessing the impact of providing traffic intent information, CD&R system capability, and the display of STBO guidance to the flight crew on both head-down and head-up displays. Evaluations were conducted during STBO taxi operations from the ramp to the departure runway utilizing two HUD conditions and two AMM conditions with airport traffic transmitting various levels of horizontal position accuracy.

5.3.1 STBO Guidance Algorithm

For all ownship routes, a nominal taxi trajectory was created and stored in a tabular data file. The trajectory was built using ownship's performance and loading and a nominal acceleration and deceleration at the start, end, and around turns to create a planned distance, time, and speed taxi profile. Since the operation was conducted in relatively low visibility (1,800 ft), the profile assumed 15 kts in straight taxi segments and 5 kts through 90 degree turns. This speed profile was based upon a general consensus of standard operating procedures, including the aircraft flight manual for the Boeing 757 aircraft, operating in relatively low visibility conditions. The designed trajectories were built by a Subject Matter Expert (SME). The trajectories were also checked and adjusted for reasonableness using two other check-pilots with Boeing 757 operational air carrier experience. This becomes relevant in the evaluation data described in the results section, which suggest that these nominal trajectory profiles were not universally accepted. The speeds, especially in the turns, were felt to be too slow. These data highlight that there exists extremely significant Standard Operating Procedure (SOP) differences between operators and air carriers during surface operations; how these differences can be accommodated in surface STBO will be a design and operational challenge.

The trajectories included ownship position (latitude, longitude, and altitude for the aircraft center-of-gravity (CG)), ground speed and heading, elapsed time along the route, and required time-of-arrivals (RTAs) at the final waypoint and at intermediate waypoints.

The starting point for the departure routes was an existing Geographical Position Marker (GPM) or "spot" just at the boundary of the maneuvering/non-maneuvering area. A two minute delay was assumed between initiation of the 'clock' and when taxi along the route was to begin based on adherence to the taxi clearance. The two minute delay was used as contingency to make sure the crews were ready to taxi (i.e., the route was understood, briefed, and all pre-taxi checklists completed).

Intermediate waypoints were selected from existing GPMs along the straight segments of the taxi route. Typically two were used. The intermediate waypoints were not identified to the pilots. The intermediate waypoints were primarily to improve the stability of the speed guidance in the surface STBO control law and also to try to create a more uniform speed trajectory profile along the entire route.

The final RTA was also at a GPM but not at the runway hold point. Previous testing [Foyle et al., 2011] has suggested that using a holding position as the RTA location can be problematic: (a) it can adversely influence or present conflicts for the pilots between meeting RTAs and braking procedures and adversely affect passenger comfort; and, (b) an aircraft may not be able to meet an RTA because the holding spot may already be occupied. For this test, the GPM at the RTA was not occupied by other traffic.

The final STBO guidance law was a very simple algorithm. More elaborate methods were tried in computing the speed commands and control laws and estimated times of arrival (ETAs), but in the end, the simple method was preferred for stability of guidance information, ease of implementation, and reductions in pilot workload - all without an observable loss in meeting RTA performance.

Ownship position was used for comparison against the stored planned data to find the *planned* trajectory information. From this, the ETA to the intermediate and final waypoint was calculated as:

$$ETA = (RTA_{planned} - Time_{planned}) + ElapsedTime;$$

where *ElapsedTime* was the time (sec) from the start of the run; $Time_{planned}$ was the planned elapsed time to this point along the trajectory (sec); and, $RTA_{planned}$ was the planned RTA to either the final or intermediate waypoint, whichever was relevant.

STBO speed guidance – the "advised speed" – was computed using a feedback control law:

$$V_{advised} = (K_{v\_i} * dTime_{\_i} + K_{v\_final} * dTime_{\_final} + V_{planned})$$

where $V_{advised}$ was the advised speed displayed to the pilot. This speed was simply the planned speed at the current ownship position ($V_{planned}$) with adjustment to that speed based upon the difference between the RTA and the ETA (i.e., RTA-ETA) at the intermediate ($dTime_{\_i}$) and final ($dTime_{\_final}$) waypoints. The gains, K_{v_final} and K_{v_i} , were equal to 0.25 fps/sec. The value for the gains was developed in simulation using SMEs. The advised speed was limited to maximum and minimum values: 30 kts and 10 kts, respectively, on straight segments and 10 kts and 4 kts in turns and was displayed to the flight crew in 2 knot increments.

The principal advantages to this method were that it relied significantly on the planned speed; yet it also reflected current ETA considerations at both the intermediate and final RTA points; it was quite stable since alternative methods using distance remaining can have stability and singularity concerns; and finally, it informed the pilot rather than guided the pilot. The gains based on the arrival time difference (i.e., RTA-ETA) effectively doubled in the last segment since, as noted in the equation above, the last *ith* segment ($dTime_i$) was identical to and used the final arrival time difference ($dTime_{final}$). Flight crews could easily modulate taxi speed to meet their RTAs and this control law did not require continual monitoring - this method provided subtle advisory information.

The crew was instructed that the advised GS (displayed in green at top left of AMM) was to be used as a reference for reaching the RTA point (green diamond near end of route) at the RTA (displayed in green at bottom of AMM display) and it was not required that they track the advised GS precisely. Acceptable performance was met if the time-of-arrival at the RTA end point was within +/- 15 seconds of the RTA (based on previous research [Foyle et al., 2011]. The ETA and seconds early or late was displayed at the bottom of the AMM in white to give the flight crew additional information on how well they were progressing along the route. If the crew were more than 15 seconds early or late, the words 'EARLY' or 'LATE' would also be displayed at the bottom of the AMM.

5.3.2 Part 2 Research Displays

Symbology was added to the basic AMM format and to the HUD to enable the flight crew to efficiently and safely conduct STBO taxi operations. Two AMM and two HUD display conditions were evaluated as described below.

The *Map C condition* consisted of a basic AMM format and added the display of textual STBO guidance information (advised GS, RTA, ETA, and seconds early or late), selected traffic information (call sign, aircraft type, bearing, heading, range from ownship, ground speed, and cleared taxi route), and the ownship cleared taxi route as a magenta line (Figure 19).

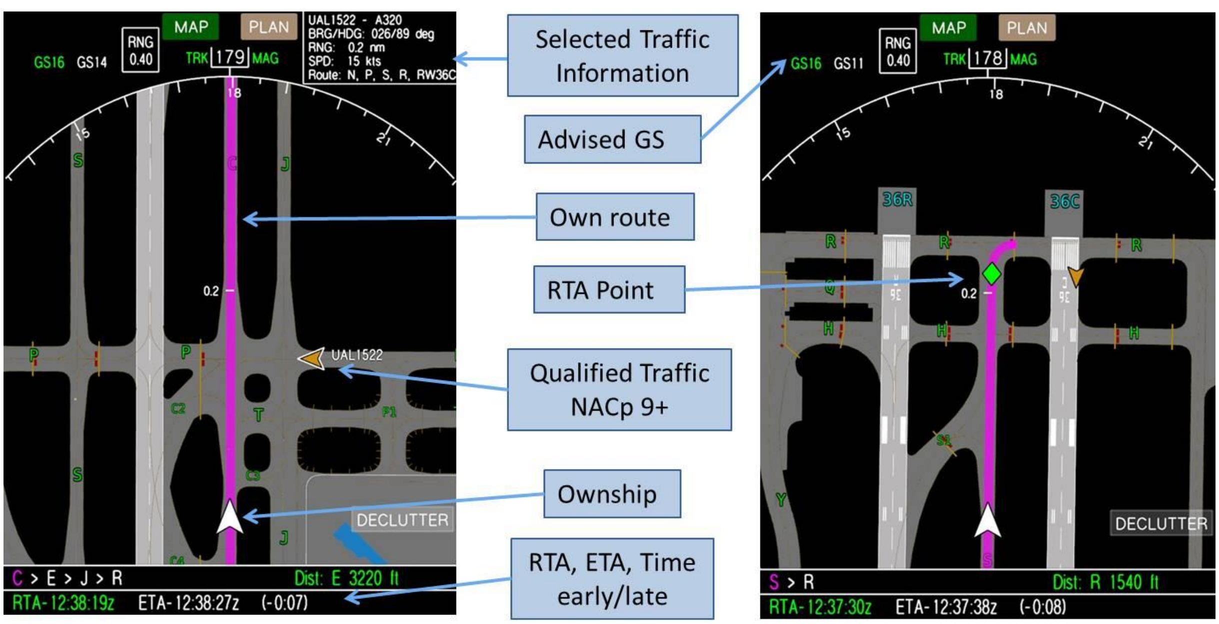


Figure 19. Map C Display Condition.

The crew had the capability to obtain selected traffic information (aircraft identification; bearing, heading, and range from ownship; ground speed; and cleared taxi route) by touching the traffic icon symbol on the AMM. The selected traffic information was displayed in white in the upper right corner of the AMM. By reading the traffic's cleared taxi route, the crew could figure out route conflicts with the ownship's cleared taxi route. For this study, the cleared taxi route was only available for traffic that could potentially conflict with ownship.

The *Map D condition* was created by the addition of graphical ownship and traffic intent and graphical traffic route (tan) (Figure 20).

Graphical intent information was displayed for both the ownship and selected traffic using solid and open circles. The solid traffic intent symbol gave an indication of where the aircraft should be positioned in 30 seconds to achieve the RTA according to the planned trajectory. The open trend symbol gave an indication of the position of the aircraft in 30 seconds based upon the current aircraft status (position and time). When the trend symbol surrounded the intent symbol, as shown in the left AMM image in Figure 20, the aircraft was precisely tracking the STBO clearance. If the trend symbol was displayed behind the intent symbol, as shown in the right AMM image in Figure 20, the aircraft was behind schedule and may reach the RTA point late. If the trend symbol was displayed ahead of the intent symbol, the aircraft was ahead of schedule and may reach the RTA point early.

The graphical taxi routes and intent, and STBO status information provided the capability to view the route conflicts at-a-glance rather than having to interpret the textual clearance in the information area to determine whether there was a potential conflict. By viewing the traffic's intent and trend symbols, it was obvious when a collision was predicted; the ownship and traffic intent and trend symbols were overlaid.

The HUD was used during a portion of the STBO taxi scenarios. The standard HUD surface symbology was used with the addition of the advised GS (displayed above the GS) (see Figure 21). This allowed the Captain to remain heads-up to view the STBO guidance. When test conditions did not require use of the HUD, the HUD was stowed so it would not be an influence or obstruction.

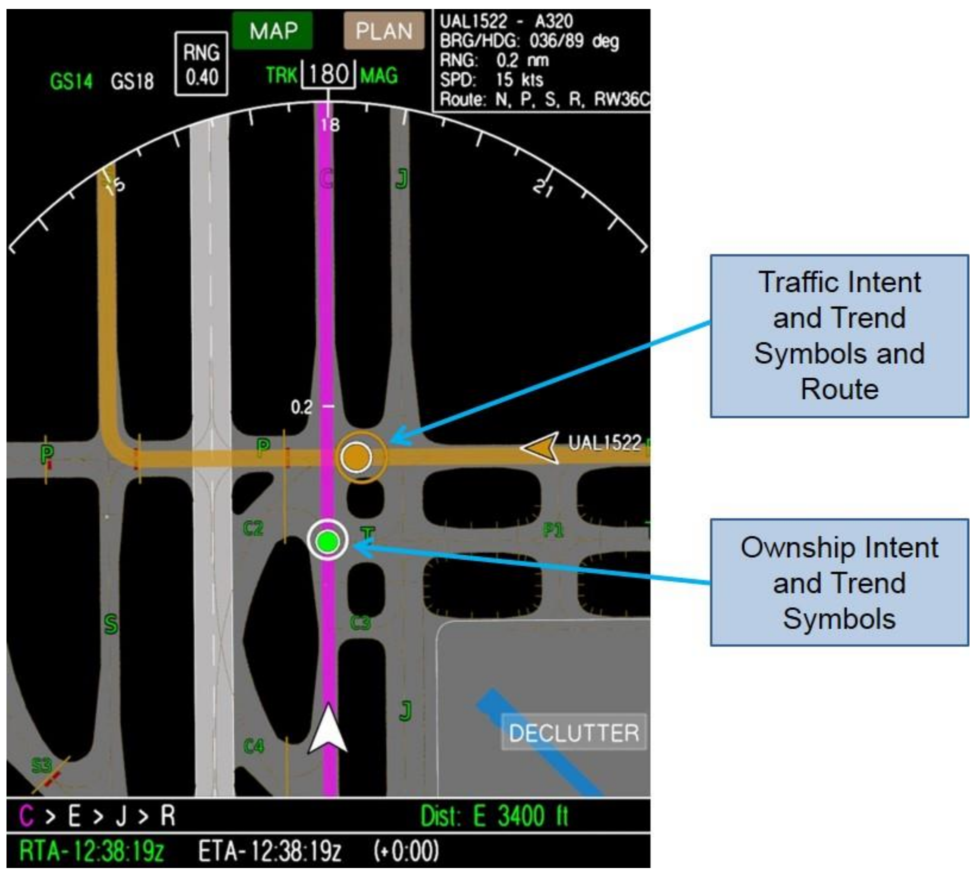


Figure 20. Map D Display Condition.

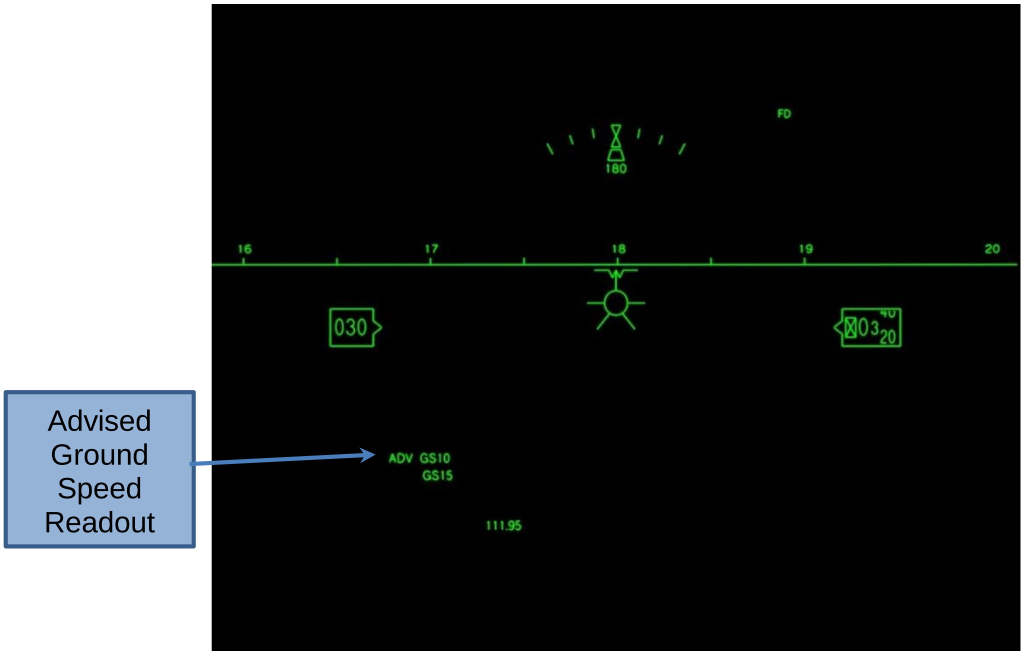


Figure 21. STBO Taxi Guidance Displayed on HUD.

5.3.3 Part 2 Test Matrix

A total of six trials (four nominal, two off-nominal) were conducted with each crew. All trials were conducted in daytime 1,800 ft visibility. Since STBO is an advanced operational concept, it was decided to follow ATSA-SURF and SURF-IA specifications regarding position accuracy; therefore, NACp8 accuracy was not used. Traffic was transmitting position accuracy ranges from NACp 9 to NACp 11; therefore, all the airport traffic was displayed on the AMM. ATC clearances were provided verbally via the voice generation system and via data-link. The full test matrix is shown in Appendix D.

Nominal trials evaluated the flight crew's performance in following STBO taxi guidance using HUD and AMM symbology. Two AMM conditions (Map C and Map D) were evaluated between subjects, using two HUD display conditions (HUD or no HUD) during departure taxi scenarios, for a total of four nominal trials (Appendix E). These display conditions were chosen to evaluate textual traffic intent information and ownship STBO guidance (Map C) versus graphical traffic intent information and ownship and traffic STBO guidance (Map D) and the utility of providing STBO guidance head-up. The STBO taxi scenarios began in the ramp; the crew was to follow the cleared taxi route and STBO guidance to the departure runway. The trial terminated once the aircraft stopped at the runway hold line. A detailed description of the STBO taxi procedure is given below.

Off-nominal trials were conducted between subjects to evaluate collision avoidance capability during STBO. The focus of the off-nominal scenarios was to determine the usefulness of traffic intent information for taxi collision avoidance and also the usefulness of CD&R for collision avoidance during STBO. Each crew completed two off-nominal trials as Test Runs 3 and 6 of six trials. The HUD was not utilized during the off-nominal trials. A detailed description of the off-nominal scenarios is given below. Each crew evaluated these two scenarios using either the Map C or D condition with conflict traffic transmitting either NACp 9 or NACp 10 position accuracy; therefore, three data points were collected for each combination of conditions. IAs were not issued for traffic transmitting NACp 9 position accuracy, but were issued for traffic transmitting NACp 10 position accuracy (as per DO-323) [RTCA, 2010b].

5.3.4 *Part 2 Conflict Scenarios*

Two taxi conflict scenarios were utilized. Every effort was made to produce similar timings; however, a certain amount of variability was naturally introduced due to the maneuvering conducted by the pilot (e.g., taxi speed).

5.3.4.1 *Taxi Head-On Conflict Scenario*

This scenario tested a potential head-on collision if no action were taken because the aircraft were given conflicting STBO taxi clearances.

An approach and departure flow was simulated. Traffic were approaching Runway 18R (three aircraft) (Figure 22, orange route) and Runway 18C (four aircraft) (Figure 22, orange dashed route), spaced 5 nm apart and staggered between runways. This traffic landed, exited the runway, and taxied to the terminal. Departure traffic (three aircraft) using Runway 18L were routed via the magenta and blue colored routes shown in Figure 22.

At the beginning of this scenario, the ownship was parked on the ramp near GPM 4W. The flight crew was cleared to taxi to Runway 18L via Taxiways A2, A, Y, and D (Figure 22, magenta route). As the ownship taxied on Taxiway A, an aircraft was taxiing toward the ownship on Taxiway A. Provided the flight crews of both aircraft followed the STBO guidance, the aircraft would collide at the intersection of Taxiways A and Y.

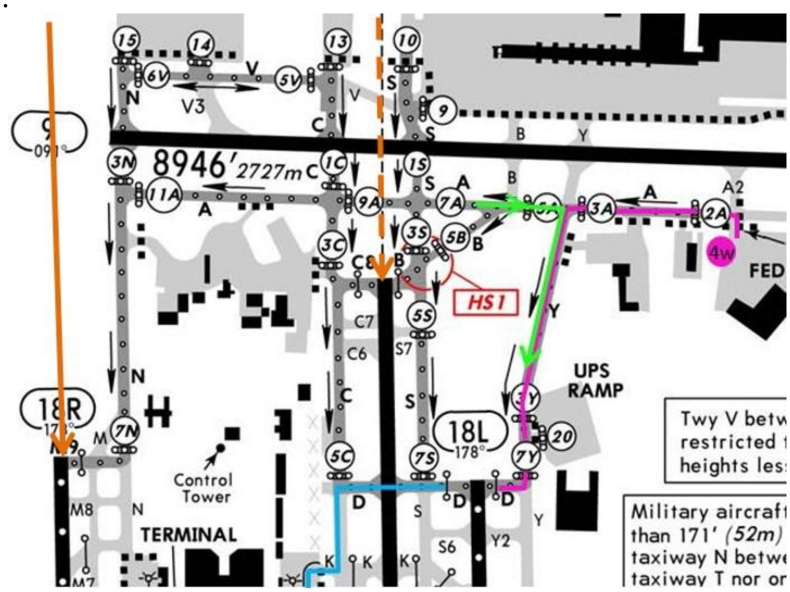


Figure 22. Part 2 Conflict Scenario, Taxi Head-On.

5.3.4.2 *Taxi Intersection Conflict Scenario*

In this scenario, both aircraft were given STBO taxi clearances that were conflict free, but the failure of the traffic aircraft to comply with its taxi clearance resulted in a taxiway intersection conflict.

The same approach and departure flow implemented for the Taxi Head-On scenario was used.

At the beginning of this scenario, the ownship was parked on the ramp near GPM 4W. The flight crew was cleared to taxi to Runway 18L via Taxiways A2, A, B, S, and D (Figure 23, magenta route). As the ownship taxied on Taxiway A, an aircraft was taxiing on Taxiway S from GPM 10, toward Taxiway A. The aircraft was given clearance to taxi to the terminal via Taxiways S, A, and N (Figure 23, green route). However, the flight crew blunders and continues straight on Taxiway S instead of turning onto Taxiway A. The aircraft conflicts with ownship at the intersection of Taxiways S and B, provided the subject flight crew followed their STBO guidance correctly.

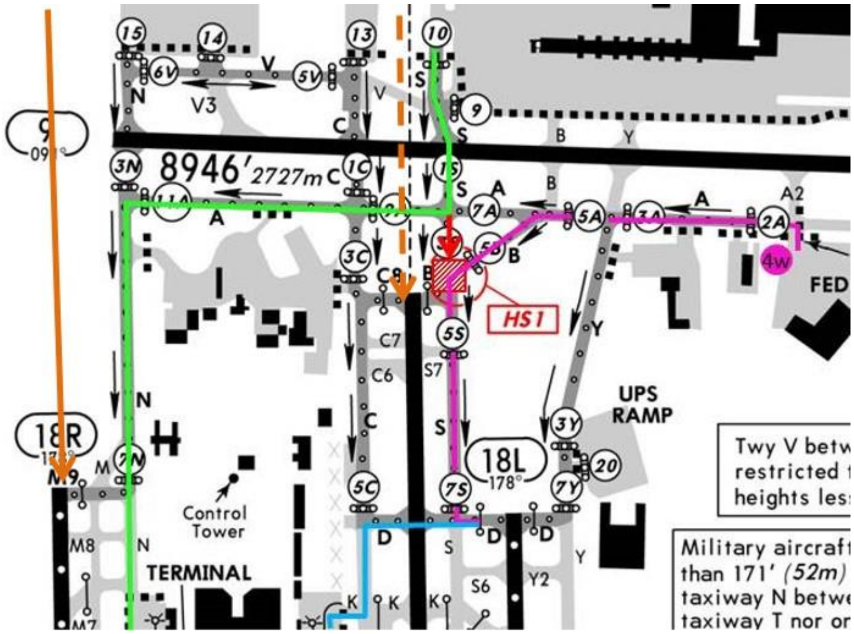


Figure 23. Part 2 Conflict Scenario, Taxi Intersection.

5.3.5 Part 2 Procedure

Prior to the testing phase, each test subject participated in a briefing and simulator training session. The training included specific items and procedures related to Part 2 testing, such as STBO taxi procedures, Map Conditions C or D depending on which map condition would be utilized by the crew, and CD&R capability during taxi operations.

Before each trial, the flight crew was briefed on the run conditions, e.g., departure runway, HUD utilization, and ATC radio frequencies. The case order list is shown in Appendix F.

STBO taxi operations began in the ramp area with an expected taxi clearance received by the ownship via data-link. An example data-link expected taxi clearance is as follows: “EXPECT TAXI TO RWY 36C FROM SPOT 30 VIA C, E, J, R WITH EXPECTED TAXI RELEASE TIME 12:32:00Z. MONITOR GROUND 121.9.” The expected taxi clearance was displayed as a dotted magenta line on the AMM (Figure 24). After acknowledging the expected taxi clearance by data-link, the flight crew taxied to the indicated GPM (also known as spot). After reaching the GPM, the actual taxi clearance was received via voice and data-link instructions. An example taxi clearance was: “TAXI RWY 36C BY 12:37:30Z VIA L-S-R. CROSS RWY 36C. TAXI RELEASE TIME 12:32:00Z.” The taxi clearance was displayed as a solid magenta line on the AMM (Figure 25). The crew was required to respond to the taxi clearance via voice and data-link. Investigation of taxi route modifications was not conducted; therefore, the expected and actual taxi clearances were always the same. The crew was to begin taxi as close as possible to the taxi release time and notify ATC they were commencing taxi. Once taxi began, the flight crew was requested to follow the taxi clearance and STBO guidance provided on the AMM and HUD, if utilized. The crews were instructed that acceptable performance was obtained if their RTA was met within +/- 15 seconds. The trial terminated once the aircraft stopped at the runway hold line

The test runs were documented via audio, video, and digital data recordings, and post-run and post-test questionnaires (see Appendices G, I, and J).

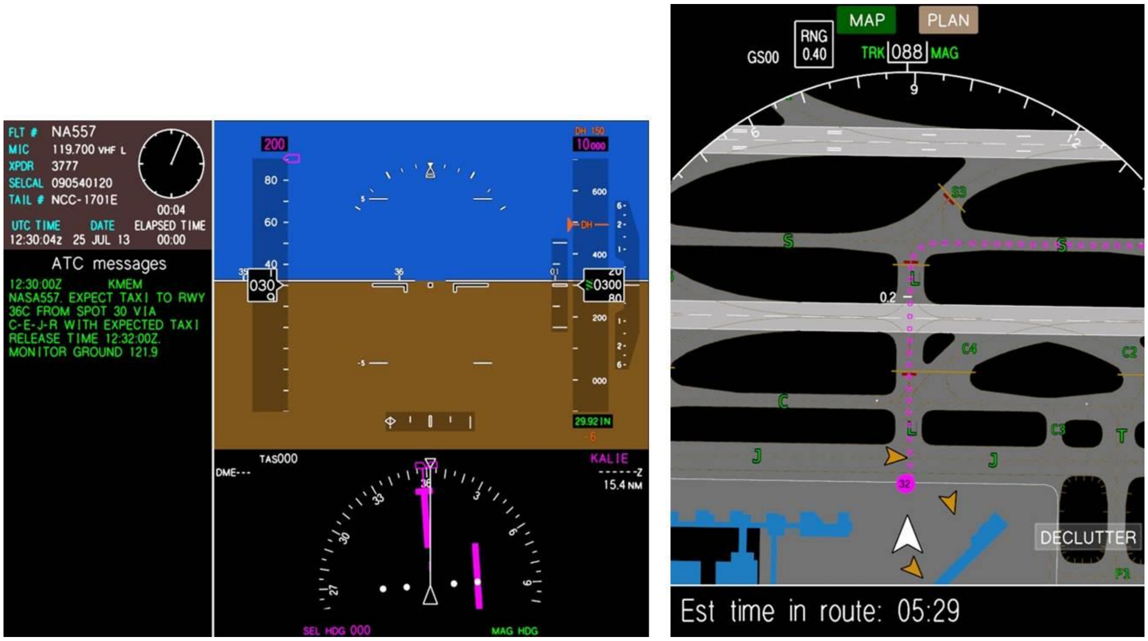


Figure 24. Expected Taxi Clearance Shown on PFD and AMM.

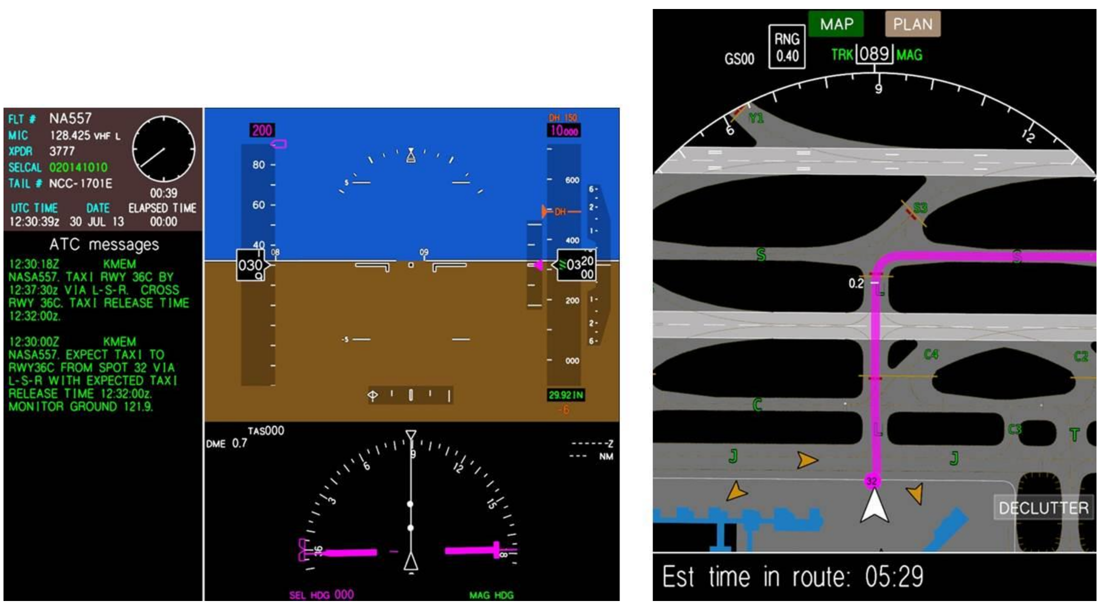


Figure 25. Taxi Clearance Shown on PFD and AMM.

5.4 Test Metrics

For runway conflicts, a near-collision was counted if the CG of the two aircraft were < 300 ft apart laterally and vertical separation was < 200 ft. A collision was counted if the aircraft were < 150 ft apart laterally and vertical separation was < 100 ft (Figure 26). The 150 ft collision separation corresponds to large aircraft with a wingspan and fuselage length of approximately 150 ft (which was used for this study). The 150 ft value also corresponds to the width of the simulated runway. Also, aircraft that are between the hold line and runway edge (150 ft distance for this study) are considered hazards and classified as near collisions.

For taxiway conflicts, a near-collision was counted if the aircraft CGs were < 185 ft apart laterally. A collision was counted if the aircraft CGs were < 150 ft apart laterally.

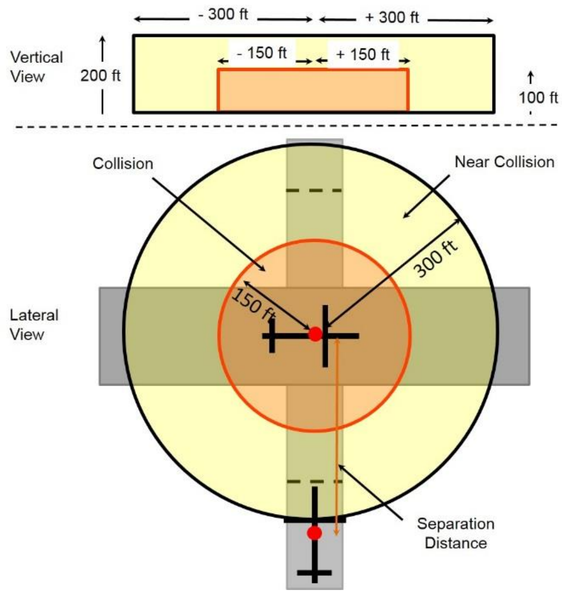


Figure 26. Near Collision and Collision Definition for Runway Conflicts.

6 Results

A summary of quantitative and qualitative results is presented for the Part 1 and Part 2 testing phases. All data are referenced from the aircraft CG. The data was analyzed using parametric and non-parametric statistics, as appropriate, using apriori level of significance of 0.05.

6.1 Part 1 Testing Results

6.1.1 Part 1 Off-Nominal Scenario Results

As described in the Test Method section, the test objective for six of the crews was to evaluate the impact of displaying qualified versus unqualified traffic on the AMM during conflict situations. These crews were given a taxi crossing and departure conflict scenario, using either Map A or B display condition (Table 3). The conflict traffic was transmitting NACp 8 position accuracy for all of these trials; therefore, IAs were not issued. When using Map A, the conflict traffic was not displayed on the AMM and could only be viewed OTW, if possible for the visibility conditions. When using Map B, the conflict traffic was displayed on the AMM and could also be viewed OTW.

When using the Map A condition, action was only taken to avoid the conflict traffic on one of six trials (17%) (Table 5). The flight crew was not aware of the conflict traffic on five of these trials and continued the operations, resulting in four collisions and one near-collision. On one trial, after seeing the traffic OTW on takeoff roll, a high speed rejected takeoff (131 kts) was conducted. The aircraft stopped just before reaching the traffic, resulting in a near-collision.

When using the Map B condition, action was taken on four of six trials (67%) (Table 5). For the taxi crossing scenario, one crew crossed the runway, unaware of the conflict traffic, resulting in a collision. This crew viewed the AMM for traffic, zooming out to the largest map scale; however, the map was scanned just before the traffic came into view. For the departure scenario, the crew that departed saw the traffic on the AMM but was not sure if the traffic was on the runway due to the traffic's position accuracy (crew commented that the aircraft symbol was "dancing" on the AMM).

Table 5. Part 1 Off-Nominal Scenario Results, Map Condition Focus.

	Taxi Crossing	Departure
Map A, NACp 8	3crossed: 2 collisions, 1 near-collision	2 departures, 1 high speed reject: 2 collisions, 1 near-collision
Map B, NACp 8	1 crossed, 2 held short: 1 collision	1 departure, 2 held in position: 1 collision

For the other six crews, the objective of the off-nominal trials was to evaluate the impact of receiving IAs versus not receiving them for traffic displayed on the AMM during conflict situations. These crews were given a taxi crossing and departure conflict scenario using the Map A display condition. The conflict traffic was transmitting either NACp 9 (no IAs) or NACp 10 (IAs issued) position accuracy (Table 4) and, therefore, was always displayed on the AMM.

When the conflict traffic was transmitting NACp 9 accuracy, no action was taken on three of six trials (50%) (Table 6). Two of the taxi crossing trials resulted in collisions; the crews did not see the traffic on the AMM and crossed the runway. Two of the departure trials also resulted in collisions. During one of the departure trials, the crew did see the conflict traffic on the AMM but they were not sure if the traffic was on the runway due to the traffic's position accuracy so they continued the departure. During the other departure trial, the crew saw the traffic OTW and conducted a high speed rejected takeoff (132 kts), having to veer to the right of the conflict traffic, which resulted in a collision.

When the conflict traffic was transmitting NACp 10 accuracy, action was taken to avoid the conflict on all six trials (Table 6). For the three taxi crossing trials, action was based on receiving RSIs. For the three departure trials, action was based on receiving a warning, receiving an RSI, and viewing the conflict traffic on the AMM.

Table 6. Part 1 Off-Nominal Scenario Results, NACp Focus.

	Taxi Crossing	Departure
Map A, NACp 9	2 crossed, 1 held short: 2 collisions	1 departure, 2 reject: 2 collisions
Map A, NACp 10	3 held short	1 held position, 2 rejected

6.1.1.1 <u>Taxi Crossing Off-Nominal Details</u>

The details of the taxi crossing off-nominal/conflict trials are presented in Table 7. The data shows that, with all traffic displayed and with an increase in position accuracy, the number of collisions/near-collisions were reduced. All trials in which the conflict traffic was not displayed on the AMM (Map A condition with conflict traffic transmitting NACp 8 position accuracy) resulted in a collision or near-collision (closest point of approach (CPA), mean (μ) = 129 ft, standard deviation (σ) = 123 ft). Collisions/near-collisions were reduced when all the traffic was displayed on the AMM and the flight crew viewed the conflict traffic on the AMM (Map B condition (CPA, μ = 331 ft, σ = 157 ft) and Map A condition with conflict traffic transmitting NACp 9 accuracy (CPA, μ = 209 ft, σ = 173 ft)). When IAs were issued (conflict traffic transmitting NACp 10 accuracy), there were no collisions or near-collisions because the flight crew became aware of the conflict traffic through RSIs (CPA, μ = 390 ft, σ = 87 ft). For all trials that resulted in a near collision or collision, the flight crew was not aware of the conflict traffic.

In Table 7, all distances are referenced to the CG (the CG of the ownship was 72.8 ft from the nose of the aircraft). For all trials but one in which the aircraft held short of the hold line (HL), the nose was well behind the HL (40 to 98 ft). In this one case, the nose did cross the HL (technically a runway incursion) but stopped 153 ft before reaching the runway edge.

IAs were possible on the conflict traffic on three taxi crossing trials (transmitting NACp 10 accuracy) (Table 8). A TI was generated on one trial, ~3.4 nm from the traffic, 213 ft prior to crossing the hold line.

An RSI was generated on all three trials, 10,341 ft mean distance from the traffic (σ = 7,373 ft), 206 ft mean distance (σ = 13.5 ft) prior to crossing the hold line. The large standard deviation was caused by the wide variability in taxi operations. One crew taxied slower than the planned 15 kts and reached the runway hold line when the traffic was only 2,586 ft from the ownship. In contrast, another crew generally taxied faster than the planned 15 kts and reached the runway hold line before conditions were met for IAs (TI and RSI later issued).

Table 7. Part 1 Taxi Crossing Scenario Results.

Map	NACp	Action	Outcome	CPA (feet)	CG Dist to HL (feet)	Traffic Awareness
A	8	Crossed Runway	Collision	21.3	N/A	Not Aware
A	8	Crossed Runway	Near-collision	262.9	N/A	Not Aware
A	8	Crossed Runway	Collision	104.1	N/A	Not Aware
B	8	Held Short	Stopped	385.3	134.5	AMM
B	8	Held Short	Stopped	452.9	114.6	AMM
B	8	Crossed Runway	Collision	154.4	N/A	Not Aware – early map check
A	9	Held Short	Stopped	400.1	156.4	AMM
A	9	Crossed Runway	Collision	161.9	N/A	Not Aware
A	9	Crossed Runway	Collision	63.9	N/A	Not Aware
A	10	Crossed HL	Stopped	299.1	19.0	RSI
A	10	Held Short	Stopped	398.2	113.6	RSI
A	10	Held Short	Stopped	471.4	171.1	RSI

Table 8. Part 1 Taxi Crossing Scenario Conflict Traffic IA Results.

Crew	IA	Distance from Traffic (feet)	Distance over HL (feet)	GS (kts)
12	TI	20,704.8	-212.6	6.3
4	RSI	2,585.9	-213.0	15.6
8	RSI	11,177.9	-214.0	6.9
12	RSI	17,259.6	-186.2	0

IAs were also generated for other traffic during the off-nominal trials. TIs were generated on all 12 taxi crossing trials for an aircraft that was landing behind the conflict traffic as ownship was crossing the runway (distance from traffic, μ = 35,222 ft, σ = 74 ft). One crew received an RSI on this same aircraft (distance from traffic, 17,147 ft). Three crews also received IAs on an aircraft parked at a gate in the ramp area (one caution, 49 ft from traffic; two warnings, μ = 265 ft, σ = 1.7 ft from traffic). Even though the static traffic was transmitting NACp 10 position accuracy, for these trials, there was a larger error on the position data, placing the aircraft closer to the path of the ownship. Since aircraft can be closer together in the congested ramp area, perhaps IAs should be inhibited in the ramp area to minimize nuisance alerting caused by position data inaccuracies.

6.1.1.2 __Departure Off-Nominal Details__

The details of the departure conflict trials are presented in Table 9. As with the taxi crossing trials, the number of collisions/near-collisions were reduced when all traffic were displayed and position accuracy was increased. All trials in which the conflict traffic was not displayed on the AMM (Map A condition with conflict traffic transmitting NACp 8 position accuracy) resulted in a collision or near-collision (CPA μ = 135 ft, σ = 84 ft); two crews were not aware of the conflict traffic and one crew saw the traffic OTW and rejected the takeoff but came close enough to ownship for a near collision to be counted. Collisions/near-collisions were reduced when all the traffic was displayed on the AMM and the flight crew was able to view the conflict traffic on the AMM (Map B condition (CPA μ = 2,781 ft, σ =

2,345.) and Map A condition with conflict traffic transmitting NACp 9 accuracy (CPA μ = 975 ft, σ = 1,431 ft)). However, when IAs were issued (traffic transmitting NACp 10 accuracy), there were no collisions or near-collisions (CPA μ = 3,006 ft, σ = 1,465 ft). For these three trials, two crews became aware of the conflict traffic through IAs; however, one crew became aware by viewing the traffic on the AMM. The CPA distance varied greatly depending on the action of the pilot. Also, in all trials in which the aircraft took-off, the collision occurred just after liftoff when the aircraft was 40 ft or less above ground level (AGL).

Based on these departure test trials, the pilots rejected the takeoff sooner when traffic awareness occurred based on either viewing the conflict traffic on the AMM or when IAs were issued. By the time the conflict traffic could be viewed OTW, it was too late to conduct a successful high speed rejected takeoff (RTO) resulting in a collision and near-collision.

IAs were possible on the conflict traffic on three departure trials (transmitting NACp 10) (Table 10). An RSI was generated on one trial prior to receiving a warning alert, 4,269 ft from the traffic, when traveling 21 kts. A warning alert was generated on two trials, 3,898 ft mean distance from the traffic (σ = 298 ft), when traveling 51 kts mean (σ = 15 kts). After initiating an RTO/stop, an RSI was generated on all three departure trials (distance from traffic, μ = 3,338 ft, σ = 1,043 ft; GS, μ = 25 kts, σ = 16 kts).

Table 9. Part 1 Departure Scenario Results.

Map	NACp	Action	Outcome	CPA (feet)	RTO GS (kts)	AGL at collision (feet)	Traffic Awareness
A	8	Took-off	Collision	44.0	N/A	2.7	Not Aware
A	8	TO roll	RTO – Near-collision	209.9	131	N/A	OTW
A	8	Took-off	Collision	151.3	N/A	11.3	Not Aware
B	8	Held Position	Stopped	4,054.4	N/A	N/A	AMM
B	8	Held Position	Stopped	4,214.1	N/A	N/A	AMM
B	8	Took-off	Collision	74.6	N/A	39.6	Map but unsure due to reduced accuracy
A	9	Start TO	RTO	2,626.5	35	N/A	AMM
A	9	TO roll	RTO-Collision	169.4	132	0	OTW
A	9	Took-off	Collision	128.3	N/A	34.7	Map but unsure due to reduced accuracy
A	10	Initial roll	Stopped	4,240.8	N/A	N/A	AMM
A	10	Start TO	RTO-Stopped	1,386.8	93	N//A	Warning
A	10	Start TO	RTO-Stopped	3,390.9	47	NA	RSI, but got Warning

Table 10. Part 1 Departure Scenario Conflict Traffic IA Results.

Crew	IA	Distance from Traffic (feet)	Ground Speed (kts)
10	RSI	4,268.7	21.0
6	Warning	3,687.8	62.2
10	Warning	4,109.1	40.6
6	RSI	2,218.5	30.5
10	RSI	3,514.5	37.0
2	RSI	4,281.9	7.3

6.1.2 Part 1 Qualitative Results

Post-run and post-test questionnaires were administered. The questionnaires were constructed and briefed to all pilot participants that the questionnaire properties were interval in nature, thereby allowing parametric statistics to be performed. Multivariate Analysis of Variance (MANOVA) and subsequent omnibus Analysis of Variance (ANOVA) were conducted on the applicable questionnaire responses. Only statistically significant results are presented at the $p < 0.05$ level.

6.1.2.1 Part 1 Run Questionnaire Results

At the end of each test trial, the evaluation pilots completed a post run questionnaire (Appendix G, Table G.1), a Situation Awareness Rating Technique (SART) [Taylor, 1990] questionnaire (Appendix G, Table G.3) to evaluate situation awareness, and a Task Load Index (TLX) workload [Hart and Staveland, 1988] questionnaire (Appendix G, Table G.4) to rate workload. The individual post run questionnaire items were grouped according to pre-test subject matter expert reviews and on exploratory factor analysis that resulted in several constructs that have similar underlying meaning. The individual questions and the grouped questionnaire constructs were analyzed. The MANOVA revealed significant main effects for Map and NACp condition that were further analyzed using ANOVAs.

6.1.2.1.1 Post Run Questionnaire

The post run questions were rated on a scale of 1 (strongly disagree) to 7 (strongly agree).

Question A. I was aware of ownship position.

For the nominal test trials, there was not a significant main effect for Map condition, $F(1, 188) = 2.707$, $p = 0.102$ (Appendix H, Table H.1) for Question A responses. Pilots reported a slightly higher mean rating for the Map A condition (showed only qualified traffic) ($\mu = 6.8$, $\sigma = 0.5$) than the Map B condition (showed all traffic) ($\mu = 6.5$, $\sigma = 0.7$) (Appendix H, Table H.2) for providing ownship position awareness; however, ownship position information was presented in the same manner for both Map conditions. The number of responses for each rating value is presented in Figure 27.

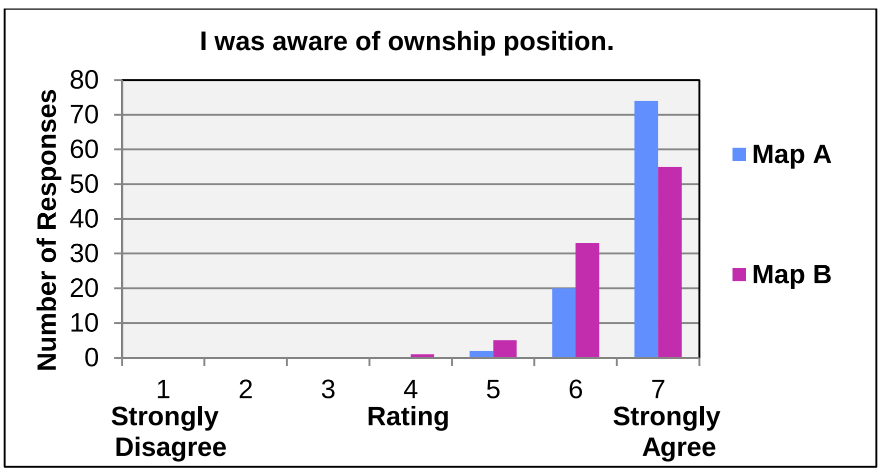


Figure 27. Question A Data for Part 1 Nominal Trials (N = 96).

Question A responses were analyzed by Map condition for the off-nominal trials and a marginally insignificant main effect was found, $F(1, 22) = 3.667$, $p = 0.069$ (Appendix H, Table H.3). The flight crews reported a slightly higher mean rating for the Map A condition ($\mu = 7.0$, $\sigma = 0.0$) than for the Map

B condition (μ = 6.8, σ = 0.5) (Appendix H, Table H.4). The number of responses for each rating value is presented in Figure 28.

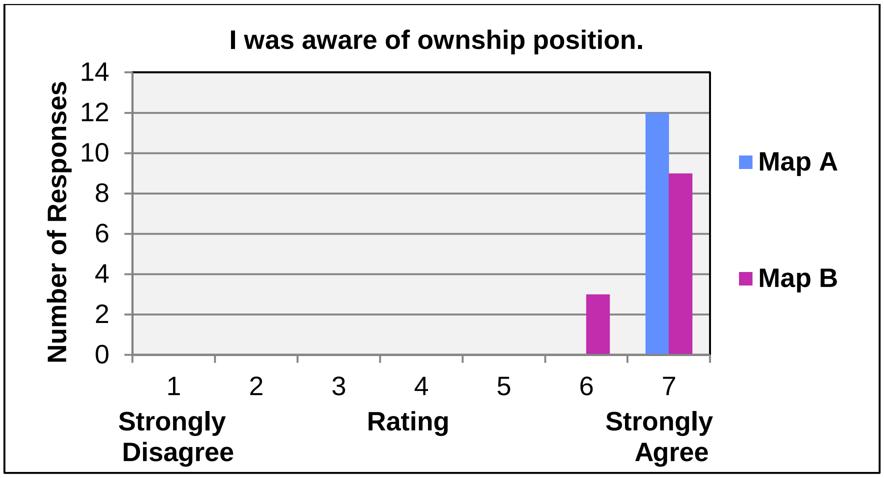


Figure 28. Question A Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic (N = 12).

For the off-nominal trials, Question A responses were also analyzed by NACp condition (NACp 8, 9, and 10) and a significant main effect was found, $F(2, 33) = 3.882$, $\underline{p} = 0.031$ (Appendix H, Table H.5). The NACp 8 condition (μ = 7.0, σ = 0.0) was rated higher than the NACp 9 condition (μ = 6.3, σ = 0.9) but not higher than the NACp 10 condition (μ = 6.7, σ = 0.5) (Appendix H, Table H.6); the NACp 9 condition was not significantly different from the NACp 10 condition. The number of responses for each rating value is presented in Figure 29.

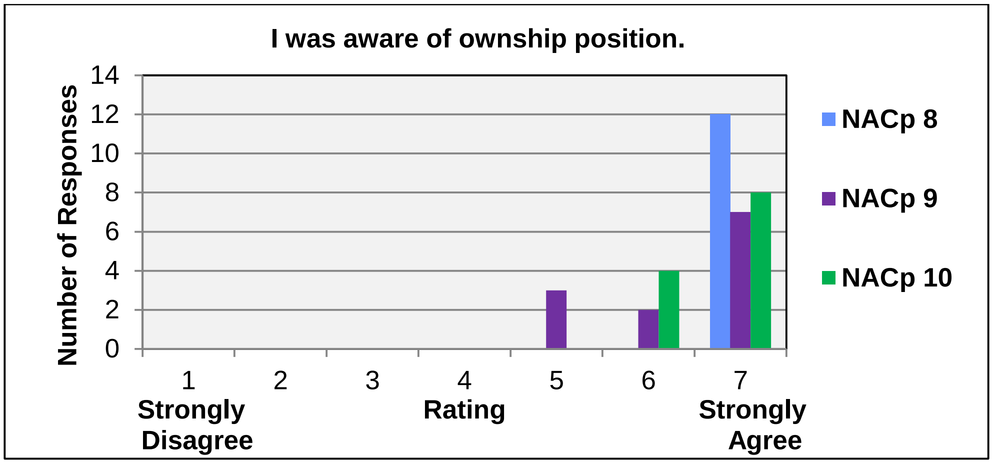


Figure 29. Question A Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic (N = 12).

It should be noted that for all conditions analyzed (Map A and B, NACp 8, 9, and 10), the same ownship position information (ownship chevron displayed on airport map layout) was available. The difference in these conditions was the display of qualified (Map A and B) vs unqualified (Map B only) traffic and the display of conflict traffic on the AMM. Traffic reporting NACp 8 accuracy were not displayed on the AMM; traffic reporting NACp 9 accuracy were displayed on the AMM but IAs were not issued; traffic reporting NACp 10 accuracy were displayed on the AMM and IAs were issued.

Question B. I was aware of traffic and other vehicles during operations.

For the nominal test trials, there was not a significant main effect for Map condition, $F(1, 188) = 0.466$, $p = 0.496$ (Appendix H, Table H.7) for Question B responses. Pilots reported identical mean ratings for both the Map A condition ($\mu = 6.1$, $\sigma = 0.8$) and the Map B condition ($\mu = 6.1$, $\sigma = 1.0$) (Appendix H, Table H.8) for providing traffic position awareness, even though all airport traffic was not displayed on the AMM when using the Map A condition. The number of responses for each rating value is presented in Figure 30.

Question B responses were analyzed by Map condition for the off-nominal trials and a significant main effect was found, $F(1, 22) = 7.954$, $p = 0.010$ (Appendix H, Table H.9). The pilots reported the Map A condition ($\mu = 3.0$, $\sigma = 2.1$) as significantly lower than the Map B condition ($\mu = 5.4$, $\sigma = 2.1$) (Appendix H, Table H.10). This was most likely due to the fact that the conflict traffic was not always displayed on the AMM when using the Map A condition. The number of responses for each rating value is presented in Figure 31.

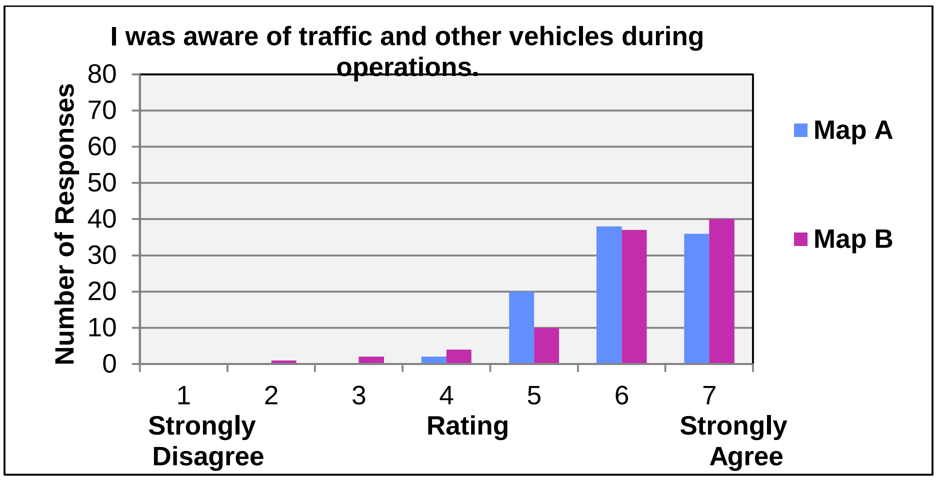


Figure 30. Question B Data for Part 1 Nominal Trials (N = 96).

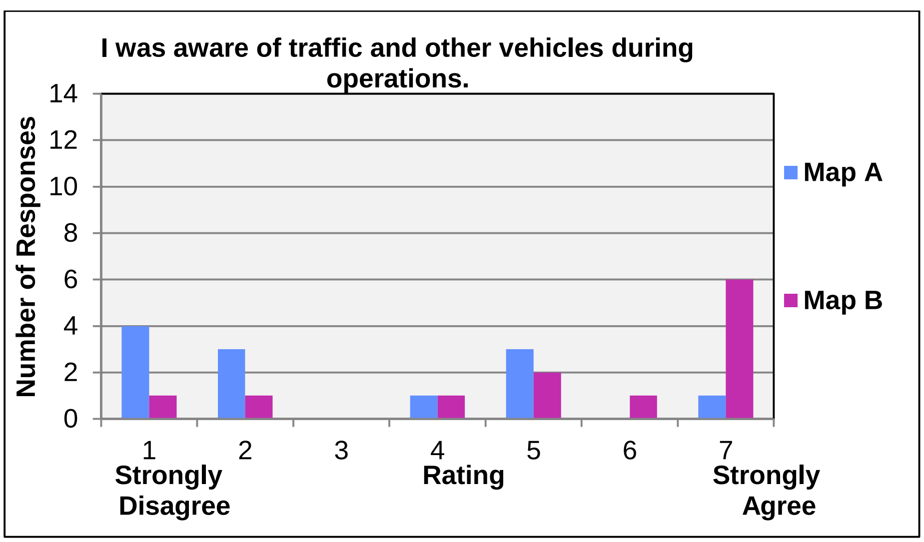


Figure 31. Question B Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic (N = 12).

For the off-nominal trials, Question B responses were also analyzed by NACp condition (NACp 8, 9, and 10) and a significant main effect was found, $F(2, 33) = 10.271$, $p = 0.000$ (Appendix H, Table H.11). The NACp 8 condition ($\mu = 3.0$, $\sigma = 2.1$) was rated lower than the NACp 9 condition ($\mu = 4.4$, $\sigma = 1.7$) and the NACp 10 condition ($\mu = 6.1$, $\sigma = 1.1$) (Appendix H, Table H.12); the NACp 9 condition was rated lower than the NACp 10 condition. When the conflict traffic was transmitting NACp 8 position accuracy, the traffic was not displayed on the AMM. The conflict traffic was displayed on the AMM when it was transmitting NACp 9 accuracy; however, IAs were not issued. When transmitting NACp 10 accuracy, the conflict traffic was displayed on the AMM and IAs were issued, providing the most information about the traffic. The number of responses for each rating value is presented in Figure 32.

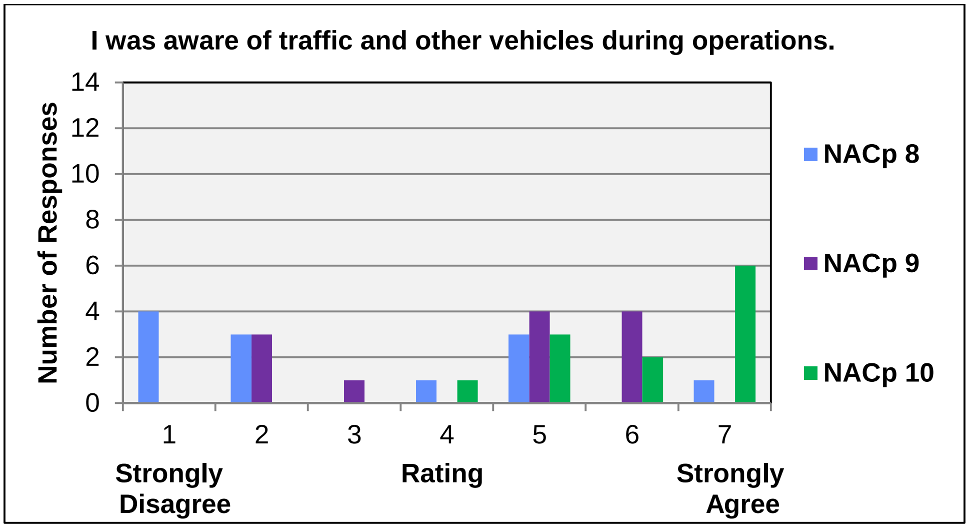


Figure 32. Question B Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic (N = 12).

Question C. The display concepts were effective for management of mental workload.

For the nominal test trials, there was not a significant main effect for Map condition, $F(1, 188) = 0.338$, $p = 0.562$ (Appendix H, Table H.13) for Question C responses. Flight crews reported similar mean ratings for the Map A condition ($\mu = 6.1$, $\sigma = 0.8$) and for the Map B condition ($\mu = 6.0$, $\sigma = 1.1$) (Appendix H, Table H.14) for managing mental workload. The number of responses for each rating value is presented in Figure 33.

Question C responses were analyzed by Map condition for the off-nominal trials and no statistically significant effects were found, $F(1, 22) = 1.665$, $p = 0.210$ (Appendix H, Table H.15). The pilots reported a slightly lower mean rating for the Map A condition ($\mu = 5.2$, $\sigma = 1.8$) than for the Map B condition ($\mu = 5.9$, $\sigma = 1.0$) (Appendix H, Table H.16). The number of responses for each rating value is presented in Figure 34.

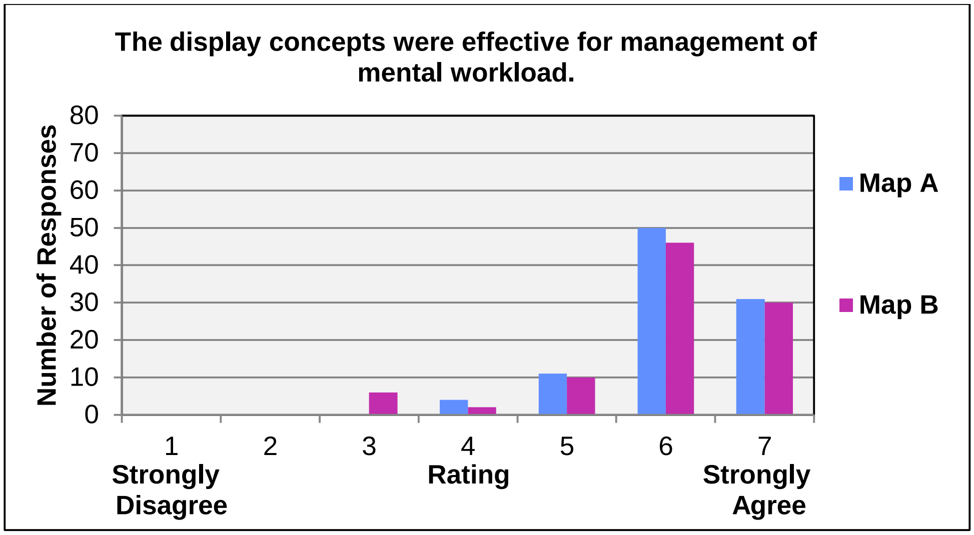


Figure 33. Question C Data for Part 1 Nominal Trials (N = 96).

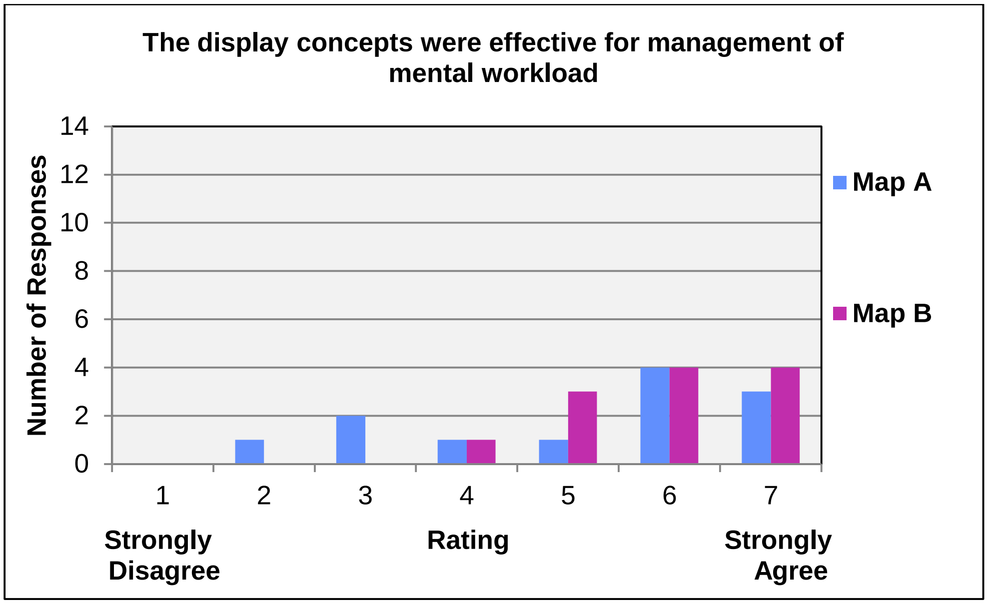


Figure 34. Question C Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic (N = 12).

Question C responses were also analyzed by NACp condition (NACp 8, 9, and 10) for the off-nominal trials and no statistically significant effects were found, $F(2, 33) = 1.179$, $\underline{p} = 0.320$ (Appendix H, Table H.17). The mean ratings for each NACp condition were as follows: NACp 8 condition ($\mu = 5.2$, $\sigma = 1.8$), NACp 9 condition ($\mu = 5.0$, $\sigma = 1.4$) and NACp 10 condition ($\mu = 5.8$, $\sigma = 0.9$) (Appendix H, Table H.18). The number of responses for each rating value is presented in Figure 35.

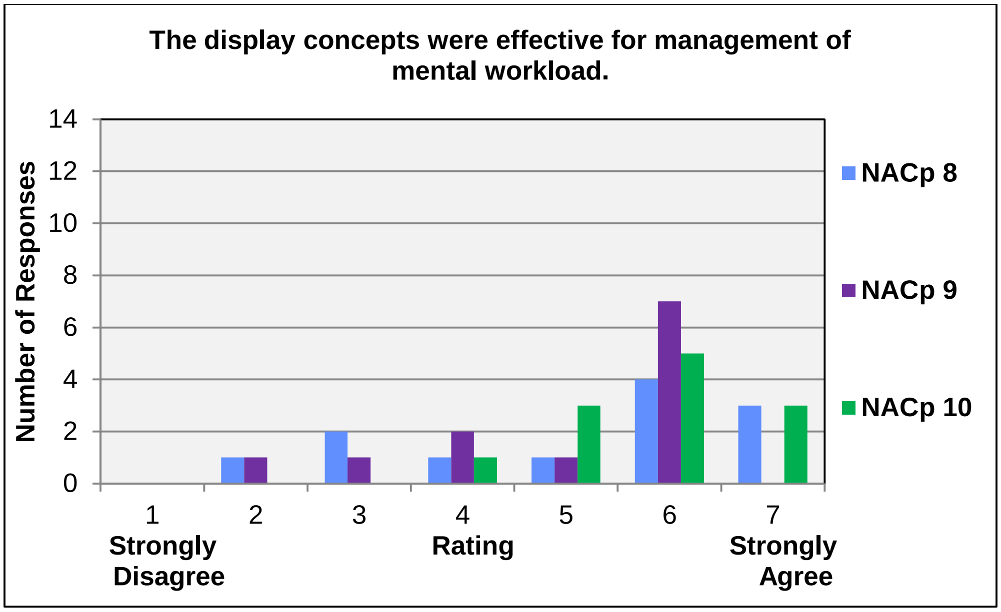


Figure 35. Question C Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic (N = 12).

Question D. The display concepts contributed to communication effectiveness (ATC and flight crew).

For the nominal test trials, there was not a significant main effect for Map condition, $F(1, 188) = 0.001$, $p = 0.981$ (Appendix H, Table H.19) for Question D responses. Flight crews reported similar mean ratings for the Map A condition ($\mu = 6.1$, $\sigma = 0.7$) and for the Map B condition ($\mu = 6.0$, $\sigma = 1.1$) (Appendix H, Table H.20) for communication effectiveness. The number of responses for each rating value is presented in Figure 36.

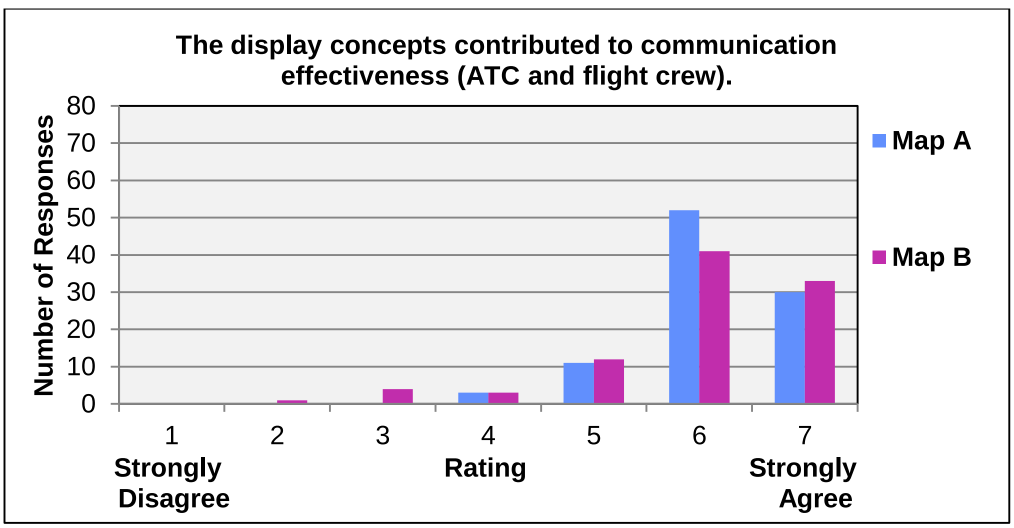


Figure 36. Question D Data for Part 1 Nominal Trials (N = 96).

Question D responses were analyzed by Map condition for the off-nominal trials and no statistically significant effects were found, $F(1, 22) = 1.774$, $p = 0.196$ (Appendix H, Table H.21). The pilots reported a slightly lower mean rating for the Map A condition ($\mu = 5.2$, $\sigma = 1.8$) than for the Map B condition ($\mu = 6.0$, $\sigma = 1.3$) (Appendix H, Table H.22). The number of responses for each rating value is presented in Figure 37.

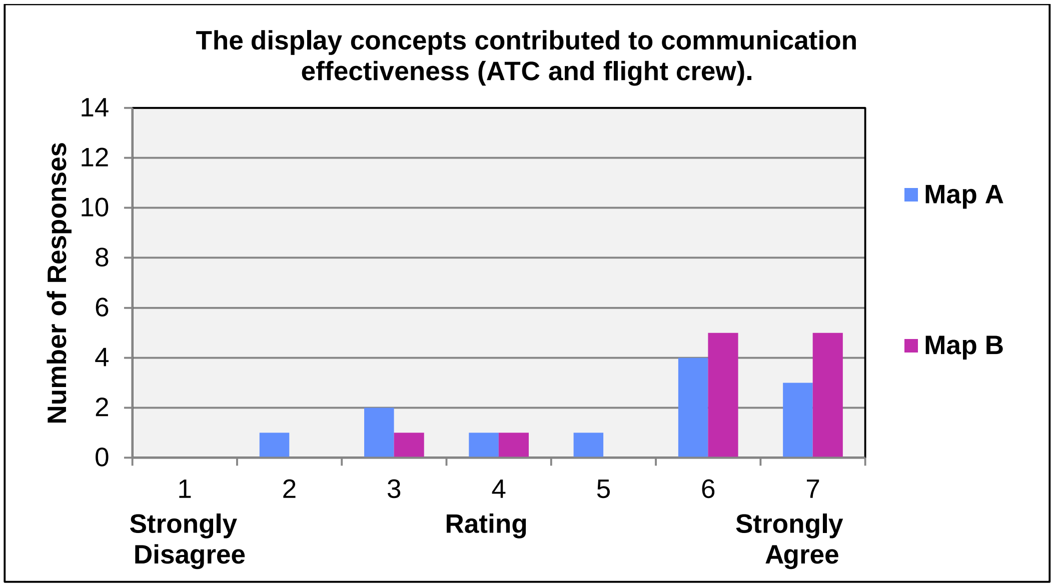


Figure 37. Question D Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic (N = 12).

Question D responses were also analyzed by NACp condition (NACp 8, 9, and 10) for the off-nominal trials and no statistically significant effects were found, $F(2, 33) = 2.049$, $p = 0.145$ (Appendix H, Table H.23). The mean ratings for each NACp condition were as follows: NACp 8 condition ($\mu = 5.2$, $\sigma = 1.8$), NACp 9 condition ($\mu = 5.1$, $\sigma = 1.4$) and NACp 10 condition ($\mu = 6.1$, $\sigma = 0.7$) (Appendix H, Table H.24). The number of responses for each rating value is presented in Figure 38.

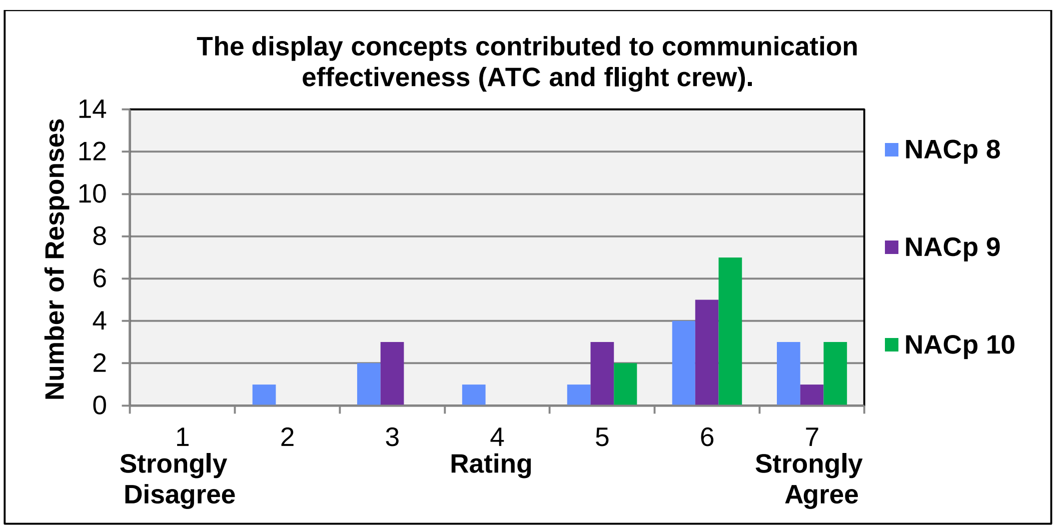


Figure 38. Question D Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic (N = 12).

Question E. The display promoted effective crew resource management, coordination, and cohesion.

For the nominal test trials, there was not a significant main effect for Map condition, $F(1, 188) = 2.843$, $p = 0.093$ (Appendix H, Table H.25) for Question E responses. Flight crews reported a slightly higher mean rating for the Map A condition ($\mu = 6.2$, $\sigma = 0.8$) than for the Map B condition ($\mu = 5.9$, $\sigma = 1.1$) (Appendix H, Table H.26) for effective crew resource management, coordination, and cohesion. The number of responses for each rating value is presented in Figure 39.

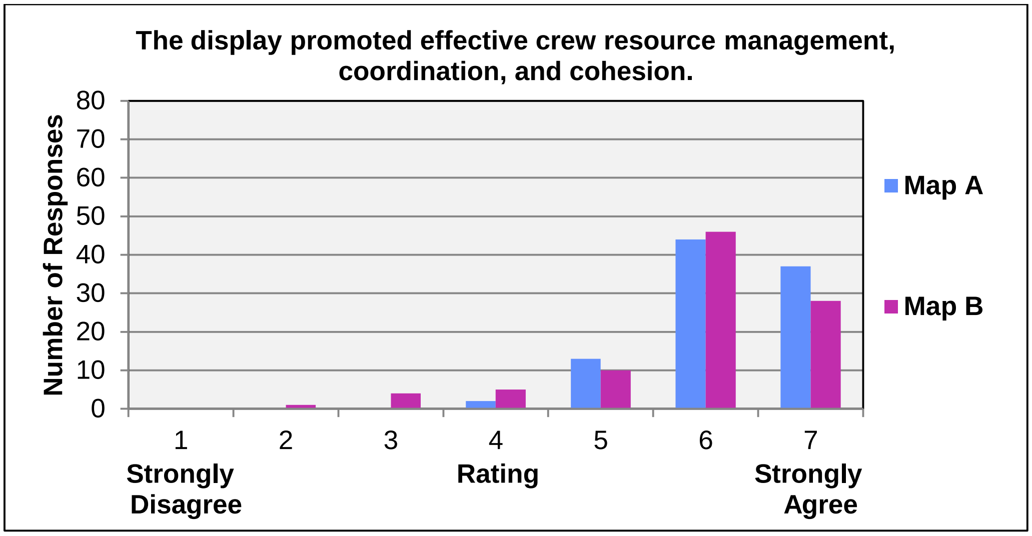


Figure 39. Question E Data for Part 1 Nominal Trials (N = 96).

Question E responses were analyzed by Map condition for the off-nominal trials and no significantly different effects were found, $F(1, 22) = 1.276$, $p = 0.271$ (Appendix H, Table H.27). The pilots reported a lower mean rating for the Map A condition ($\mu = 4.8$, $\sigma = 2.1$) than for the Map B condition ($\mu = 5.7$, $\sigma = 1.8$) (Appendix H, Table H.28). The number of responses for each rating value is presented in Figure 40.

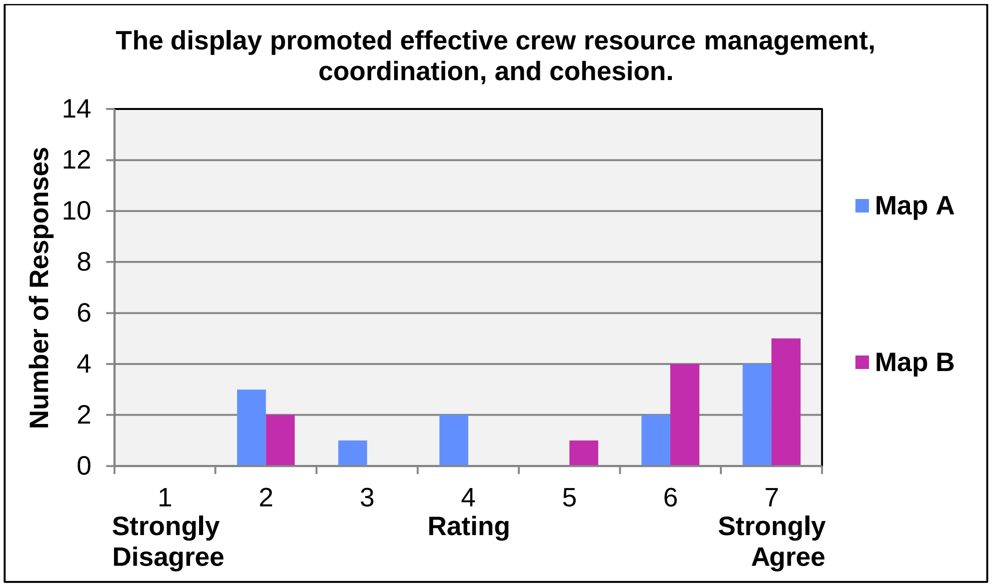


Figure 40. Question E Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic (N = 12).

For the off-nominal trials, Question E responses were also analyzed by NACp condition (NACp 8, 9, and 10) and a significant main effect was found, $F(2, 33) = 3.878$, $p = 0.031$ (Appendix H, Table H.29). The NACp 8 condition ($\mu = 4.8$, $\sigma = 2.1$) was not significantly different from the NACp 9 condition ($\mu = 5.1$, $\sigma = 1.7$); the NACp 8 and NACp 9 conditions were rated lower than the NACp 10 condition ($\mu = 6.5$, $\sigma = 0.7$) (Appendix H, Table H.30). The number of responses for each rating value is presented in Figure 41.

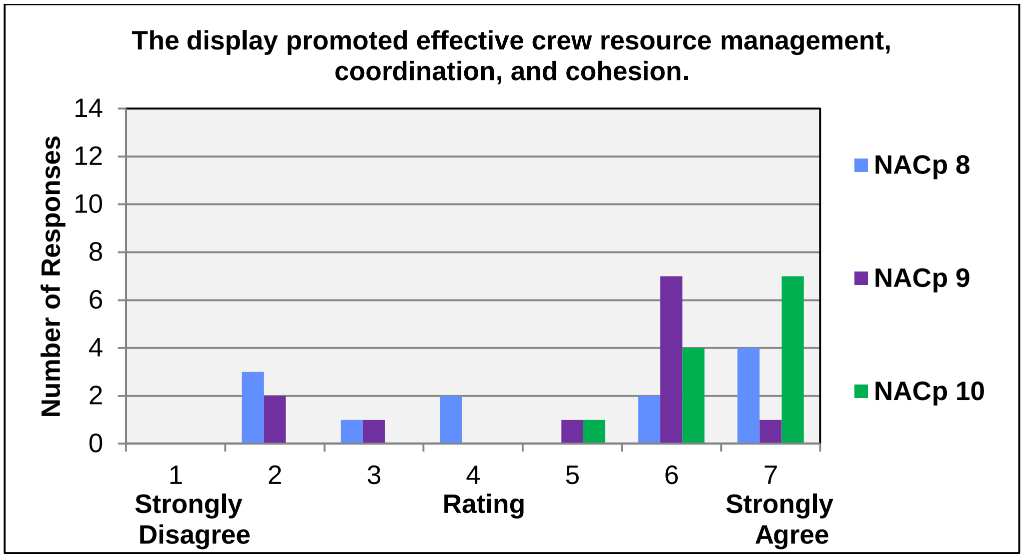


Figure 41. Question E Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic (N = 12).

Question F. The display concepts contributed to perceived safety during operation.

For the nominal test trials, there was not a significant main effect for Map condition, $F(1, 188) = 0.268$, $p = 0.605$ (Appendix H, Table H.31) for Question F responses. Flight crews reported similar mean ratings for the Map A condition ($\mu = 6.2$, $\sigma = 0.8$) and for the Map B condition ($\mu = 6.0$, $\sigma = 1.0$) (Appendix H, Table H.32) for contributing to perceived safety. The number of responses for each rating value is presented in Figure 42.

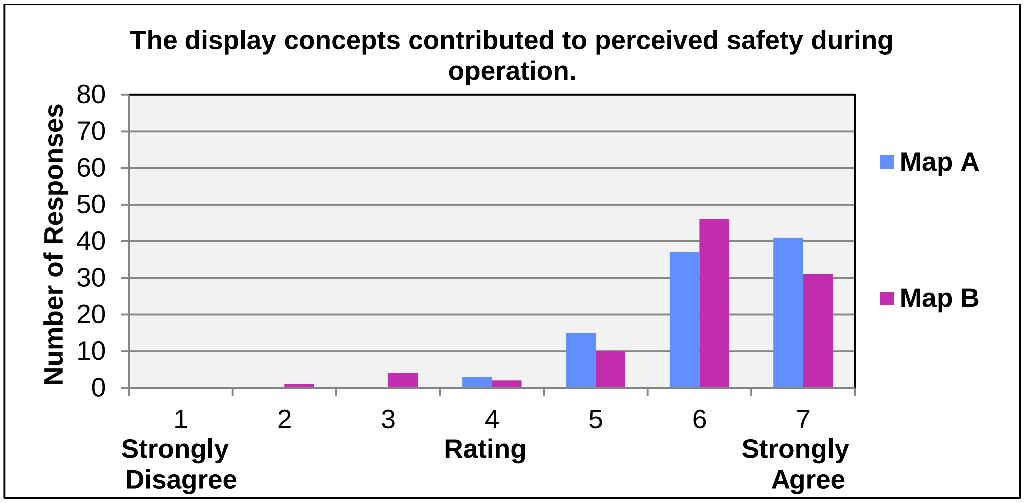


Figure 42. Question F Data for Part 1 Nominal Trials (N = 96).

Question F responses were analyzed by Map condition for the off-nominal trials and no statistically significant effects were found, $F(1, 22) = 2.179$, $p = 0.154$ (Appendix H, Table H.33). The pilots reported a lower mean rating for the Map A condition ($\mu = 3.9$, $\sigma = 2.5$) than for the Map B condition ($\mu = 5.3$, $\sigma = 2.2$) (Appendix H, Table H.34). However, due to the large variance in ratings, the statistical analysis failed to find a significant effect. The number of responses for each rating value is presented in Figure 43.

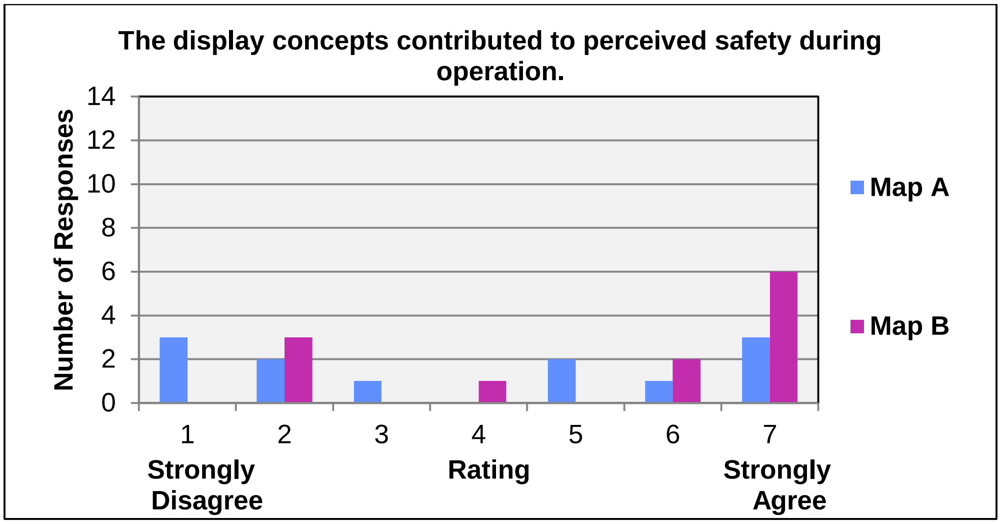


Figure 43. Question F Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic (N = 12).

For the off-nominal trials, Question F responses were also analyzed by NACp condition (NACp 8, 9, and 10) and a significant main effect was found, $F(2, 33) = 8.023$, $p = 0.001$ (Appendix H, Table H.35). The NACp 8 condition ($\mu = 3.9$, $\sigma = 2.5$) was rated lower than the NACp 9 condition ($\mu = 5.1$, $\sigma = 1.6$) and NACp 10 condition ($\mu = 6.8$, $\sigma = 0.5$) (Appendix H, Table H.36); the NACp 9 condition was rated lower than the NACp 10 condition. The number of responses for each rating value are presented in Figure 44.

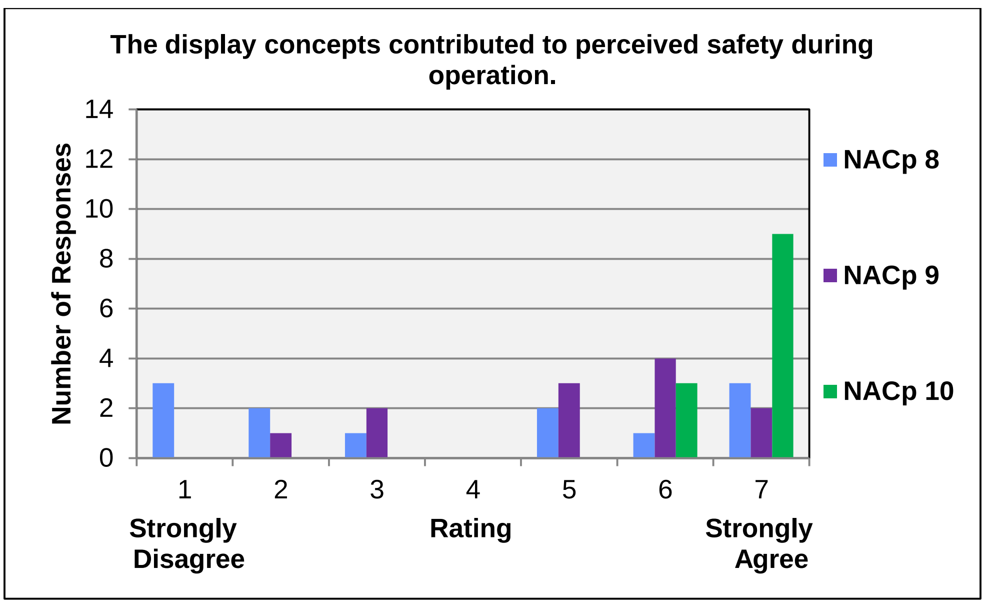


Figure 44. Question F Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic (N = 12).

Question G. The display concepts were effective for detection of potential surface conflicts.

Question G was only administered during the off-nominal test trials since these were the scenarios in which surface conflicts occurred. Question G responses were analyzed by Map condition and statistically significant effects were found, $F(1, 22) = 53.790$, $\underline{p} = 0.0001$ (Appendix H, Table H.37). The pilots rated the Map B condition ($\mu = 5.3$, $\sigma = 1.9$) as significantly better for detection of potential surface conflicts than the Map A condition ($\mu = 1.3$, $\sigma = 0.5$) (Appendix H, Table H.38). This was due to the fact that all airport traffic was displayed on the AMM for the Map B condition but only qualified traffic (NACp 9 and higher) was displayed on the AMM for the Map A condition. As a result, the possibility exists that the flight crew may not be aware of potential traffic when using the Map A condition (showing only qualified traffic), particularly if visibility is low and traffic cannot be visually acquired OTW. The number of responses for each rating value is presented in Figure 45.

For the off-nominal trials, Question G responses were also analyzed by NACp condition (NACp 8, 9, and 10) and a significant main effect was found, $F(2, 33) = 50.229$, $\underline{p} = 0.000$ (Appendix H, Table H.39). The NACp 8 condition ($\mu = 1.3$, $\sigma = 0.5$) was rated lower than the NACp 9 condition ($\mu = 3.9$, $\sigma = 2.2$) and NACp 10 condition ($\mu = 6.7$, $\sigma = 0.5$) (Appendix H, Table H.40); the NACp 9 condition was rated lower than the NACp 10 condition. When the conflict traffic was transmitting NACp 8 position accuracy, the traffic was not displayed on the AMM. The conflict traffic was displayed on the AMM when it was transmitting NACp 9 accuracy; however, IAs were not issued. When transmitting NACp 10 accuracy, the conflict traffic was displayed on the AMM and IAs were issued, providing the most information related to potential surface conflicts. The number of responses for each rating value is presented in Figure 46.

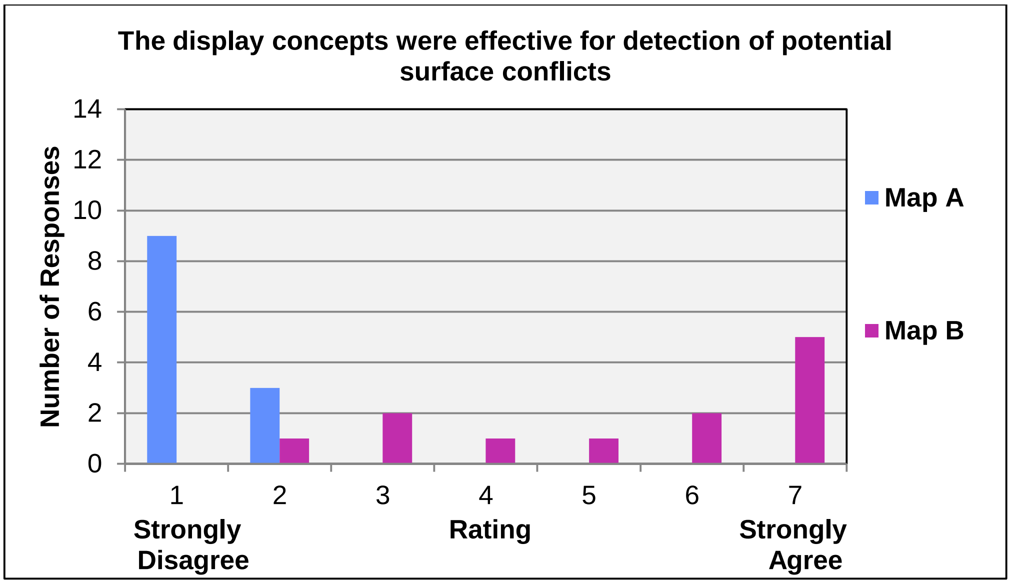


Figure 45. Question G Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic (N = 12).

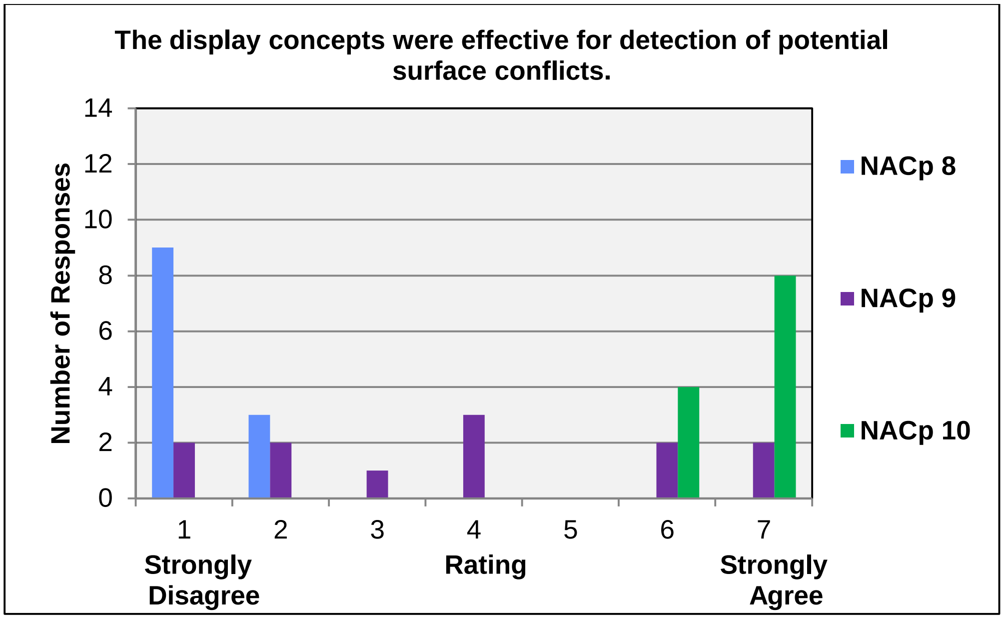


Figure 46. Question G Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic (N = 12).

6.1.2.1.2 Questionnaire Constructs

The individual post run questionnaire items were grouped into several constructs that have similar underlying meaning: Task Management (questions A – C), Communicative Efficacy (questions D – E), and Hazard Awareness (questions F – G).

Task Management

Flight crew responses to run questions A, B, and C were combined to form the Task Management construct:

Question A: I was aware of ownship position.
Question B: I was aware of traffic and other vehicles during operations.
Question C: The display concepts were effective for management of mental workload.

For the nominal trials, there was not a significant main effect for Map condition, $F(1, 188) = 0.042$, $p = 0.837$ (Appendix H, Table H.41) for the Task Management construct responses. Similar mean ratings were reported for the Map A condition ($\mu = 6.3$, $\sigma = 0.8$) and for the Map B condition ($\mu = 6.2$, $\sigma = 1.0$) (Appendix H, Table H.42). The number of responses for each rating value is presented in Figure 47.

Task Management construct responses were analyzed by Map condition for the off-nominal trials and a significant main effect was found, $F(1, 22) = 4.481$, $p = 0.046$ (Appendix H, Table H.43). The Map B condition was rated significantly higher ($\mu = 6.0$, $\sigma = 1.4$) than the Map A condition ($\mu = 5.1$, $\sigma = 2.3$) (Appendix H, Table H.44). The number of responses for each rating value is presented in Figure 48.

For the off-nominal trials, the Task Management construct responses were also analyzed by NACp condition (NACp 8, 9, and 10) and a significant main effect was found, $F(2, 33) = 4.228$, $p = 0.023$ (Appendix H, Table H.45). The NACp 8 condition ($\mu = 5.1$, $\sigma = 2.3$) was not significantly different from the NACp 9 condition ($\mu = 5.3$, $\sigma = 1.6$); the NACp 8 and NACp 9 conditions were both rated lower than NACp 10 condition ($\mu = 6.2$, $\sigma = 0.9$) (Appendix H, Table H.46). The number of responses for each rating value is presented in Figure 49.

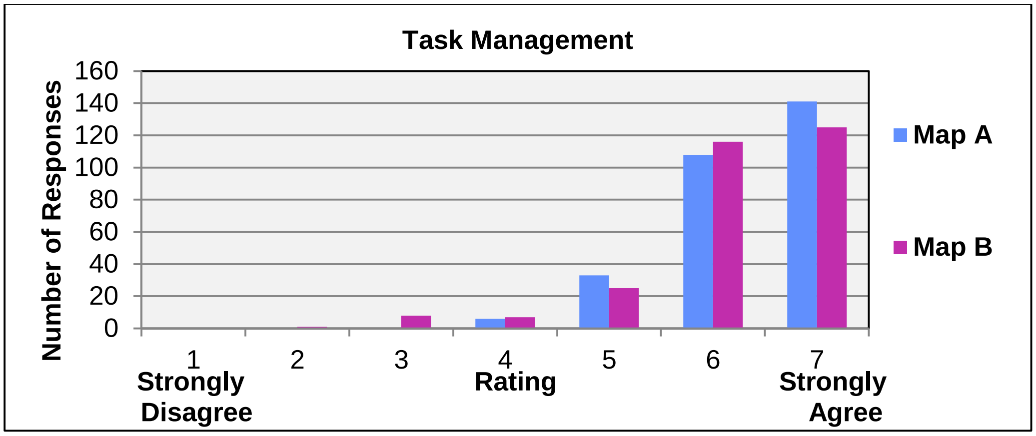


Figure 47. Task Management Construct Data for Part 1 Nominal Trials (Map A, N = 288; Map B, N = 282).

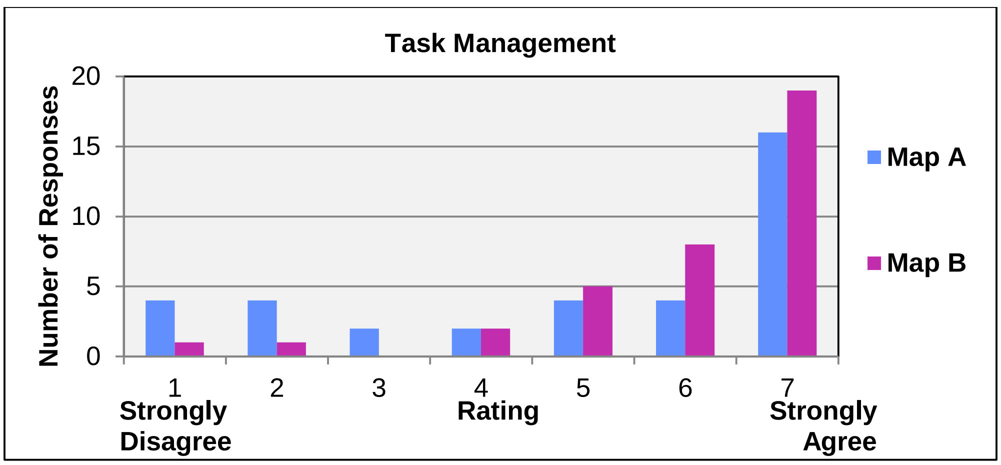


Figure 48. Task Management Construct Data for Part 1 Off-Nominal trials – Map A and B with NACp 8 Conflicting Traffic (N = 36).

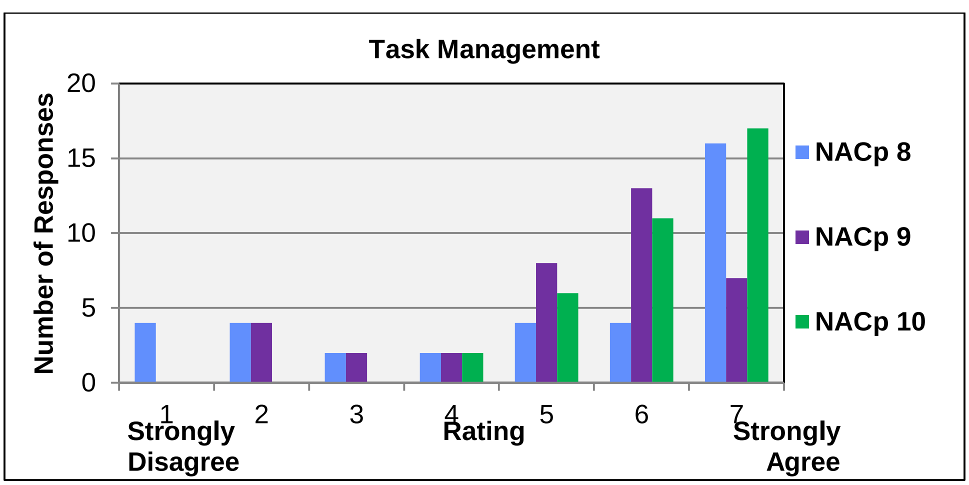


Figure 49. Task Management Construct Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic (N = 36).

Communicative Efficacy

Flight crew responses to run questions D and E were combined to form the Communicative Efficacy construct:

Question D. The display concepts contributed to communication effectiveness (ATC and flight crew).

Question E. The display promoted effective crew resource management, coordination, and cohesion.

For the nominal trials, there was not a significant main effect for Map condition, $F(1, 188) = 0.777$, $p = 0.379$ (Appendix H, Table H.47) for the Communicative Efficacy construct responses. Similar mean ratings were reported for the Map A condition ($\mu = 6.2$, $\sigma = 0.7$) and for the Map B condition ($\mu = 6.0$, $\sigma = 1.1$) (Appendix H, Table H.48). The number of responses for each rating value is presented in Figure 50.

Communicative Efficacy construct responses were analyzed by Map condition for the off-nominal trials and no significant main effects were found, $F(1, 22) = 1.620$, $p = 0.216$ (Appendix H, Table H.49). The pilots reported the following average mean ratings: Map A condition ($\mu = 5.0$, $\sigma = 1.9$), Map B condition ($\mu = 5.8$, $\sigma = 1.6$) (Appendix H, Table H.50). The number of responses for each rating value is presented in Figure 51.

For the off-nominal trials, the Communicative Efficacy construct responses were also analyzed by NACp condition (NACp 8, 9, and 10) and a significant main effect was found, $F(2, 33) = 3.304$, $p = 0.049$ (Appendix H, Table H.51). The NACp 8 condition ($\mu = 5.0$, $\sigma = 1.9$) was not significantly different from the NACp 9 condition ($\mu = 5.1$, $\sigma = 1.5$); the NACp 8 and NACp 9 conditions were both rated lower than NACp 10 condition ($\mu = 6.3$, $\sigma = 0.7$) (Appendix H, Table H.52). The number of responses for each rating value is presented in Figure 52.

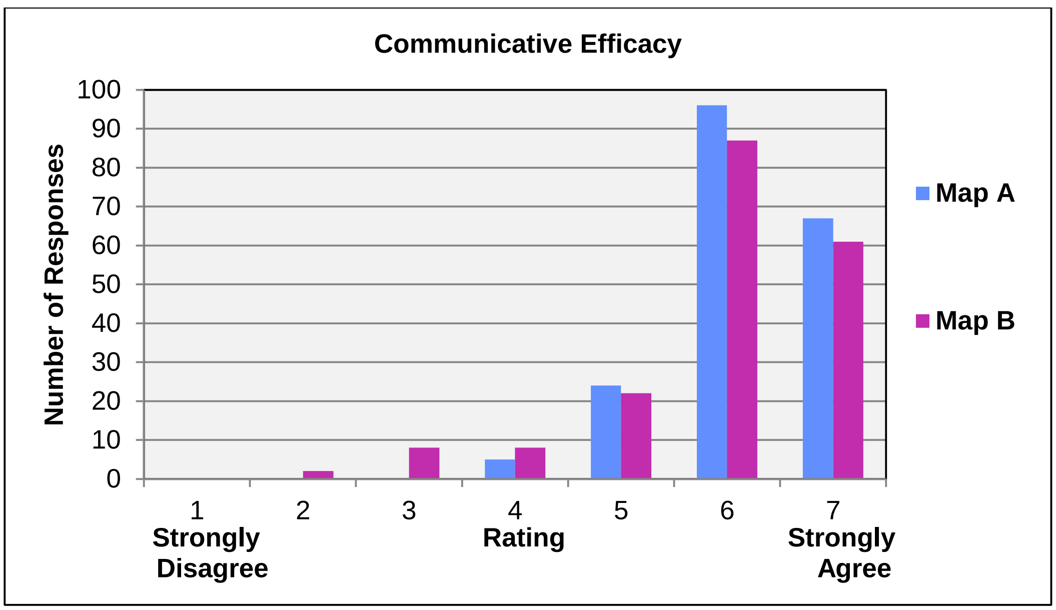


Figure 50. Communicative Efficacy Construct Data for Part 1 Nominal Trials (Map A, N = 192; Map B, N = 188).

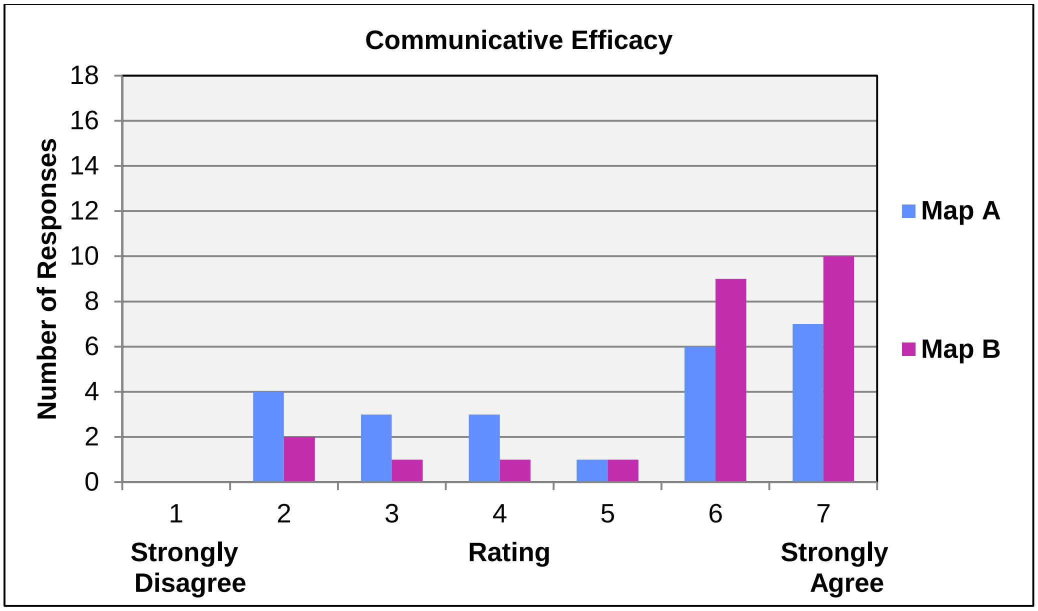


Figure 51. Communicative Efficacy Construct Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic (N = 24).

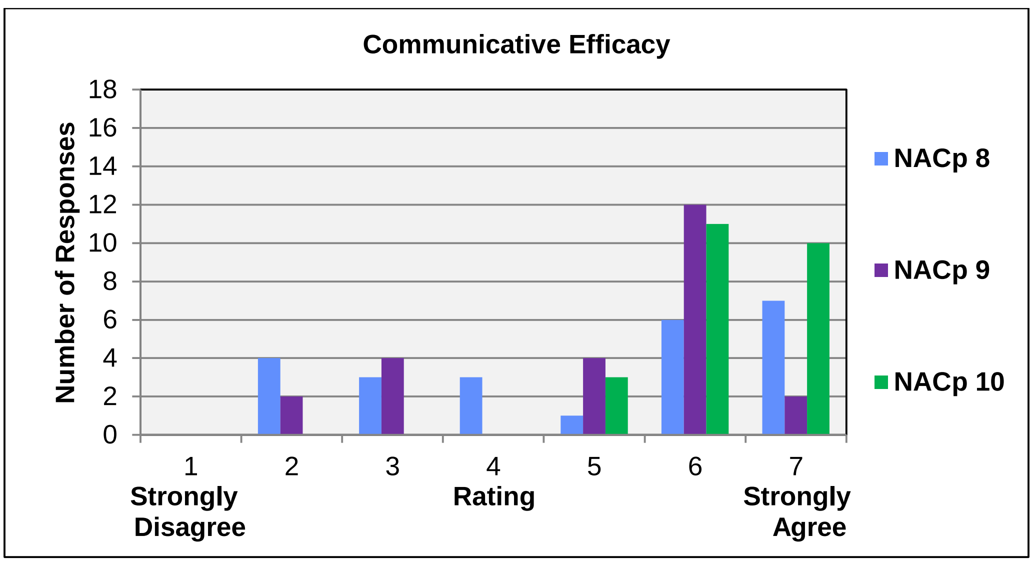


Figure 52. Communicative Efficacy Construct Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic (N = 24).

Hazard Awareness

Flight crew responses to run questions F and G were combined to form the Hazard Awareness construct:

Question F. The display concepts contributed to perceived safety during operation.

Question G. The display concepts were effective for detection of potential surface conflicts.

The Hazard Awareness construct was only analyzed for the off-nominal (surface conflict) trials. A significant effect was found for Map condition, $F(1, 22) = 15.106$, $p = 0.001$ (Appendix H, Table H.53).

Pilots reported that the Map B condition (μ = 5.3, σ = 2.0) was significantly better for detection of hazards (e.g. aircraft, vehicles) than the Map A condition (μ = 2.6, σ = 2.2) (Appendix H, Table H.54). The number of responses for each rating value is presented in Figure 53.

The Hazard Awareness construct responses were also analyzed by NACp condition (NACp 8, 9, and 10) and a significant main effect was found, $F(2, 33) = 33.649$, $p = 0.000$ (Appendix H, Table H.55). The NACp 8 condition (μ = 2.6, σ = 2.2) was rated lower than the NACp 9 (μ = 4.5, σ = 2.0) and NACp 10 conditions (μ = 6.7, σ = 0.5) (Appendix H, Table H.56); the NACp 9 condition was rated lower than the NACp 10 condition. The number of responses for each rating value is presented in Figure 54.

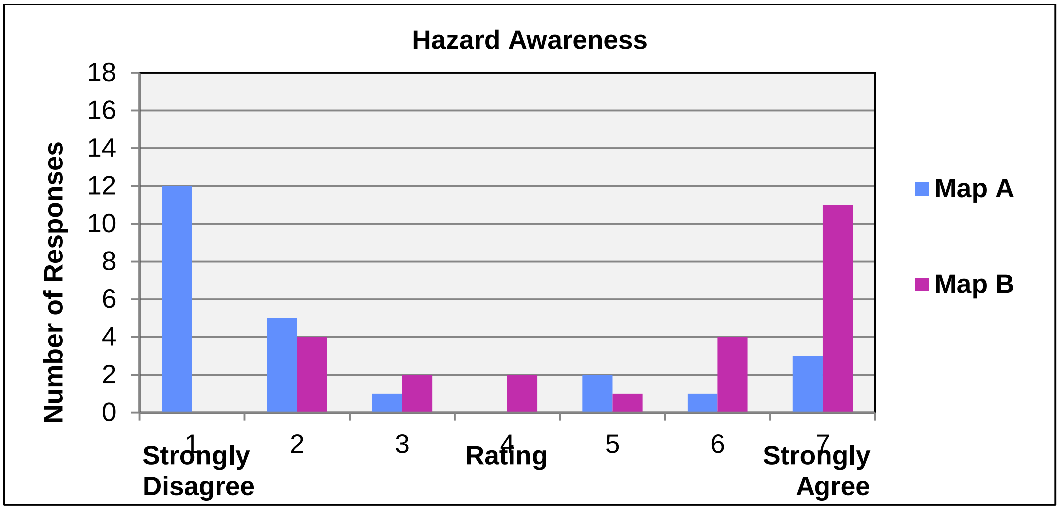


Figure 53. Hazard Awareness Construct Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic (N = 24).

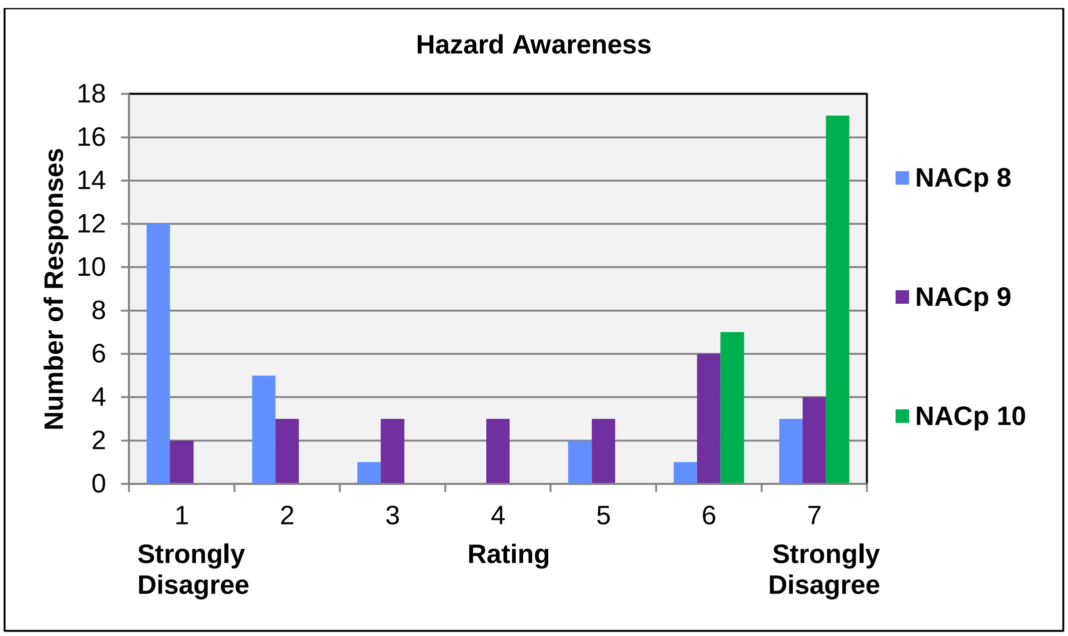


Figure 54. Hazard Awareness Construct Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic (N = 24).

6.1.2.1.3 SART (Situational Awareness)

The 3-dimensional SART scale was used: demand on attentional resources, supply of attentional resources, and understanding [Taylor, 1990] (Appendix G, Table G.3). The three scores are used to calculate a total situation awareness score using the equation: situational awareness = understanding – (demand – supply). The resulting situational awareness score can range in value from -5 to 13.

For the nominal test trials, there was a marginally insignificant effect for Map condition, $F(1, 188) = 3.198$, $\underline{p} = 0.075$ (Appendix H, Table H.57) for the SART responses. Pilots rated the Map B condition ($\mu = 7.2$, $\sigma = 2.2$) higher than the Map A condition ($\mu = 6.6$, $\sigma = 2.3$) (Appendix H, Table H.58). The number of responses for each rating value is presented in Figure 55.

SART responses were analyzed by Map condition for the off-nominal trials and no significant main effects were found, $F(1, 22) = 0.051$, $\underline{p} = 0.823$ (Appendix H, Table H.59). The pilots reported similar mean ratings for the Map A condition ($\mu = 6.0$, $\sigma = 1.8$) and the Map B condition ($\mu = 6.2$, $\sigma = 1.9$) (Appendix H, Table H.60). The number of responses for each rating value is presented in Figure 56.

For the off-nominal trials, the SART responses were also analyzed by NACp condition (NACp 8, 9, and 10) and a significant main effect was found, $F(2, 33) = 7.508$, $\underline{p} = 0.002$ (Appendix H, Table H.61). The NACp 8 condition ($\mu = 6.0$, $\sigma = 1.8$) was rated lower than the NACp 9 ($\mu = 7.7$, $\sigma = 1.9$) and NACp 10 conditions ($\mu = 9.6$, $\sigma = 2.9$) (Appendix H, Table H.62); the NACp 9 condition was not significantly different from the NACp 10 condition. The number of responses for each rating value is presented in Figure 57.

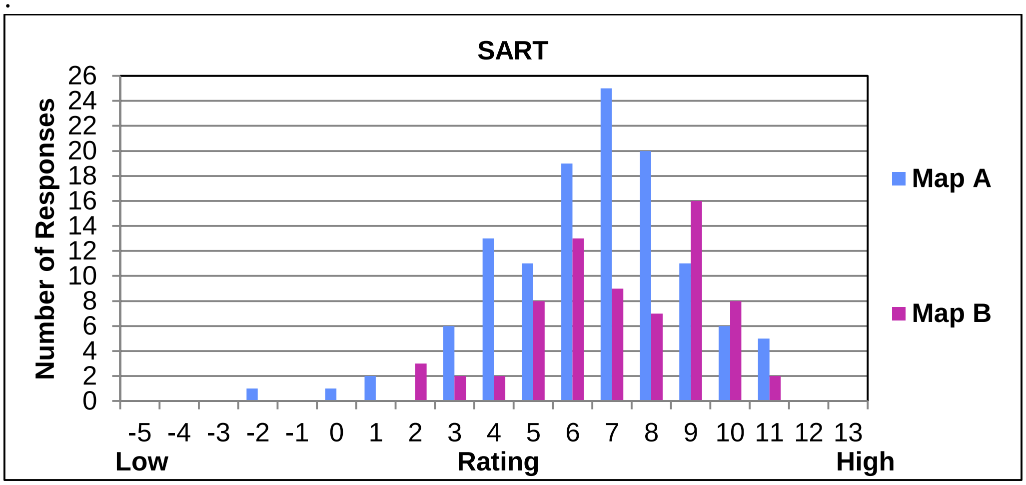


Figure 55. SART Situational Awareness Data for Part 1 Nominal Trials.

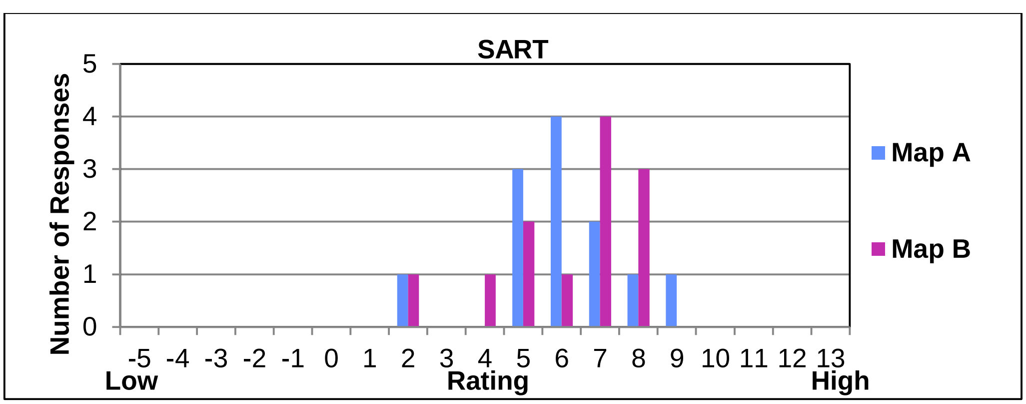


Figure 56. SART Situational Awareness Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic.

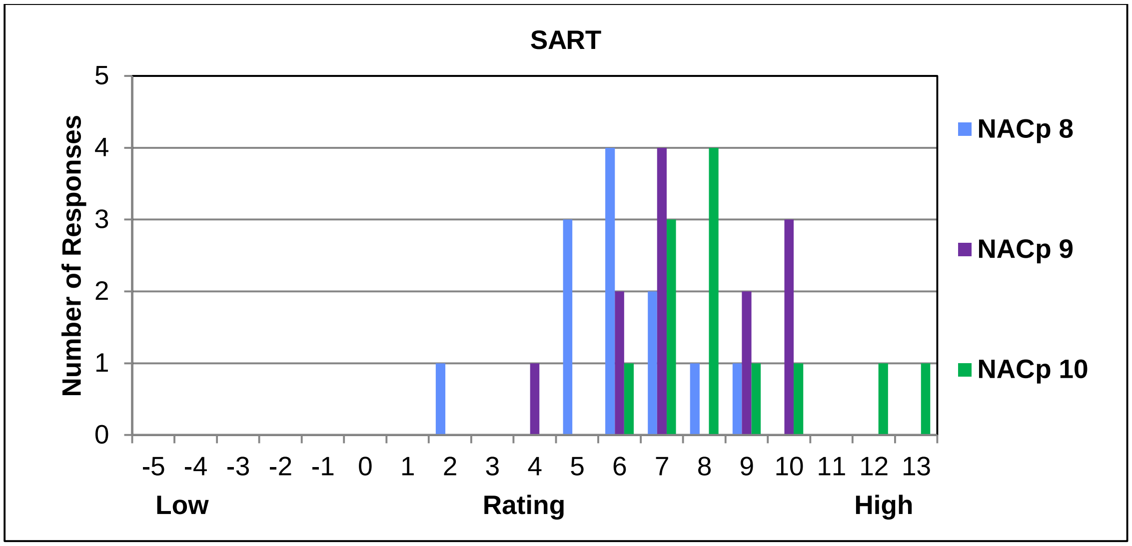


Figure 57. SART Situational Awareness Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic.

6.1.2.1.4 TLX (Workload)

For the nominal test trials, there was not a statistically significant effect for Map condition, F(1, 188) = 1.085, p = 0.299 (Appendix H, Table H.63) for the TLX responses. The mean ratings for the Map B condition (μ = 33.1, σ = 14.3) were slightly lower than for the Map A condition (μ = 35.5, σ = 15.8) (Appendix H, Table H.64); however, for both map conditions, the perceived overall mental workload was low to moderate. The number of responses for each rating value is presented in Figure 58.

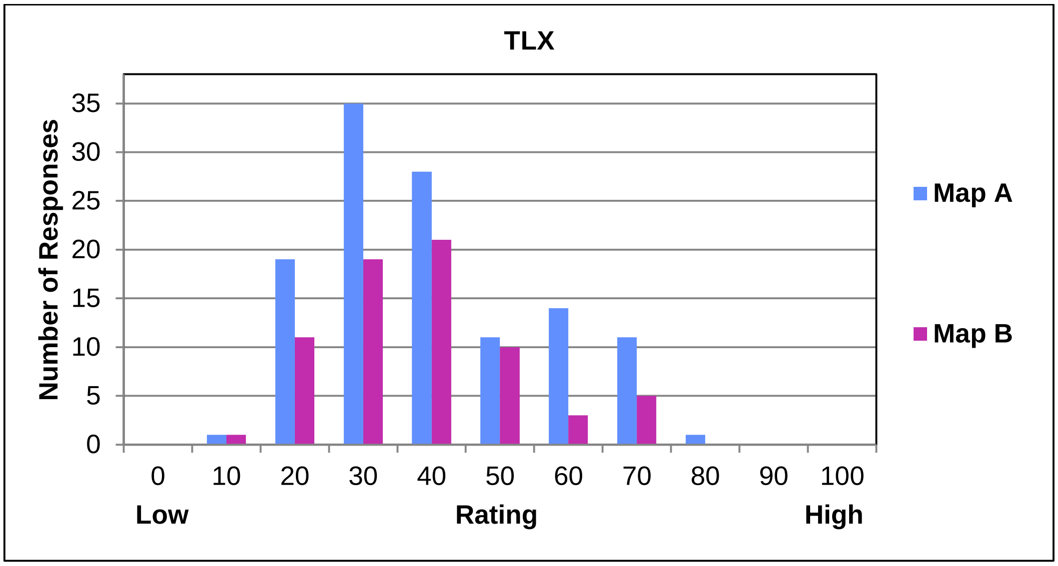


Figure 58. TLX Workload Data for Part 1 Nominal Trials.

TLX responses were analyzed by Map condition for the off-nominal trials and no significant main effects were found, F(1, 22) = 0.524, p = 0.477 (Appendix H, Table H.65). The pilots gave moderate workload ratings for both the Map A (μ = 26.3, σ = 11.4) and Map B (μ = 30.0, σ = 13.4) conditions (Appendix H, Table H.66). The number of responses for each rating value is presented in Figure 59.

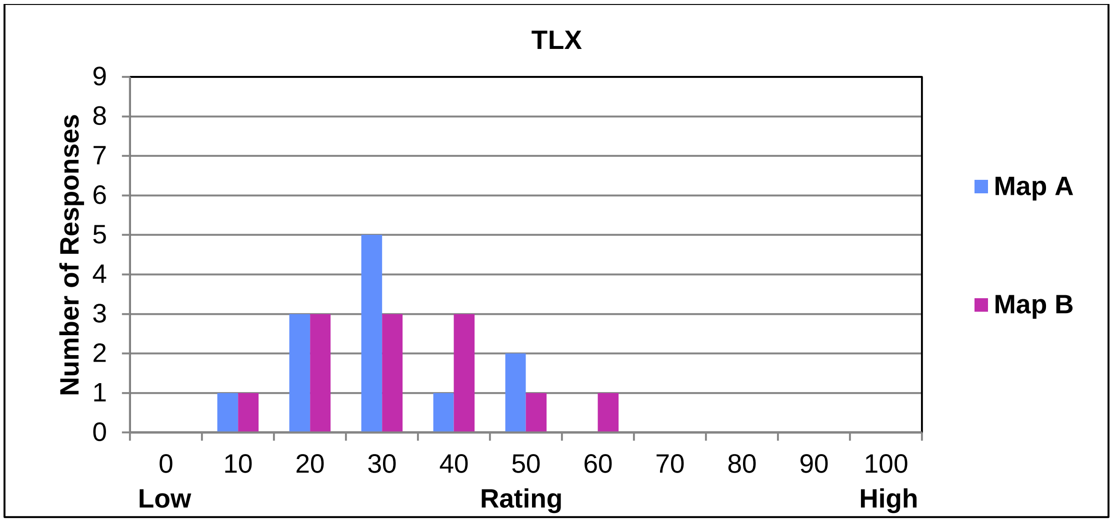


Figure 59. TLX Workload Data for Part 1 Off-Nominal Trials – Map A and B with NACp 8 Conflicting Traffic.

For the off-nominal trials, the TLX responses were also analyzed by NACp condition (NACp 8, 9, and 10) and no statistically significant effects were found, $F(2, 33) = 0.430$, $p = 0.654$ (Appendix H, Table H.67). Low to moderate workload ratings were given for all NACp conditions: NACp 8 ($\mu = 26.3$, $\sigma = 11.4$), NACp 9 ($\mu = 31.0$, $\sigma = 14.6$), and NACp 10 ($\mu = 28.5$, $\sigma = 11.1$) (Appendix H, Table H.68). The number of responses for each rating value is presented in Figure 60.

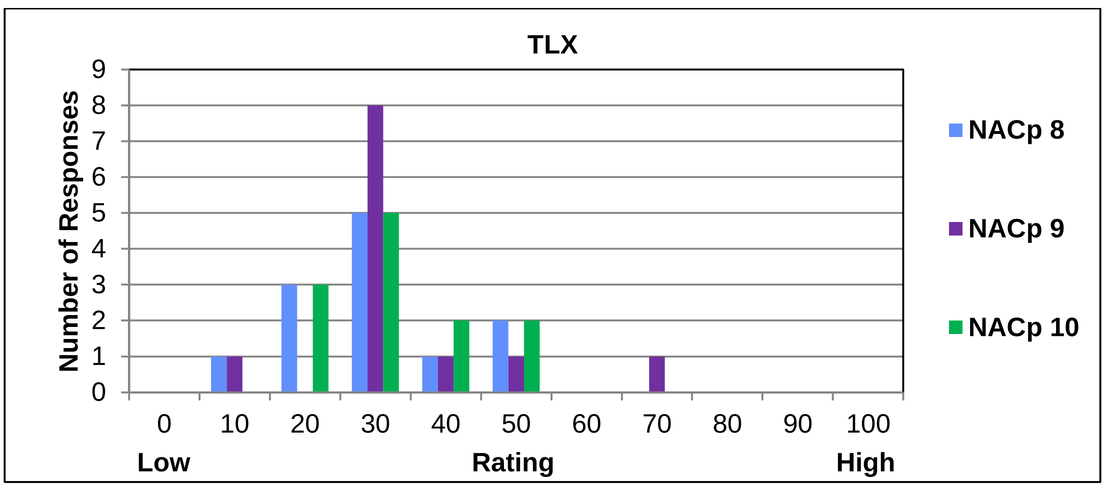


Figure 60. TLX Workload Data for Part 1 Off-Nominal Trials – Map A with NACp 8, 9, and 10 Conflicting Traffic.

6.1.2.2 <u>Part 1 Final Questionnaire Results</u>

At the conclusion of the testing, the evaluation pilots completed a final questionnaire. All questions along with the pilots' responses can be found in Appendix J. Most of the questions were rated on a scale of 1 ("strongly disagree", "low", "not useful") to 7 ("strongly agree", "high", "very useful").

6.1.2.2.1 Traffic Awareness and Symbology

Pilots indicated a higher level of traffic awareness when all traffic was displayed on the AMM ($\mu = 6.6$, $\sigma = 0.6$) than when only qualified traffic (NACp 9 and higher) was displayed ($\mu = 4.9$, $\sigma = 1.6$)

(Appendix J, Figure J.4, Table J.2). Furthermore, the pilots indicated the presentation of only qualified traffic on the AMM was a greater safety issue ($\mu = 6.3$, $\sigma = 1.1$) than displaying all traffic ($\mu = 2.3$, $\sigma = 1.7$) (Figure J.5, Table J.3). They also felt the display of only qualified traffic on the AMM will increase the potential for accidents ($\mu = 5.5$, $\sigma = 1.4$) than the display of all traffic ($\mu = 2.0$, $\sigma = 1.6$) (Figure J.6, Table J.4). All these results were statistically significant. When asked if all traffic should be displayed on the AMM or only the traffic that meets NACp 9 and higher position accuracy levels, 23 of 24 pilots (95.8%) responded that all traffic should be displayed (confidence level of $\mu = 6.4$, $\sigma = 0.6$, where 7 = 100% confidence). These results are consistent with the quantitative performance that shows fewer accidents and incidents with all traffic being displayed.

The pilots were asked if the NACp surveillance accuracy should be shown on the AMM. The pilot ratings indicated a slight preference for using different symbology for qualified and unqualified traffic ($\mu = 5.4$, $\sigma = 2.0$) instead of using the same symbology ($\mu = 4.5$, $\sigma = 1.7$) to avoid potentially misleading information (Figure J.8) (no statistical significance, Table J.5). They felt there should be a distinction (difference) between the symbology representing qualified traffic and unqualified traffic (NACp 8 or less) ($\mu = 5.6$, $\sigma = 1.7$) (Figure J.9). Of 21 pilot ratings, 12 pilots (57%) would prefer a different symbol such as a rounded chevron, 5 pilots (24%) would prefer an accuracy range ring around the chevron symbol, and 4 pilots (19%) would prefer some other type of symbol, such as a segmented/dashed chevron, hollow symbol, different color symbol, or touching symbol to see accuracy of signal. Some pilots commented that the traffic chevron symbol was too large when the map was scaled down (2 of 24 pilots, 8.3%) and touch/pinch/pan capability is desirable (4 of 24 pilots, 16.7%).

For this study, the AMM was located on the EFB outboard of the PFD. The pilots moderately agreed that this was an optimal location for viewing the AMM ($\mu = 5.3$, $\sigma = 1.4$) (Figure J.7). Several pilots (9 of 24 pilots, 37.5%) commented that the AMM should be located on a forward display, preferably the ND, or in a central location for viewing by both pilots. Also, there were too many menu levels (2 of 24 pilots, 8.3%) and perhaps a hard button to go directly to the AMM would be useful.

6.1.2.2.2 CD&R Symbology

The pilots rated the CD&R symbology as effective in providing information on the conflict traffic ($\mu = 6.4$, $\sigma = 1.0$) (Appendix J, Figure J.34) and providing a clear indication of the relative location of the conflict traffic ($\mu = 6.5$, $\sigma = 0.7$) (Figure J.35). Both indications and alerts were helpful in determining critical runway safety information (indications: $\mu = 6.3$, $\sigma = 1.2$ (Figure J.36), alerts: $\mu = 6.5$, $\sigma = 0.6$ (Figure J.39), provided additional information over AMM traffic (indications: $\mu = 6.2$, $\sigma = 0.9$ (Figure J.37), alerts: $\mu = 6.4$, $\sigma = 0.7$ (Figure J.40)), and helped in determining the location and movement of traffic that was relevant to the safety of their own aircraft (indications: $\mu = 6.3$, $\sigma = 0.8$ (Figure J.38), alerts: $\mu = 6.4$, $\sigma = 0.7$ (Figure J.41)).

The pilots felt there should be a distinction (difference) between the symbology representing traffic qualified for the CD&R indication and alerting function (traffic transmitting NACp 10 or 11) versus traffic not qualified for that function (traffic transmitting NACp 9 or less) ($\mu = 5.3$, $\sigma = 1.7$) (Figure J.10). Of 21 pilot ratings, 11 pilots (52%) would prefer a different symbol, 6 pilots (29%) would prefer an accuracy range ring around the chevron symbol, and 4 pilots (19%) would prefer some other type of symbol, such as a different color symbol, hollow symbol, or touching symbol to see accuracy of signal.

When an indication or alert occurred and the potential conflict traffic was not shown on the AMM at the current map scale, an off-scale traffic symbol was displayed at the edge of the AMM in the direction of the traffic (see Figure 14). The pilots felt the off-scale symbology was moderately effective in providing information on the conflict traffic ($\mu = 5.1$, $\sigma = 1.6$) (Figure J.43) and in providing a clear indication of the relative location of the conflict traffic ($\mu = 5.5$, $\sigma = 1.4$) (Figure J.44). Of 24 pilot ratings, 15 pilots (62.5%) felt that the AMM should auto-zoom to a scale that shows the conflict traffic symbol, 6 pilots (25%) felt the AMM should not auto zoom, and 3 pilots (12.5%) did not know if the AMM should auto-zoom. These ratings were given without the pilots viewing the auto-zoom feature in practice.

6.1.2.2.3 General

The pilots rated their level of perceived safety higher having the CD&R system onboard their aircraft during similar operations (μ = 6.2, σ = 0.6) than without having the system onboard (μ = 4.8, σ = 0.9) (Figure J.1) (statistically significant, Table J.1). With a rating of 7 being completely safe, the pilots rated the level of safety felt during runway conflict incidents (μ = 5.7, σ = 1.0) (Figure J.2) and during taxi conflict incidents (μ = 5.9, σ = 0.8) (Figure J.3) as moderately high. The pilots were asked to provide suggestions for improvements that would increase the safety of the system. Some of the prevalent comments were: more experience with the system (4 of 24 pilots, 16.7%); detailed training, including appropriate map scale per operation (3 of 24 pilots, 12.5%); reduce head-down time (6 of 24 pilots, 25%); display all traffic on the AMM (23 of 24 pilots, 95.8%); display taxi clearance for all traffic, preferably graphically (3 of 24 pilots, 12.5%); provide IAs for all traffic (3 of 24 pilots, 12.5%); and directive alerting (2 of 24 pilots, 8.3%). Also, the question of qualified vs. unqualified traffic and traffic position accuracy added to mental workload and uncertainty (4 of 24 pilots, 16.7%). Some of the best features identified were the display of traffic on the AMM (6 of 24 pilots, 25%), graphical depiction of the taxi route (7 of 24 pilots, 29.2%), and IAs (5 of 24 pilots, 20.8%). The general safety and system improvement responses are presented in Appendix J, questions 1 through 7.

6.2 Part 2 Testing Results

6.2.1 STBO Taxi Conformance Results

Conformance in following STBO taxi guidance was evaluated by comparing actual performance against planned guidance at various locations along the cleared STBO taxi route. The following locations were evaluated for conformance: route start, straight segment mid-points, entering and exiting 90 degree turns, and route end. These locations were chosen to ensure homogeneity across the scenarios for analysis purposes. Examples of the taxi conformance segment locations are shown in Figure 61. The independent variables for this analysis were Map condition (Map C (Figure 19) and Map D (Figure 20)) and the absence or presence of a HUD showing STBO guidance information (Figure 21). The dependent measure was the conformance time in seconds which was displayed to the flight crew on the AMM as seconds early (+) or late (-). Histograms are also included that present the conformance time grouped into 5 second bins.

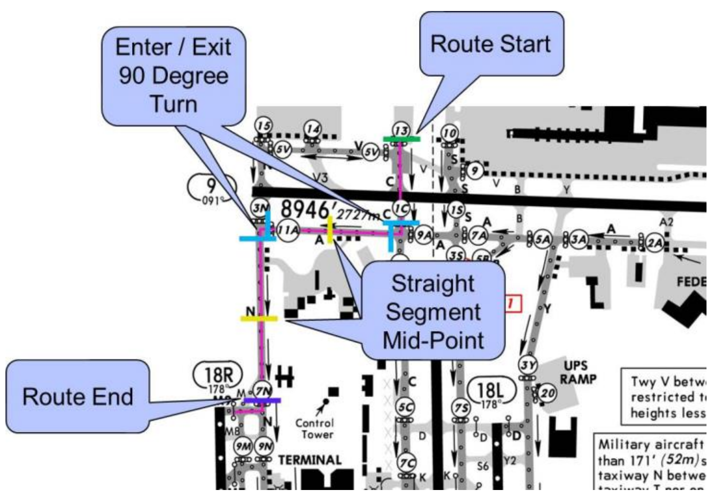


Figure 61. Example Taxi Conformance Segment Locations.

6.2.1.1 STBO Route Start Location

The crew was instructed to begin taxi as close as possible to the taxi release time. The "route start" conformance time measurement was taken when the aircraft CG crossed the hold line near the GPM.

Data for all 72 STBO test trials but one (nominal and off-nominal) were analyzed for start location conformance. Data for one crew was considered an outlier and omitted because the crew held for traffic in the ramp area before taxiing to the designated GPM, causing them to miss the release time. In all other test runs, the crew taxied to the GPM prior to the release time and could begin the trial in a timely manner.

After the taxi release time occurred, it took time for the engines to spool up and the aircraft to begin moving. As a result, for all test trials, the conformance measurement at the start location was always negative (Figure 62), i.e. late in comparison to the planned STBO guidance. The flight crews were within +/- 15 seconds of the planned STBO guidance on 54.9% (39 of 71) of the trials. The 95th percentile data was between 7.8 and 20 seconds late. No significant effects for STBO route start times were found for Map condition, $F(1, 67) = 0.038$, $p = 0.847$; HUD, $F(1, 67) = 0.992$, $p = 0.323$; or Map by HUD interaction, $F(1, 67) = 0.730$, $p = 0.396$. Descriptive statistics are presented in Table 11.

Many pilots made comments regarding starting out with a late conformance time. As a result, some pilots started advancing the throttles slightly before the release time to begin engine spool up earlier on later trials. Future STBO designs need to incorporate more latency in crew and aircraft spool-up at the start of the STBO route.

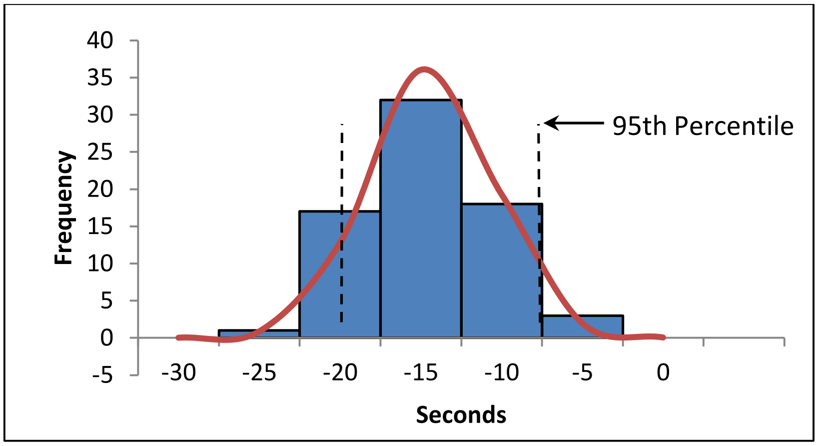


Figure 62. STBO Route Start Location Conformance.

Table 11. STBO Route Start Location Conformance (seconds).

Display	HUD	μ	σ	N
C	No	-13.5	3.6	24
	Yes	-15.4	3.7	12
	Total	-14.1	3.7	36
D	No	-14.6	4.3	23
	Yes	-14.7	3.9	12
	Total	-14.6	4.1	35
C + D	No	-14.0	3.9	47
	Yes	-15.0	3.8	24
	Total	-14.4	3.9	71

6.2.1.2 STBO Straight Segment Mid-Point Locations

For this measurement, the conformance time was taken at the mid-point of a straight taxi segment. Some cleared STBO taxi routes only had one straight segment while others had multiple straight segments. Data for all STBO test trials (nominal and off-nominal) were analyzed for the straight segment mid-point location (a total of 108 data points).

In general, the flight crews were able to conform well to the STBO guidance during the straight taxi segments (Figure 63). The crews were able to maintain +/- 10 seconds of the guidance at the straight segment mid-point location 86.1% (93 of 108) of the time and +/- 15 seconds for 92.6% (100 of 108) of the time.

A marginally insignificant effect was found for Map condition, $F(1,104) = 3.046$, $p = 0.084$. A significant main effect was found for HUD condition, $F(1, 104) = 3.970$, $p = 0.049$. The Map by HUD interaction was not statistically significant, $F(1,104) = 1.074$, $p = 0.302$. Descriptive statistics are presented in Table 12. Pilots had significantly better STBO guidance conformance, on the straight route segments, using a HUD ($\mu = 1.1$ sec, $\sigma = 11.3$ sec) than without using a HUD ($\mu = -2.6$ sec, $\sigma = 7.9$ sec). The time delta from 0 seconds (perfect conformance) between these HUD conditions equates to 1.5 seconds ($|2.6| - |1.1|$). This equates to approximately 37 feet of travel at 15 kts, which is approximately 25% of the length of a Boeing 757-200 and signifies that the use of a HUD affected STBO conformance.

Although marginally statistically insignificant, pilots using the Map C condition had an average conformance of -2.7 seconds ($\sigma = 7.0$ sec) compared to using the Map D condition, which resulted in an average conformance of -0.1 seconds ($\sigma = 11.0$ sec). The time delta between these Map conditions equates to 2.6 seconds or approximately 66 feet of travel at 15 kts, which is approximately 43% of the length of a Boeing 757-200, signifying that Map type affected STBO conformance.

In the straight-segments, crews were able to adjust their speed to meet their RTA. When viewed as conformance along the route, the data shows relatively good performance (92.6% compliance) but with some very significant tails in the data (i.e., one ~50 seconds early and several ~30 seconds late). Along route conformance was suboptimal in these cases since the crews were only asked to meet the end-of-route RTA performance. Intermediate/ waypoint RTAs were not explicitly displayed to the crews. How the crews performed without these data were analyzed to assess this effect.

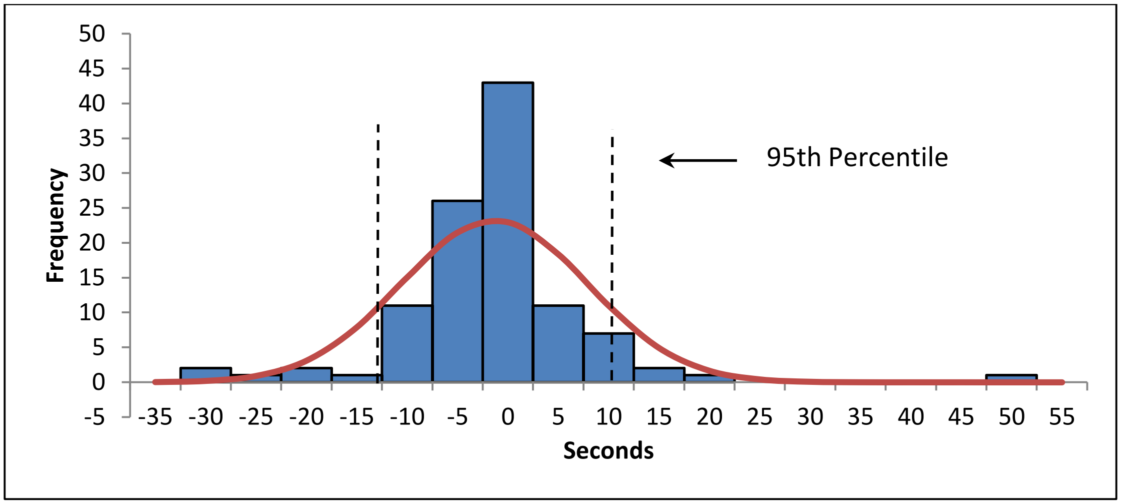


Figure 63. STBO Straight Segment Location Conformance.

Table 12. STBO Straight Segment Location Conformance (seconds).

Display	HUD	Mean	SD	N
C	No	-3.3	7.2	36
	Yes	-1.5	6.8	18
	Total	-2.7	7.0	54
D	No	-1.9	8.7	36
	Yes	3.7	14.2	18
	Total	-0.1	11.0	54
C+D	No	-2.6	7.9	72
	Yes	1.1	11.3	36
	Total	-1.4	9.3	108

6.2.1.3 STBO 90 Degree Turn Locations

To analyze STBO performance during 90 degree turns, conformance time was taken 20 seconds prior to the center of the turn and 20 seconds after the center of the turn based on the planned route guidance. Some cleared STBO taxi routes only had one 90 degree turn while others had multiple 90 degree turns. Data for only nominal STBO test trials were analyzed because the off-nominal scenarios did not contain any 90 degree turns.

Of the 96 data points available, only 90 were included in the analysis. On three trials using the Map D condition, a wrong turn was made and data was not available. After discussing the error with the crews, it was determined that the Captains mistakenly thought that their aircraft was at the location of the trend symbol (Figure 20) instead of the white chevron and, as a result, turned early onto another taxiway. For three other trials, one turn produced outliers. The ownship was taxiing on Taxiway C for a turn onto Taxiway A. Another aircraft was taxiing along Taxiway A. On these three occasions, the subject crew's STBO conformance was late approaching the turn and the crew did not think the turn could be made onto Taxiway A in advance of the other aircraft; therefore, they held for the other traffic and thus, were very late entering the turn. Since performance was significantly different than on the other trials, these data were omitted as outliers.

There was a wide variability for conformance at the entry and exit location of the 90 degree turns (Figures 64 and 65 respectively). The STBO guidance was reduced to 4 kts during 88.9% (80 of 90) of the 90 degree turns, 6 kts during 8.9% (8 of 90) of turns, 8 kts on one turn, and 10 kts on one turn. Four knots is apparently slower than turns are usually taken because, in general, the actual speed during the turns (center of turn) was higher (μ = 9.5 kts, σ = 2.7 kts) and, as a result, conformance time at the entry location was later (μ = 0.9 sec, σ = 13.9 sec (see Table 13)) than conformance time at the exit location (μ = 9.5 sec, σ = 13.6 sec (see Table 14)). The entry location was reached early 51.1% (46 of 90) of the time, while the exit location was reached early 77.8% (70 of 90) of the time. From observation (data not collected) it was noticed that as some of the pilots realized that the planned speed was very slow in the turns, they began going into them late so the turn could be taken faster. Many pilots commented that the STBO speed guidance in the turns was too slow and, for a transport category aircraft, should be 8 to 10 kts.

When entering a 90 degree turn, the flight crews maintained +/- 15 seconds of the planned STBO guidance on 78.9% (71 of 90) of the turns. No statistically significant effects were found for Map condition, $F(1, 86) = 1.907$, $p = 0.171$; HUD, $F(1, 68) = 0.097$ $p = 0.757$; or Map by HUD interaction, $F(1, 68) = 1.547$, $p = 0.217$. The descriptive statistics are presented in Table 13.

When exiting a 90 degree turn, the flight crews maintained +/- 15 seconds of the planned STBO guidance on 73.3% (66 of 90) of the turns. No statistically significant effects were found for Map condition, $F(1, 92) = 3.148$, $p = 0.080$; HUD, $F(1, 68) = 0.162$, $p = 0.689$; or Map by HUD interaction, $F(1, 68) = 0.745$, $p = 0.391$. There was a marginally insignificant finding ($p = 0.081$) for Map condition for the exit locations, however. The descriptive statistics (Table 14) suggest that STBO conformance was better when using Map C than Map D, although the pilots preferred using the graphical intent information shown on Map D.

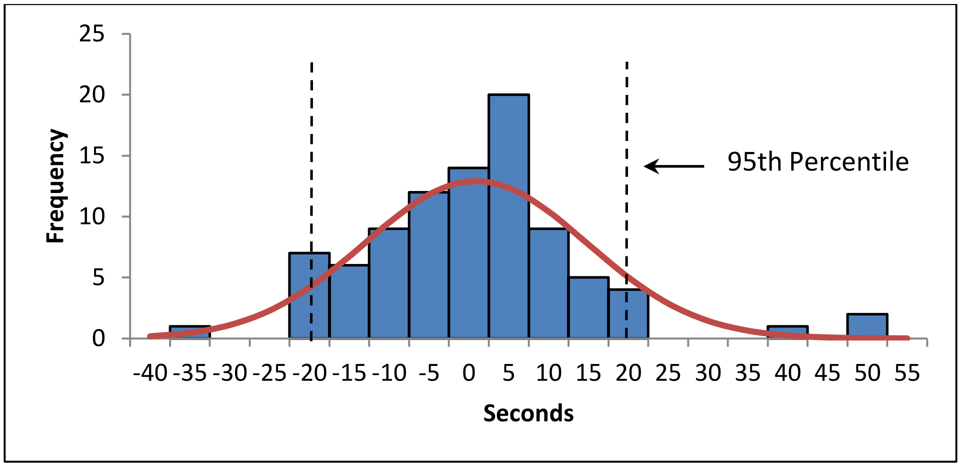


Figure 64. STBO Enter 90 Degree Turn Location Conformance.

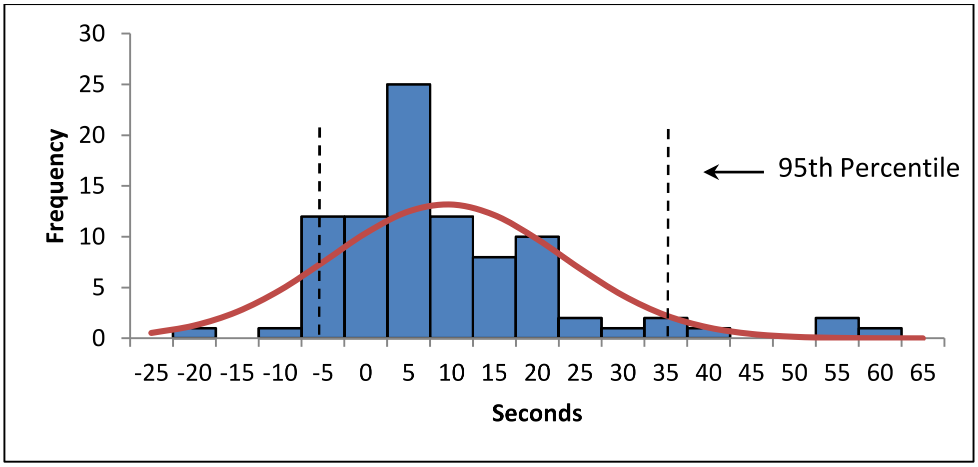


Figure 65. STBO Exit 90 Degree Turn Location Conformance.

Table 13. STBO Enter 90 Degree Turn Location Conformance (seconds).

Display	HUD	Mean	SD	N
C	No	0.2	11.1	23
	Yes	-2.5	10.8	23
	Total	-1.1	10.9	46
D	No	0.6	16.3	21
	Yes	5.2	16.4	23
	Total	3.0	16.3	44
C+D	No	0.4	13.7	44
	Yes	1.3	14.3	46
	Total	0.9	13.9	90

Table 14. STBO Exit 90 Degree Turn Location Conformance (seconds).

Display	HUD	Mean	SD	N
C	No	7.6	8.1	23
	Yes	6.3	8.7	23
	Total	7.0	8.4	46
D	No	10.2	17.3	21
	Yes	13.8	17.3	23
	Total	12.1	17.2	44
C+D	No	8.9	13.2	44
	Yes	10.1	14.1	46
	Total	9.5	13.6	90

6.2.1.4 STBO Route End Location

The goal of providing STBO guidance was to enable flight crews to reach the end of the taxi route at the RTA. This "RTA point" was shown on the AMM as a green diamond near the end of the cleared route (Figure 19). The conformance time measurement was taken when the aircraft CG crossed the RTA point. Data for only nominal STBO test trials were analyzed because the RTA point was never reached during the off-nominal trials.

Of the 48 data points available, only 47 were included in the analysis. On one trial, the crew slowed to conduct the before takeoff checklist just before crossing the RTA point, making the conformance time very late (-27 seconds). Since performance was significantly different than on the other trials, this data was omitted as an outlier. Consideration must be given to these types of actions in the development of procedures and training for STBO.

STBO route end location data is presented in Figure 66. On 97.9% (46 of 47) of the trials, the RTA point was crossed within +/- 10 seconds of the RTA, and within +/- 5 seconds of the RTA on 87.2% (41 of 47) of trials. The crews were instructed that acceptable performance was met if the RTA point was reached within +/- 15 seconds of the RTA; these data show excellent compliance to this goal.

On the one trial in which the 15 second requirement was not met, the crew was focused on oncoming traffic near the taxi route and crossed the RTA point 20 seconds early.

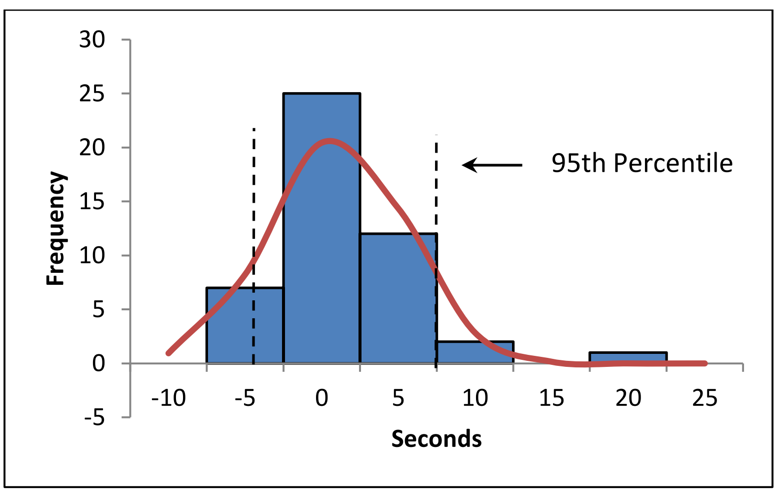


Figure 66. STBO Route End Location Conformance.

No statistically significant effects were found for Map condition, $F(1, 43) = 1.117$, $p = 0.296$; HUD, $F(1, 43) = 3.002$, $p = 0.090$; or Map by HUD interaction, $F(1, 43) = 1.547$, $p = 0.220$. The statistical result for HUD use was marginally insignificant with an observed power of 0.395. The descriptive statistics (Table 15) suggest that using the HUD (μ = -0.0 sec, σ = 3.8 sec) helped the pilots meet the RTA more effectively than when not using the HUD (μ = 2.2 sec, σ = 4.8 sec). The conformance difference between using a HUD and not using a HUD (2.2 seconds) results in approximately 55 feet of travel at 15 kts. Even though using Map D was slightly less effective (μ = 1.8 sec, σ = 5.7 sec) in meeting the RTA than using Map C (μ = 0.4 sec, σ = 2.8 sec) overall, an examination of Figure 67 suggests that using Map D combined with a HUD is as equally effective (μ = -0.1 sec, σ = 4.7 sec) as using Map C combined with a HUD (μ = 0.1 sec, σ = 3.0 sec).

The STBO data shows that intermediate performance could vary significantly but the crews met their instructed goal – the end route RTA. If compliance along the route is necessary, intermediate RTAs/waypoints will be required. The data also shows that STBO guidance development is not and may never be a trivial task. An STBO RTA significantly impacts air carrier SOPs and crew procedures (e.g., influencing when checklists can be started and completed), taxi speeds (including how this may vary by aircraft type and aircraft loading) and how they vary with traffic, taxi route (e.g., turns, hot spots) and prevailing visibility, and passenger comfort (e.g., how quickly to turn, accelerate, and decelerate).

Table 15. STBO Route End Location Conformance (Seconds).

Display	HUD	Mean	SD	N
C	No	0.7	2.8	12
	Yes	0.1	3.0	12
	Total	0.4	2.8	24
D	No	3.6	6.1	12
	Yes	-0.1	4.7	11
	Total	1.8	5.7	23
C+D	No	2.2	4.8	24
	Yes	-0.0	3.8	23
	Total	1.1	4.5	47

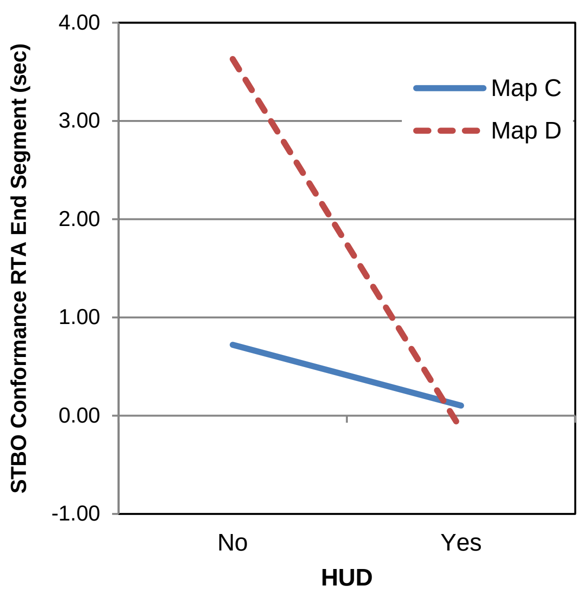


Figure 67. HUD by Map Condition Non-Significant Interaction.

6.2.2 Part 2 Off-Nominal Scenario Results

As described in the Test Method section, the off-nominal trials were conducted between subjects to evaluate collision avoidance capability during STBO. The focus of the off-nominal scenarios was to determine the usefulness of traffic intent information for taxi collision avoidance and to determine the usefulness of CD&R for collision avoidance during STBO. Each crew evaluated the off-nominal scenarios using either the Map C or D condition with conflict traffic transmitting either NACp 9 or NACp 10 position accuracy; therefore, three data points were collected for each combination of conditions. Intent information was displayed graphically on Map D but only textually on Map C. IAs were not issued for traffic transmitting NACp 9 position accuracy, but were issued for traffic transmitting NACp 10 position accuracy. Since all traffic on the airport was transmitting position accuracy of NACp 9 and higher, all traffic was displayed on the AMM.

6.2.2.1 Taxi Head-On Conflict Scenario Results

The taxi head-on scenario was given as Trial 3 of six trials for each crew. This scenario simulated faulty STBO guidance where conflicting traffic would meet the ownship head-on at an intersection, if the ownship followed the STBO guidance.

For all of the taxi head-on trials, the ownship either slowed down or stopped for traffic to turn ahead of them at the intersection, averting a collision or conflict (Table 16). The flight crew was aware of the conflict traffic on each trial by either viewing the traffic intent information or seeing the traffic OTW. It was relatively easy to visually acquire the traffic OTW since the visibility was 1,800 ft.

Table 16. Part 2 Off-Nominal Taxi Head-on Scenario Results.

Map	NACp	Action	Outcome	CPA (feet)	Viewed Intent
C	9	Stopped		202.1	Yes
C	9	Slowed		274.0	Yes
C	9	Stopped		275.8	Yes
C	10	Slowed		317.4	Yes
C	10	Slowed	Near-collision	213.4	Yes
C	10	Slowed	Near-collision	186.6	Yes
D	9	Slowed		384.5	Yes
D	9	Stopped		268.8	Yes
D	9	Stopped		213.2	Yes
D	10	Slowed	Near-collision	222.2	Yes
D	10	Stopped		333.6	Yes
D	10	Stopped		319.3	Yes

Alerts were possible on the conflict traffic on six taxi head-on trials (i.e., NACp 10) (Table 17). Nine caution alerts were generated over all six trials prior to reaching the conflict intersection, at an average distance of 577 ft from the traffic ($\sigma = 300$ ft). The caution alert was generated earlier when the ownship was traveling faster. Multiple caution alerts were issued for two crews; i.e., alert toggling. No provisions were made to reduce the occurrence of alert toggling which occurs when multiple instances of indications or alerts are generated as a result of position accuracy or aircraft maneuvering. Alert toggling can be a distraction to the flight crew and could cause mistrust in the technology. A warning alert was also generated on all three trials, 268 ft mean distance from the traffic ($\sigma = 15$ ft).

Three trials where traffic was transmitting NACp 10 accuracy (i.e., with alerts generated) resulted in near-collisions per our criteria. The near-collision calculation was made by determining whether the aircraft CGs were separated by less than 185 ft laterally; which is different than the CPA calculation (slant range). Two of the near-collisions occurred at the conflict intersection because the pilot slowed instead of stopping and eventually met the near-collision criteria. The third near-collision occurred when taxiing behind the conflict traffic after turning at the conflict intersection. The subject crew had gotten behind in following the STBO guidance because of waiting for the conflict traffic to turn ahead, and was trying to reacquire the STBO planned timing but, because they were judging separation distance visually, met the near-collision criteria.

After turning at the subject intersection, alerts were generated while following the taxiing conflict traffic (Table 17). As in the near-collision trial above, the pilots were trying to reacquire their STBO conformance and taxied close enough to the traffic to generate alerts. Four caution alerts were generated for three trials, at an average distance of 280 ft from the traffic (σ = 83 ft). One warning alert was generated on one trial 222 ft from the traffic.

Alerts were not generated for any other traffic during these off-nominal trials.

Table 17. Part 2 Taxi Head-on Scenario Conflict Traffic IA Results.

Map	Crew	IA	Distance from Traffic (feet)	Location	GS
C	1	Caution	551.3	Approaching intersection	8.2
C	5	Caution	309.6	Approaching intersection	5.3
C	9	Caution	862.2	Approaching intersection	15.2
C	9	Caution	308.1	Approaching intersection	1.2
D	2	Caution	466.2	Approaching intersection	7.9
D	2	Caution	406.1	Approaching intersection	6.0
D	2	Caution	281.4	Approaching intersection	7.8
D	6	Caution	1,011.4	Approaching intersection	16.0
D	10	Caution	995.7	Approaching intersection	17.1
C	5	Warning	270.1	At intersection	6.4
C	9	Warning	282.1	Approaching intersection	6.2
D	2	Warning	251.5	Approaching intersection	8.2
C	5	Caution	277.5	Following traffic	14.5
C	5	Caution	216.4	Following traffic	7.1
C	9	Caution	229.2	Following traffic	14.6
D	10	Caution	398.8	Following traffic	21.0
C	9	Warning	222.5	Following traffic	14.4

6.2.2.2 <u>Taxi Intersection Conflict Scenario Results</u>

The taxi intersection scenario was given as Trial 6 of six trials for each crew. This scenario simulated a blunder, with the conflicting traffic missing its planned turn and instead, incurring from the right of the ownship, if the subject crew followed the STBO guidance.

One or both pilots were aware of the conflict traffic on each trial by either viewing the traffic symbol or traffic intent on the AMM or viewing OTW. For 10 of the taxi intersection trials, the ownship either slowed down or stopped for the taxiing traffic prior to the intersection (Table 18). On two trials, the pilots were early in following their STBO planned guidance (by 8 and 10 seconds) at the intersection, they were aware of the conflict traffic and they knew the aircraft missed its turn. The crews decided to speed up and turn in front of the traffic. The automated conflict traffic taxiing from behind overran the ownship while the crew was trying to follow their STBO guidance, causing the two collisions. Alerts were not generated for the conflict traffic on these two trials because the traffic was transmitting NACp 9 accuracy. Perhaps the crew was more willing to proceed ahead of the traffic when not provided with alerts.

Four trials resulted in near-collisions. Three of the near-collisions occurred at the conflict intersection. The fourth near-collision occurred when taxiing behind the conflict traffic after turning at the conflict intersection. The ownship taxied very close to the traffic near the end of the route, trying to cross the RTA point. Only one near-collision occurred on the trials in which alerts were generated.

Table 18. Part 2 Off-Nominal Taxi Intersection Scenario Results.

Map	NACp	Action	Outcome	CPA (feet)	Viewed Intent
C	9	Stopped		303.9	Yes
C	9	Slowed	Near-collision	214.6	Yes, late
C	9	Stopped	Near-collision	251.7	Yes
C	10	Stopped		262.9	Yes
C	10	Stopped	Near-collision	170.4	No, stopped based on caution
C	10	Stopped		220.5	Yes, stopped based on caution
D	9	Turned in front	Collision	36.2	Yes
D	9	Turned in front	Collision	42.2	Yes
D	9	Stopped	Near-collision	179.7	Yes, early
D	10	Stopped		303.0	Yes
D	10	Stopped		268.9	Yes
D	10	Stopped		235.4	Yes, early

Alerts were possible on six taxi intersection trials (NACp 10) (Table 19). A caution alert was generated for each of the six trials prior to reaching the conflict intersection, at an average distance of 460 ft from the traffic (σ = 32 ft). A warning alert was also generated on four of the trials, 265 ft mean distance from the traffic (σ = 7 ft).

After turning at the subject intersection, alerts were generated while following the conflict traffic (Table 19). The pilots were trying to reacquire their STBO conformance and taxied close enough to the traffic to generate alerts. Three caution alerts were generated for two trials, at an average distance of 410 ft from the traffic (σ = 123 ft). Multiple alerts were issued for one crew. One warning alert was generated on one trial 290 ft from the traffic.

Alerts were not generated for any other traffic during these off-nominal trials.

Table 19. Part 2 Taxi Intersection Scenario Conflict Traffic IA Results.

Map	Crew	IA	Distance from Traffic (feet)	Location	GS
C	3	Caution	444.6	Approaching intersection	12.4
C	7	Caution	441.3	Approaching intersection	11.4
C	11	Caution	449.6	Approaching intersection	10.5
D	4	Caution	433.8	Approaching intersection	9.5
D	8	Caution	518.3	Approaching intersection	13.0
D	12	Caution	474.9	Approaching intersection	10.6
C	3	Warning	266.5	Slowed at intersection	1.9
C	7	Warning	258.5	Stopped at intersection	0.0
C	11	Warning	260.3	Stopped at intersection	0.0
D	8	Warning	273.2	Slowed at intersection	2.2
C	7	Caution	511.4	Following Traffic	19.8
D	12	Caution	445.4	Following Traffic	23.5
D	12	Caution	273.3	Following Traffic	10.4
D	12	Warning	290.4	Following Traffic	12.1

6.2.3 Part 2 Qualitative Results

Post-run and post-test questionnaires were administered. Most of the questions were rated on a scale of 1 ("strongly disagree", "low", "not useful") to 7 ("strongly agree", "high", "very useful"). An ANOVA was conducted on the questionnaire responses. Statistically significant results are presented at the $\underline{p} < 0.05$ level.

6.2.3.1 Part 2 Run Questionnaire Results

At the end of each test trial, the evaluation pilots completed a post run questionnaire (Appendix G, Table G.2), a SART questionnaire (Appendix G, Table G.3) to evaluate situation awareness, and a TLX questionnaire (Appendix G, Table G.4) to rate workload. The individual post run questionnaire items were grouped according to pre-test subject matter expert reviews and on exploratory factor analysis that resulted in several constructs that have similar underlying meaning. The individual questions and the grouped questionnaire constructs were analyzed. For the nominal test trials, the questionnaire ratings were analyzed by Map condition, HUD condition, and Map by HUD interaction. For the off-nominal test trials, the ratings were analyzed by Map condition, NACp condition, and Map by NACp interaction. The HUD was not utilized during the off-nominal trials; therefore, analysis was not conducted for the HUD condition.

6.2.3.1.1 Post Run Questionnaire

For analysis of run questions A through I for the off-nominal trials, MANOVA statistics revealed a statistically significant effect for Map condition only, $F(9, 36) = 4.974$, $\underline{p} = 0.000$. The NACp condition, $F(9,36) = 1.356$, $\underline{p} = 0.244$, and Map by NACp interaction, $F(9,36) = 0.687$, $\underline{p} = 0.716$, were not significantly different; therefore, only the Map condition was analyzed for the ANOVA (results shown below by question).

Question A. I was aware of ownship position.

For the nominal test trials, there was not a significant main effect for Map condition ($F(1, 92) = 2.265$, $\underline{p} = 0.136$), HUD condition ($F(1, 92) = 1.531$, $\underline{p} = 0.219$), or Map by HUD interaction ($F(1, 92) = 0.252$, $\underline{p} = 0.617$) (Appendix I, Table I.1) for Question A responses. Pilots reported similar mean ratings for both the Map C ($\mu = 6.9$, $\sigma = 0.3$) and Map D ($\mu = 6.6$, $\sigma = 0.9$) conditions and the HUD ($\mu = 6.8$, $\sigma = 0.5$) and no HUD ($\mu = 6.8$, $\sigma = 0.8$) conditions (Appendix I, Table I.2) for providing ownship position awareness. The number of responses for each rating value is presented in Figure 68.

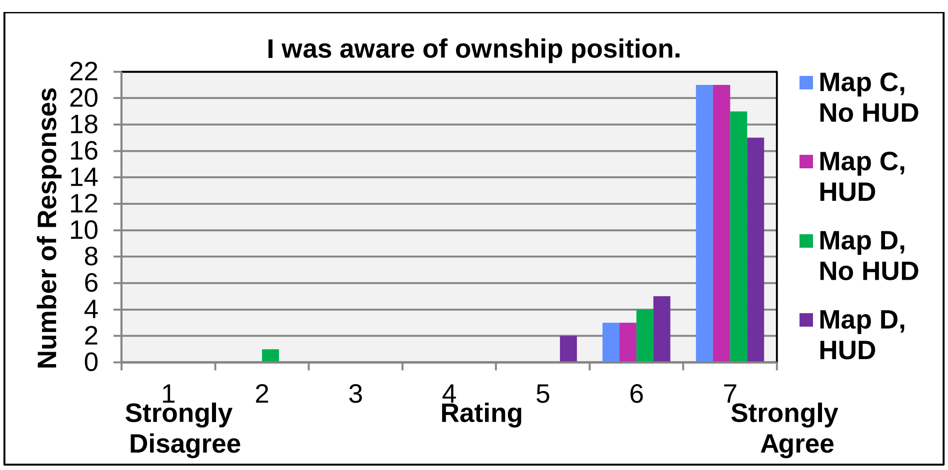


Figure 68. Question A Data for Part 2 Nominal Trials (N = 24).

For the off-nominal trials, there was not a significant effect for Map condition, F(1, 46) = 0.246, p = 0.622 (Appendix I, Table I.3). The flight crews reported similar mean ratings for both the Map C (μ = 6.9, σ = 0.3) and Map D (μ = 6.6, σ = 0.7) conditions (Appendix I, Table I.4) for providing ownship position awareness. The number of responses for each rating value is presented in Figure 69.

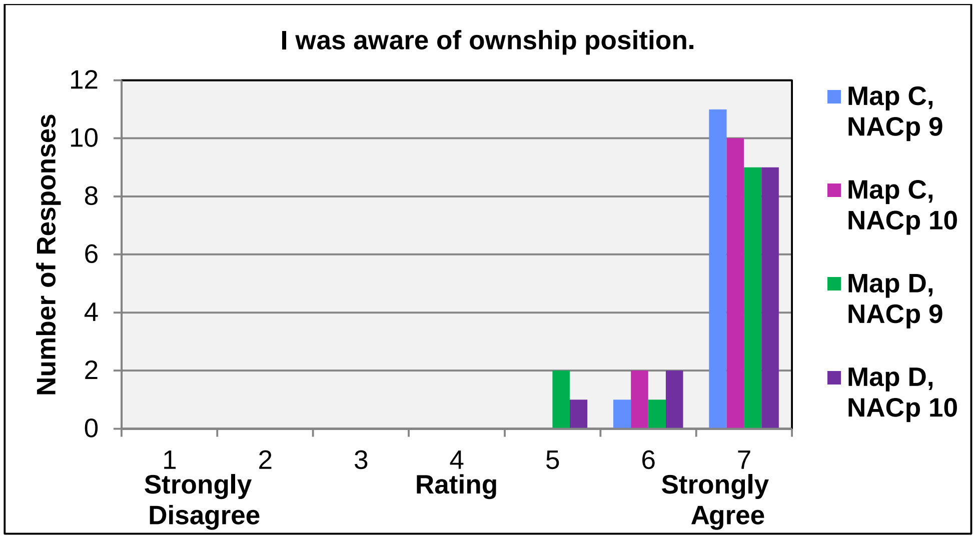


Figure 69. Question A Data for Part 2 Off-Nominal Trials (N = 12).

Question B. The display concepts were effective for maintaining my situation awareness of ownship.

For the nominal test trials, there was not a significant main effect for Map condition (F(1, 92) = 0.006, p = 0.938), HUD condition (F(1, 92) = 0.082, p = 0.775), or Map by HUD interaction (F(1, 92) = 2.215, p = 0.140) (Appendix I, Table I.5) for Question B responses. Pilots reported similar mean ratings for both the Map C (μ = 6.6, σ = 0.5) and Map D (μ = 6.5, σ = 0.7) conditions and for the HUD (μ = 6.5, σ = 0.6) and no HUD (μ = 6.6, σ = 0.6) conditions (Appendix I, Table I.6) regarding effectiveness for maintaining situation awareness of ownship. The number of responses for each rating value is presented in Figure 70.

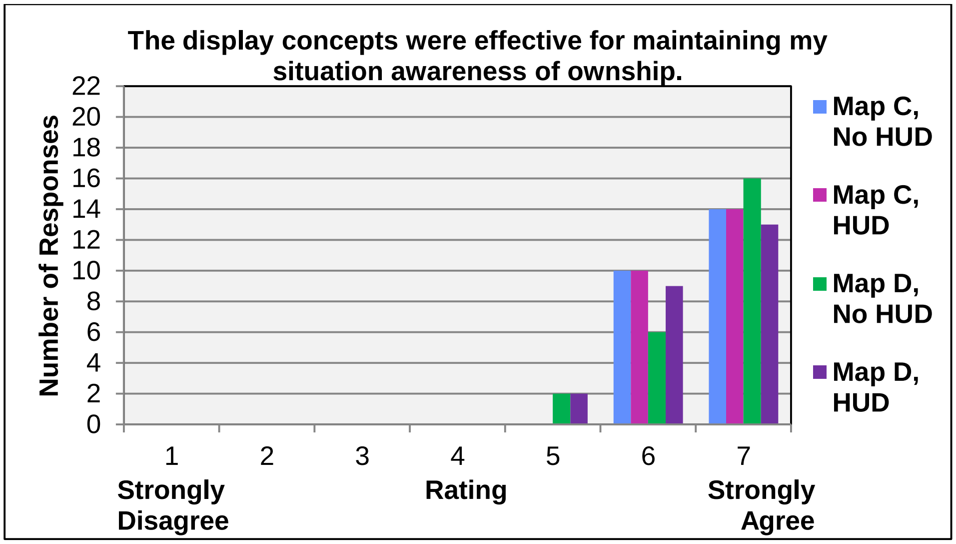


Figure 70. Question B Data for Part 2 Nominal Trials (N = 24).

For the off-nominal trials, there was not a statistically significant effect for Map condition, F(1, 46) = 0.899, p = 0.342 (Appendix I, Table I.7). The pilots rated the Map D condition (μ = 6.5, σ = 0.7) significantly higher than the Map C condition (μ = 6.5, σ = 0.6) (Appendix I, Table I.8) regarding effectiveness for maintaining situation awareness of ownship. The number of responses for each rating value is presented in Figure 71.

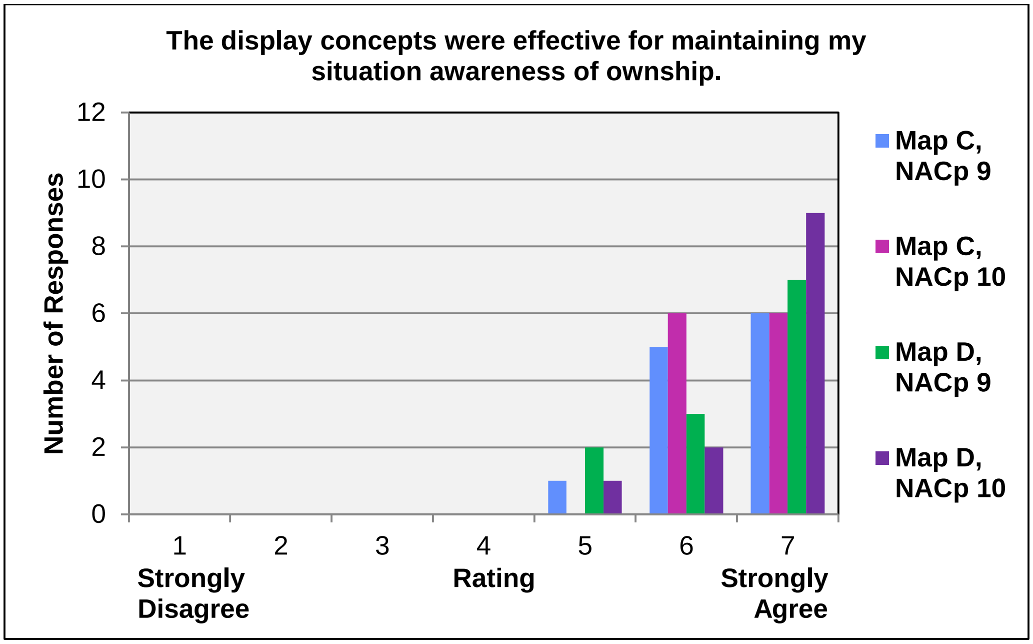


Figure 71. Question B Data for Part 2 Off-Nominal Trials (N = 12).

Question C. I was aware of traffic and other vehicles during operations.

For the nominal test trials, there was not a significant main effect for Map condition (F(1, 92) = 2.362, p = 0.128), HUD condition (F(1, 92) = 1.464, p = 0.229), or Map by HUD interaction (F(1, 92) = 3.004, p = 0.086) (Appendix I, Table I.9) for Question C responses. Pilots reported similar mean ratings for both the Map C (μ = 6.5, σ = 0.6) and Map D (μ = 6.4, σ = 0.6) conditions and for the HUD (μ = 6.4, σ = 0.6) and no HUD (μ = 6.5, σ = 0.6) conditions (Appendix I, Table I.10) for traffic awareness. The number of responses for each rating value is presented in Figure 72.

For the off-nominal trials, there was not a statistically significant effect for Map condition, F(1, 46) = 1.25, p = 0.272 (Appendix I, Table I.11). The pilots rated the Map D condition (μ = 6.3, σ = 0.9) significantly higher than the Map C condition (μ = 6.1, σ = 1.1) (Appendix I, Table I.12) for traffic awareness. The number of responses for each rating value is presented in Figure 73.

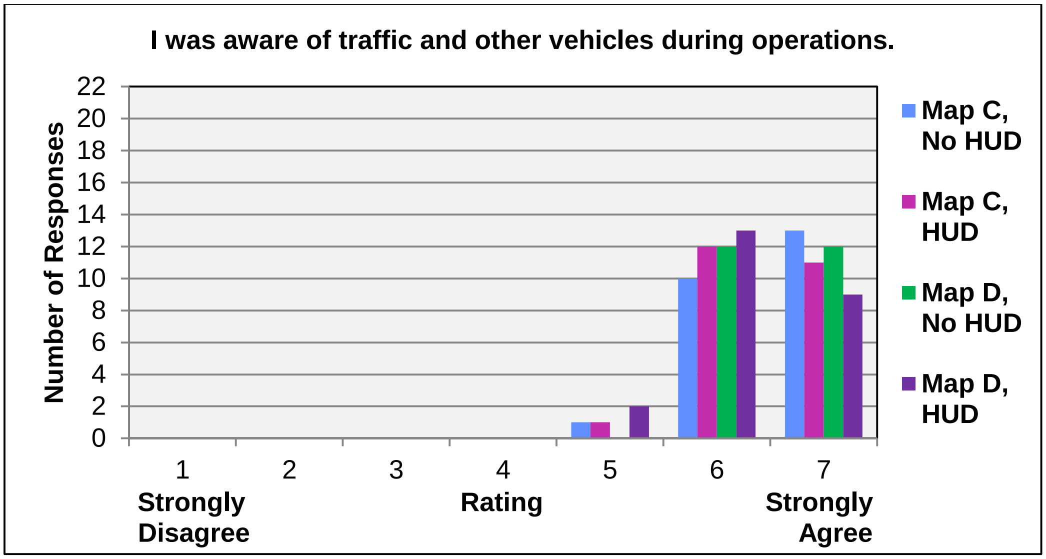


Figure 72. Question C Data for Part 2 Nominal Trials (N = 24).

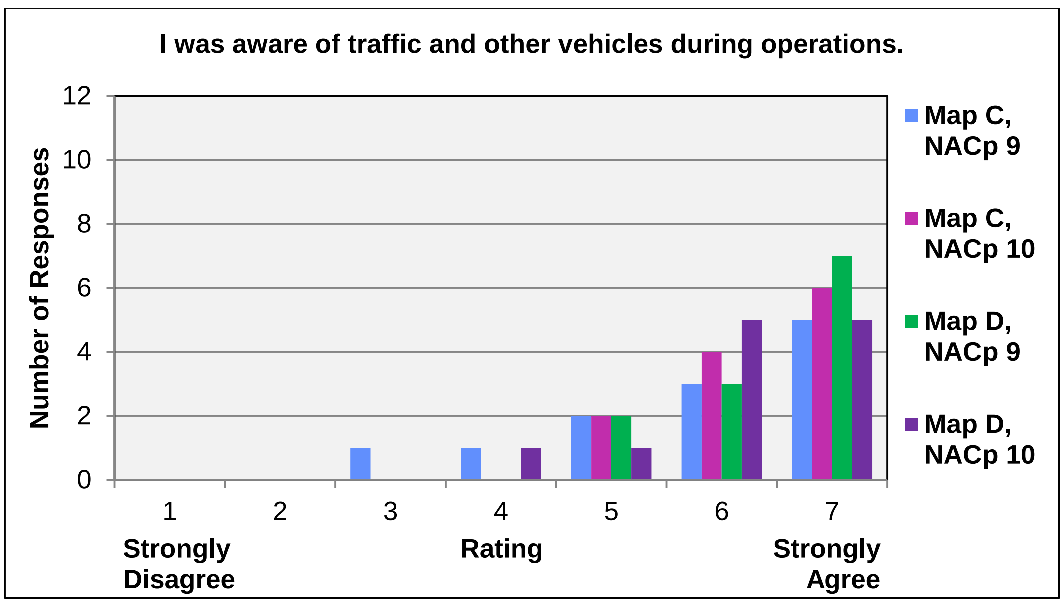


Figure 73. Question C Data for Part 2 Off-Nominal Trials (N = 12).

Question D. The display concepts provided effective awareness of traffic intent information.

For the nominal test trials, there was not a significant main effect for Map condition ($F(1, 92) = 0.419$, $\underline{p} = 0.519$), HUD condition ($F(1, 92) = 0.346$, $\underline{p} = 0.558$), or Map by HUD interaction ($F(1, 92) = 2.910$, $\underline{p} = 0.091$) (Appendix I, Table I.13) for Question D responses. Pilots reported similar mean ratings for both the Map C ($\mu = 6.1$, $\sigma = 0.8$) and Map D ($\mu = 6.3$, $\sigma = 0.6$) conditions and for the HUD ($\mu = 6.1$, $\sigma = 0.8$) and no HUD ($\mu = 6.3$, $\sigma = 0.7$) conditions (Appendix I, Table I.14) for awareness of traffic intent information. The number of responses for each rating value is presented in Figure 74.

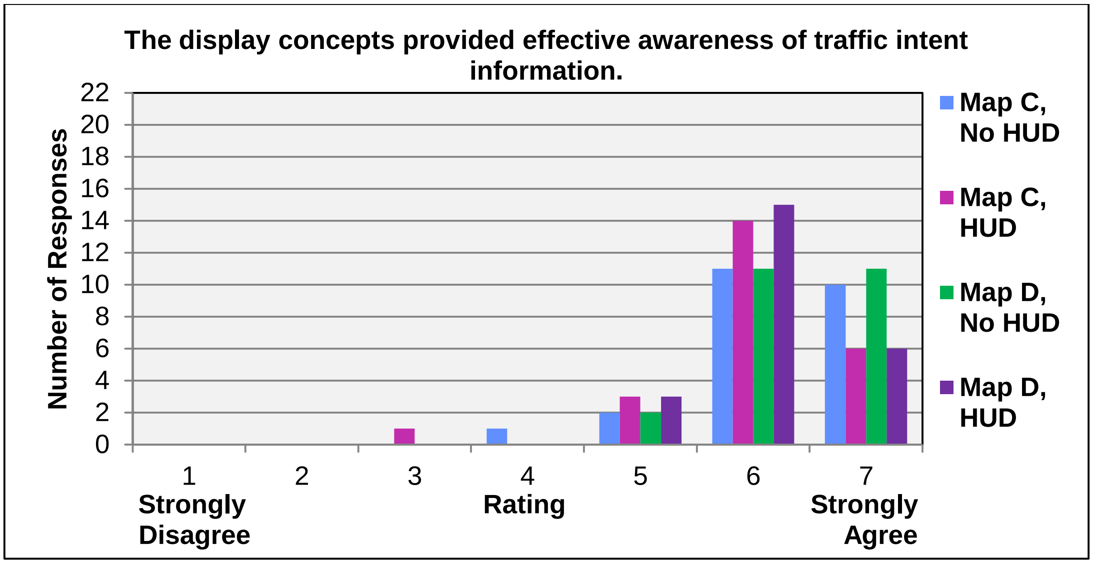


Figure 74. Question D Data for Part 2 Nominal Trials (N = 24).

For the off-nominal trials, there was not a statistically significant effect for Map condition, $F(1, 46) = 1.824$, $\underline{p} = 0.183$ (Appendix I, Table I.15). The flight crews reported similar mean ratings for both the Map C ($\mu = 5.8$, $\sigma = 1.2$) and Map D ($\mu = 5.5$, $\sigma = 1.3$) conditions (Appendix I, Table I.16) for awareness of traffic intent information. The number of responses for each rating value is presented in Figure 75.

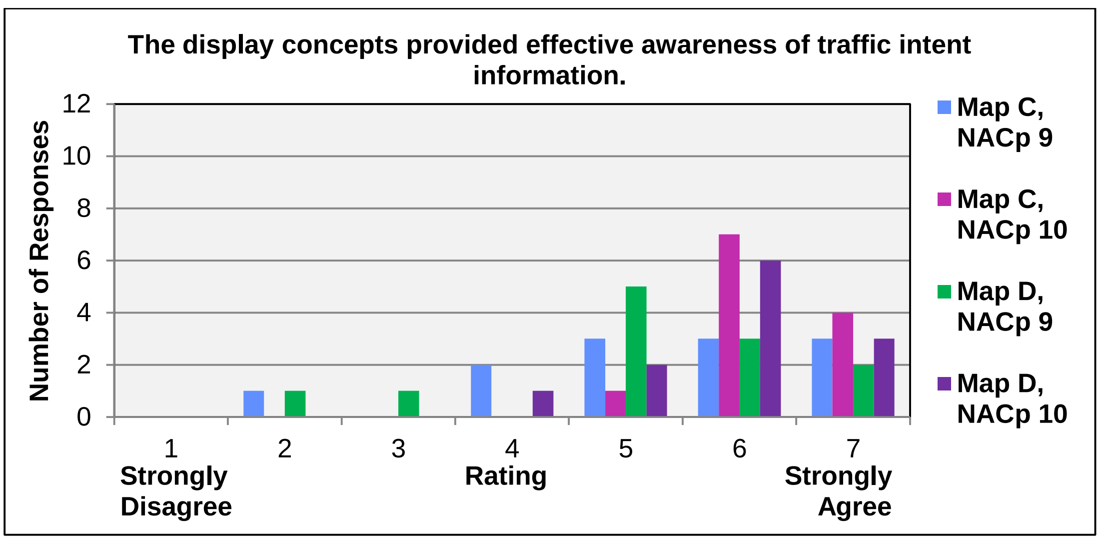


Figure 75. Question D Data for Part 2 Off-Nominal Trials (N = 12).

Question E. The display concepts were effective for required time-of-arrival taxi conformance.

For the nominal test trials, there was not a significant main effect for Map condition ($F(1, 92) = 1.680$, $\underline{p} = 0.198$), HUD condition ($F(1, 92) = 0.014$, $\underline{p} = 0.906$), or Map by HUD interaction ($F(1, 92) = 2.721$, $\underline{p} = 0.102$) (Appendix I, Table I.17) for Question E responses. Pilots reported the same mean ratings for both the Map C ($\mu = 6.4$, $\sigma = 0.7$) and Map D ($\mu = 6.4$, $\sigma = 0.7$) conditions and for the HUD ($\mu = 6.4$, $\sigma = 0.7$) and no HUD ($\mu = 6.4$, $\sigma = 0.7$) conditions (Appendix I, Table I.18) for required time-of-arrival conformance. The number of responses for each rating value is presented in Figure 76.

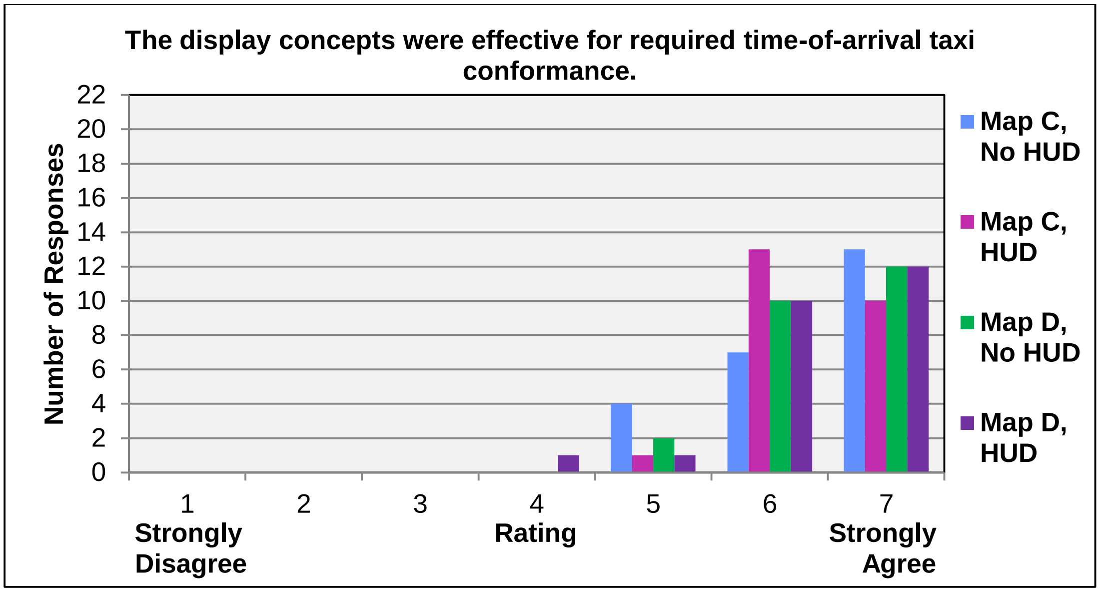


Figure 76. Question E Data for Part 2 Nominal Trials (N = 24).

For the off-nominal trials, there was not a statistically significant effect for Map condition, F(1, 46) = 2.793, p = 0.101 (Appendix I, Table I.19). The flight crews reported similar mean ratings for both the Map C (μ = 6.1, σ = 0.7) and Map D (μ = 6.3, σ = 0.6) conditions (Appendix I, Table I.20) for required time-of-arrival conformance. The number of responses for each rating value is presented in Figure 77.

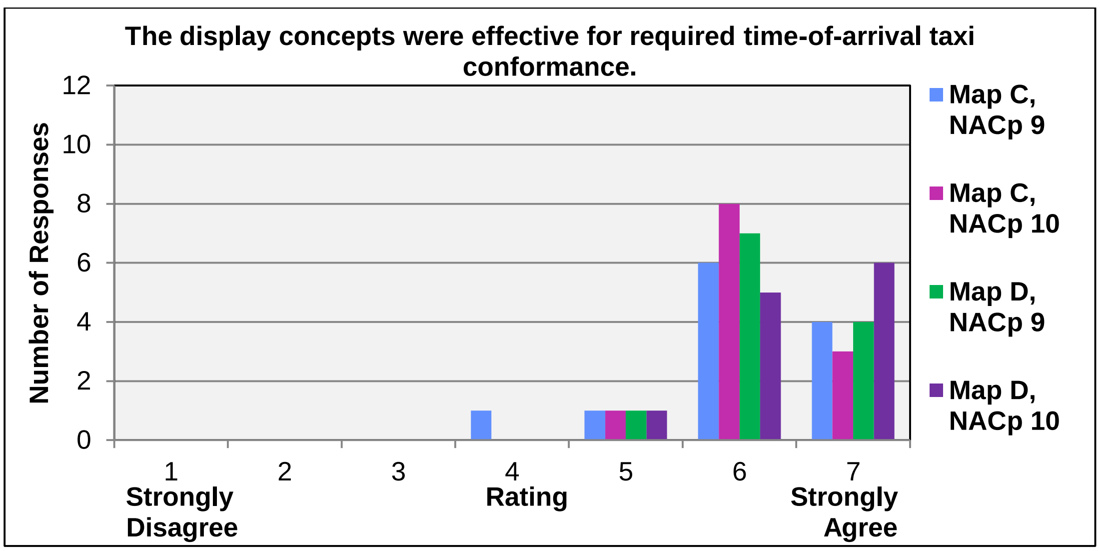


Figure 77. Question E Data for Part 2 Off-Nominal Trials (N = 12).

Question F. The display location of STBO taxi guidance information was effective for situation awareness.

For the nominal test trials, there was not a significant main effect for Map condition (F(1, 92) = 0.232, p = 0.631), HUD condition (F(1, 92) = 0.443, p = 0.507), or Map by HUD interaction (F(1, 92) = 0.801, p = 0.373) (Appendix I, Table I.21) for Question F responses. Pilots reported similar mean ratings for both the Map C (μ = 6.4, σ = 0.5) and Map D (μ = 6.1, σ = 1.0) conditions and for the HUD (μ = 6.3, σ = 0.7) and no HUD (μ = 6.2, σ = 1.0) conditions (Appendix I, Table I.22) for effectiveness of display location of STBO taxi guidance information for situation awareness. The number of responses for each rating value is presented in Figure 78.

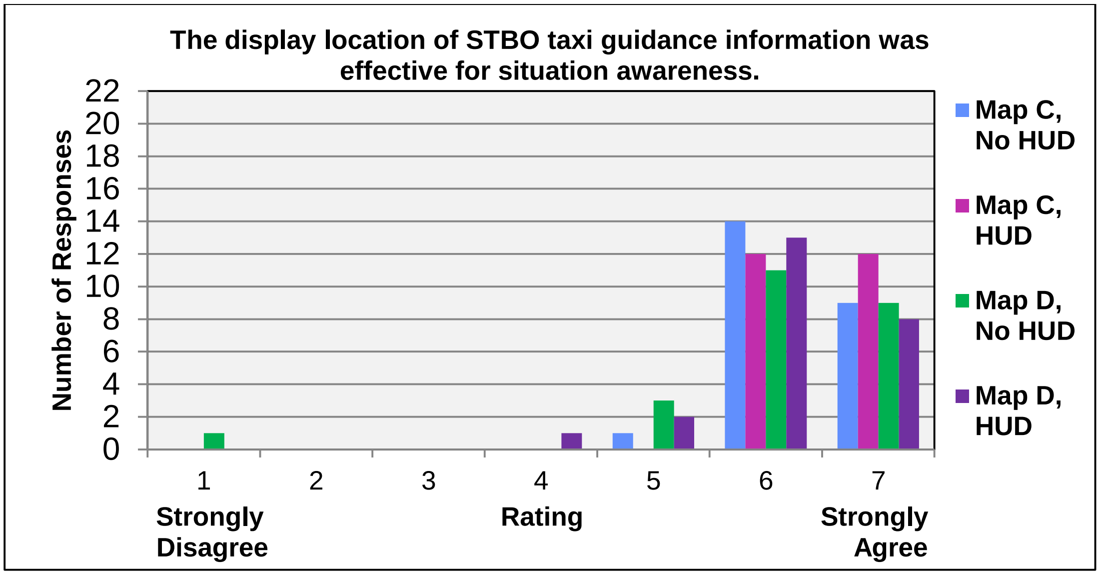


Figure 78. Question F Data for Part 2 Nominal Trials (N = 24).

For the off-nominal trials, there was not a statistically significant effect for Map condition, $F(1, 46) = 2.507$, $\underline{p} = 0.120$ (Appendix I, Table I.23). The flight crews reported similar mean ratings for both the Map C (μ = 6.2, σ = 0.7) and Map D (μ = 6.3, σ = 0.6) conditions (Appendix I, Table I.24) for effectiveness of display location of STBO taxi guidance information for situation awareness. The number of responses for each rating value is presented in Figure 79.

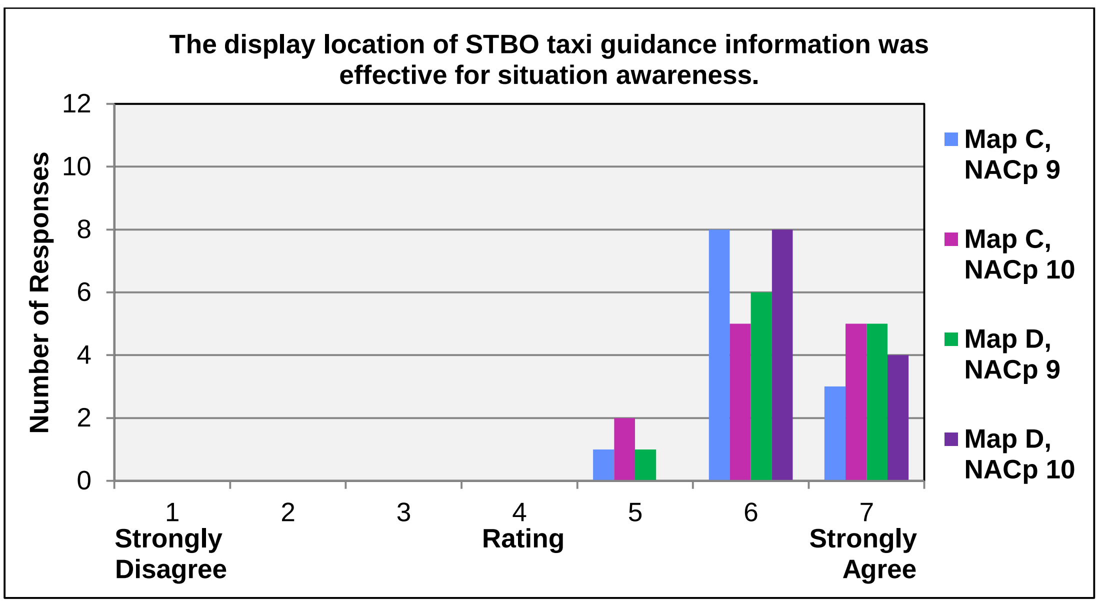


Figure 79. Question F Data for Part 2 Off-Nominal Trials (N = 12).

Question G. The display location of STBO taxi guidance information was effective for mental workload.

For the nominal test trials, there was not a significant main effect for Map condition ($F(1, 92) = 1.365$, $\underline{p} = 0.246$), HUD condition ($F(1, 92) = 0.705$, $\underline{p} = 0.403$), or Map by HUD interaction ($F(1, 92) = 2.942$, $\underline{p} = 0.090$) (Appendix I, Table I.25) for Question G responses. Pilots reported similar mean ratings for both the Map C ($\mu = 6.3$, $\sigma = 0.6$) and Map D ($\mu = 6.0$, $\sigma = 1.0$) conditions and for the HUD ($\mu = 6.1$, $\sigma = 0.7$) and no HUD ($\mu = 6.2$, $\sigma = 0.9$) conditions (Appendix I, Table I.26) for effectiveness of display location of STBO taxi guidance information for mental workload. The number of responses for each rating value is presented in Figure 80.

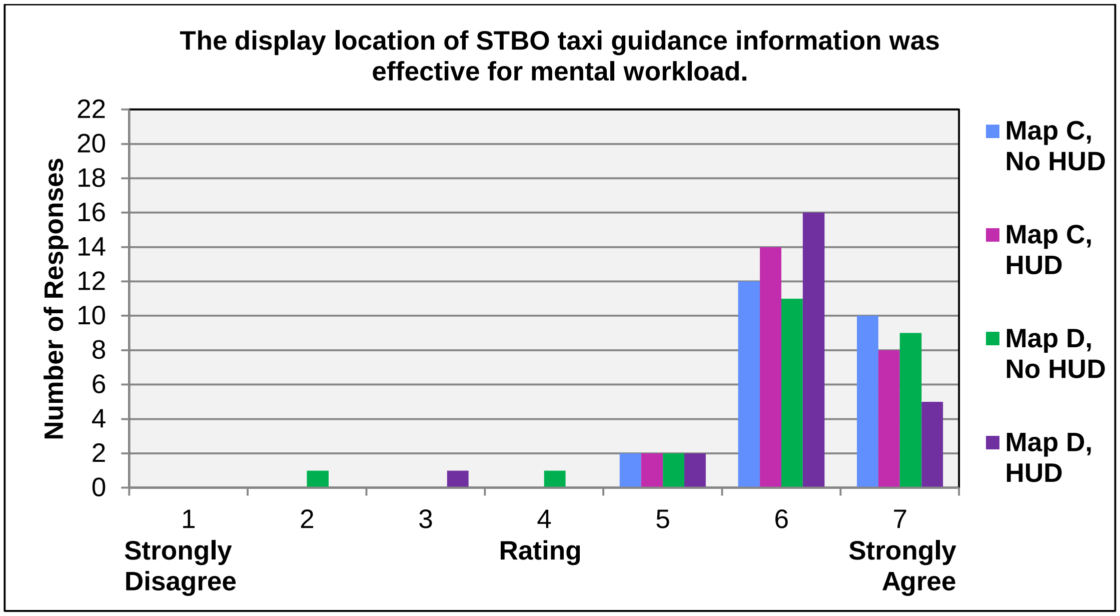


Figure 80. Question G Data for Part 2 Nominal Trials (N = 24).

For the off-nominal trials, there was not a statistically significant effect for Map condition, $F(1, 46) = 0.951$, $\underline{p} = 0.329$ (Appendix I, Table I.27). The pilots rated the Map D condition ($\mu = 6.1$, $\sigma = 0.6$) significantly higher than the Map C condition ($\mu = 6.1$, $\sigma = 0.8$) (Appendix I, Table I.28) for effectiveness of display location of STBO taxi guidance information for mental workload. The number of responses for each rating value is presented in Figure 81.

Question H. The display concepts contributed to perceived safety during operation.

For the nominal test trials, there was not a significant main effect for Map condition ($F(1, 92) = 0.232$, $\underline{p} = 0.631$), HUD condition ($F(1, 92) = 2.452$, $\underline{p} = 0.121$), or Map by HUD interaction ($F(1, 92) = 0.015$, $\underline{p} = 0.904$) (Appendix I, Table I.29) for Question H responses. Pilots reported similar mean ratings for both the Map C ($\mu = 6.5$, $\sigma = 0.6$) and Map D ($\mu = 6.3$, $\sigma = 0.9$) conditions and for the HUD ($\mu = 6.4$, $\sigma = 0.6$) and no HUD ($\mu = 6.4$, $\sigma = 0.9$) conditions (Appendix I, Table I.30) for display concepts contributing to perceived safety. The number of responses for each rating value is presented in Figure 82.

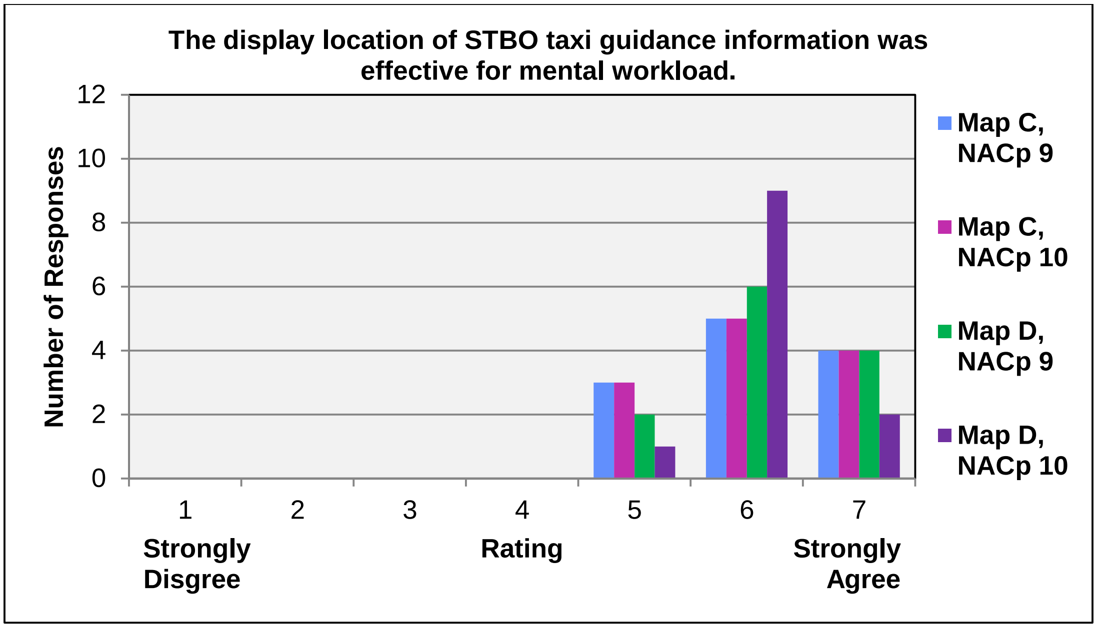


Figure 81. Question G Data for Part 2 Off-Nominal Trials (N = 12).

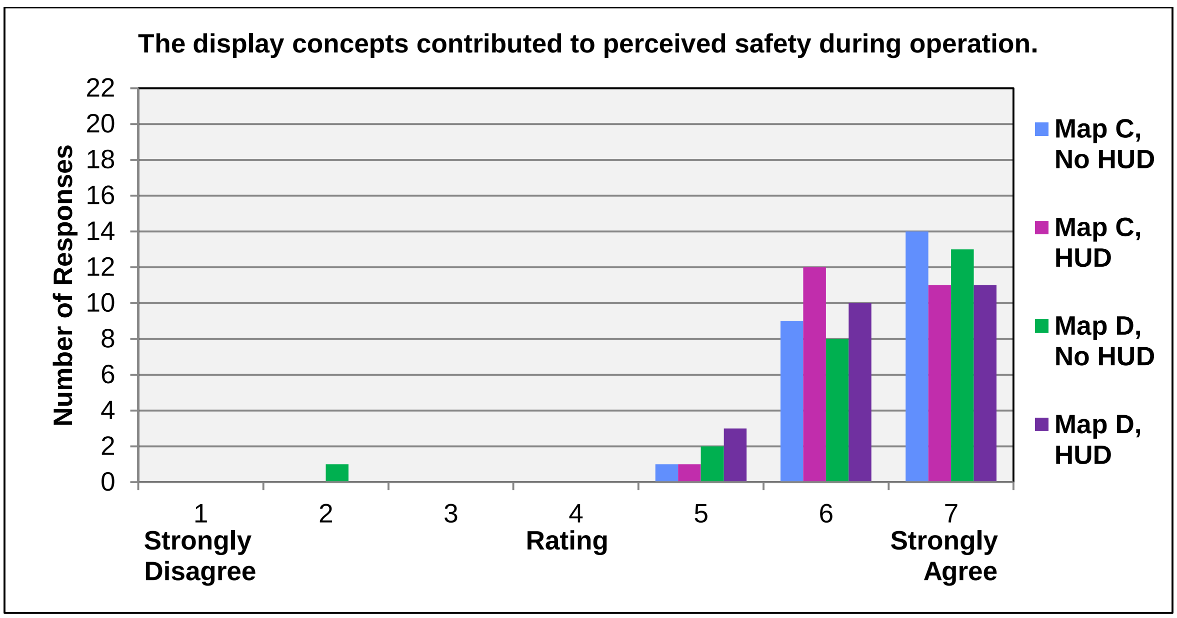


Figure 82. Question H Data for Part 2 Nominal Trials (N = 24).

For the off-nominal trials, there was not a statistically significant effect for Map condition, $F(1, 46) = 1.465$, $p = 0.229$ (Appendix I, Table I.31). The pilots rated the Map D condition ($\mu = 6.3$, $\sigma = 0.6$) significantly higher than the Map C condition ($\mu = 6.2$, $\sigma = 1.0$) (Appendix I, Table I.32) for display concepts contributing to perceived safety. The number of responses for each rating value is presented in Figure 83.

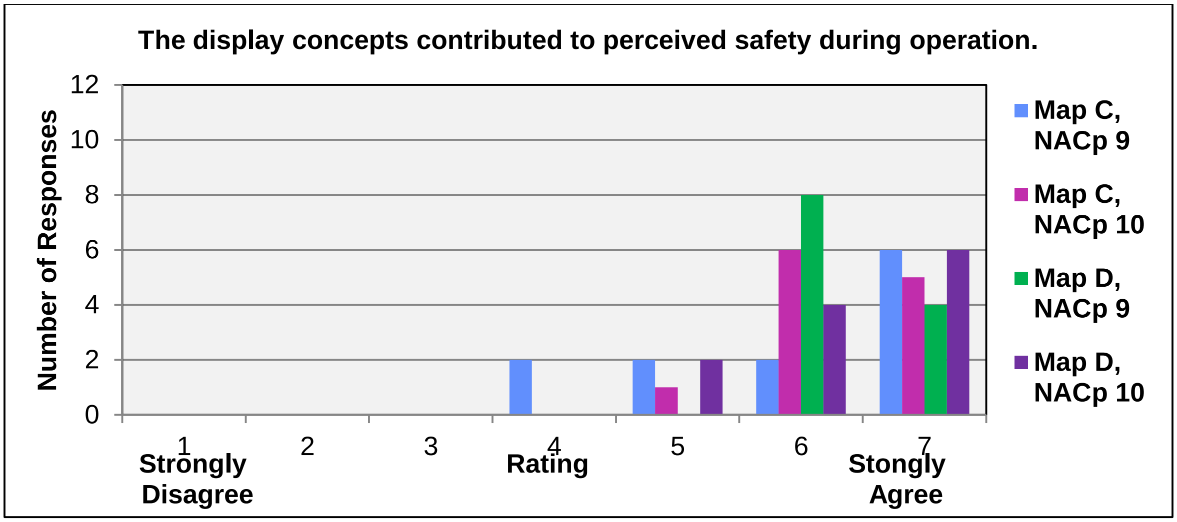


Figure 83. Question H Data for Part 2 Off-Nominal Trials (N = 12).

Question I. The display concepts were effective for detection of potential surface conflicts during STBO taxi.

Question I was only administered during the off-nominal (surface conflict) test trials. There was not a statistically significant effect for Map condition, $F(1, 46) = 1.310$, $p = 0.258$ (Appendix I, Table I.33). The pilots reported a slightly higher mean rating for the Map D condition ($\mu = 6.0$, $\sigma = 1.0$) than the Map C condition ($\mu = 5.7$, $\sigma = 1.7$) (Appendix I, Table I.34) for detection of potential surface conflicts during STBO taxi. The number of responses for each rating value is presented in Figure 84.

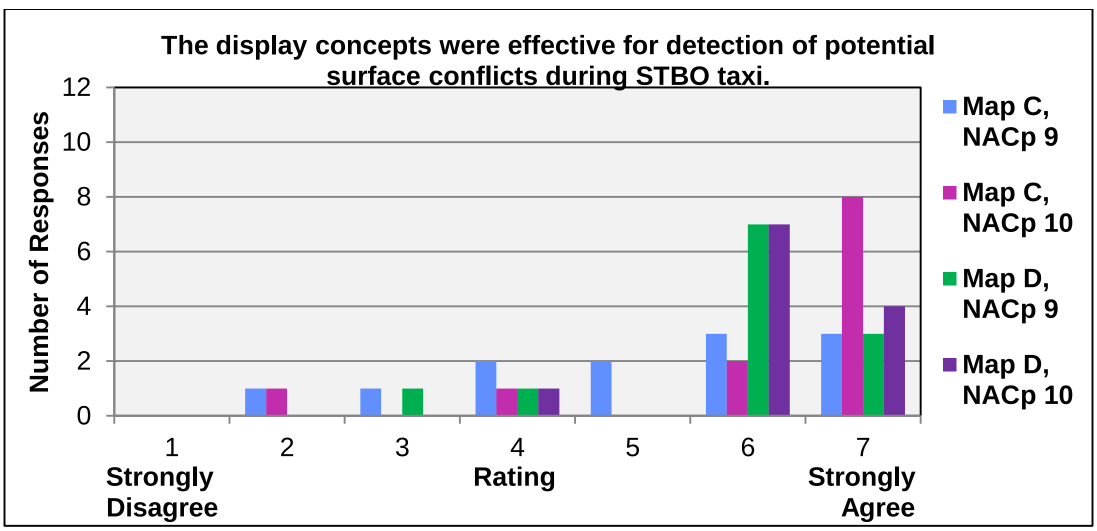


Figure 84. Question I Data for Part 2 Off-Nominal Trials (N = 12).

6.2.3.1.2 Questionnaire Constructs

Task Management

Flight crew responses to run questions A, B, and C were combined to form the Task Management construct. For the nominal test trials, there was not a significant main effect for Map condition (F(1, 92) = 2.728, p = 0.102), HUD condition (F(1, 92) = 0.303, p = 0.583), or Map by HUD interaction (F(1, 92) = 0.109, p = 0.742) (Appendix I, Table I.35) for Task Management construct responses. Pilots reported similar mean ratings for both the Map C (μ = 6.6, σ = 0.5) and Map D (μ = 6.5, σ = 0.7) conditions and for the HUD (μ = 6.5, σ = 0.6) and no HUD (μ = 6.6, σ = 0.7) conditions (Appendix I, Table I.36). The number of responses for each rating value is presented in Figure 85.

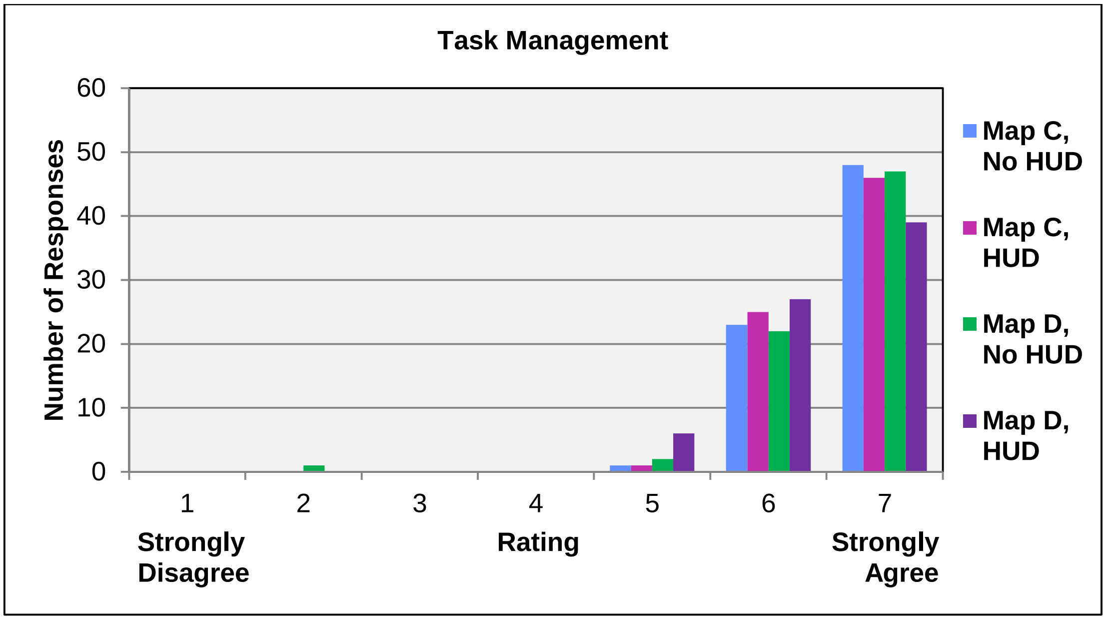


Figure 85. Task Management Construct Data for Part 2 Nominal Trials (N = 72).

For the off-nominal trials, there was not a statistically significant effect for Map condition, F(1, 44) = 0.165, p = 0.689), NACp condition, F(1, 44) = 0.179, p = 0.675, or Map by NACp interaction, F(1, 44) = 0.145, p = 0.712 (Appendix I, Table I.37). Pilots reported similar mean ratings for both the Map C (μ = 6.5, σ = 0.8) and Map D (μ = 6.5, σ = 0.8) conditions and the NACp 9 (μ = 6.4, σ = 0.9) and NACp 10 (μ = 6.5, σ = 0.7) conditions (Appendix I, Table I.38). The number of responses for each rating value is presented in Figure 86.

Communicative Efficacy

Flight crew responses to run questions D, E, F, and G were combined to form the Communicative Efficacy construct. For the nominal test trials, there was not a significant main effect for Map condition (F(1, 92) = 2.505, p = 0.117), HUD condition (F(1, 92) = 2.005, p = 0.160), or Map by HUD interaction (F(1, 92) = 1.173, p = 0.282) (Appendix I, Table I.39) for Communicative Efficacy construct responses. Pilots reported similar mean ratings for both the Map C (μ = 6.3, σ = 0.7) and Map D (μ = 6.2, σ = 0.9) conditions and for the HUD (μ = 6.2, σ = 0.7) and no HUD (μ = 6.3, σ = 0.8) conditions (Appendix I, Table I.40). The number of responses for each rating value is presented in Figure 87.

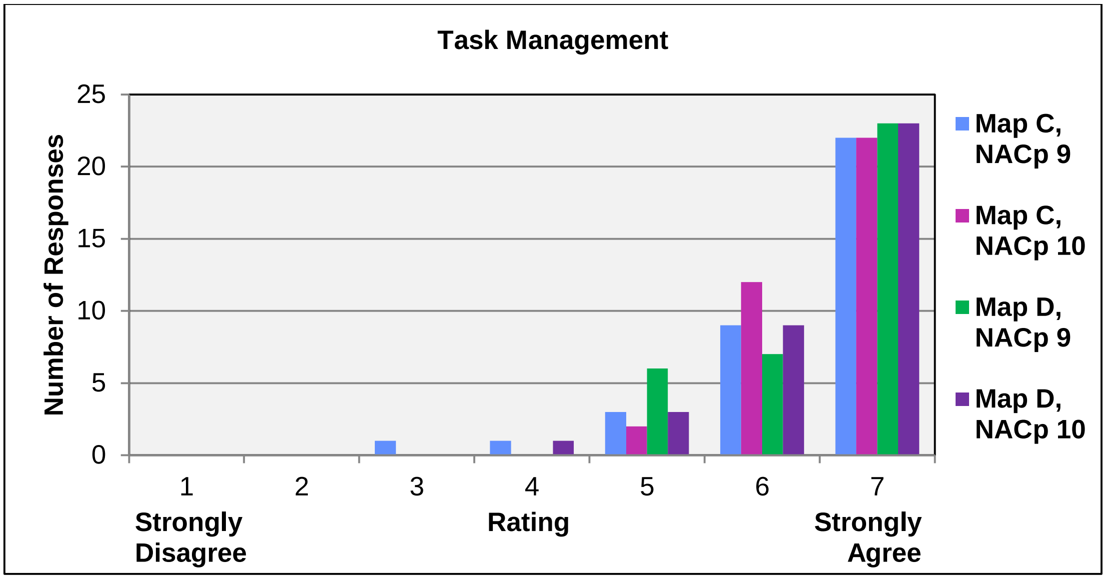


Figure 86. Task Management Construct Data for Part 2 Off-Nominal Trials (N = 36).

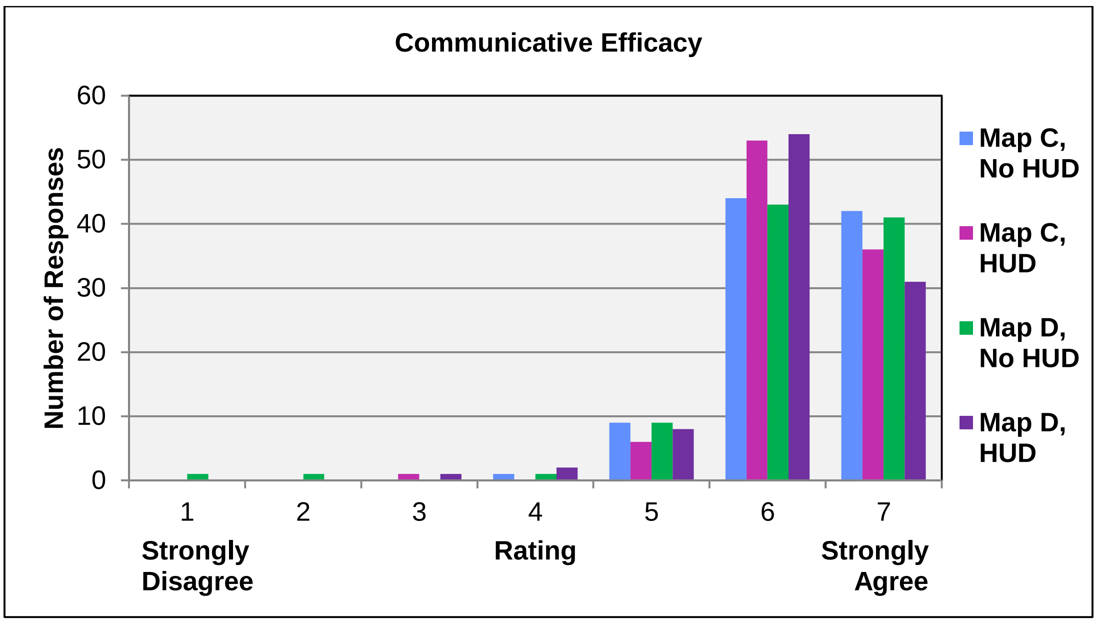


Figure 87. Communicative Efficacy Construct Data for Part 2 Nominal Trials (N = 96).

For the off-nominal trials, there was not a statistically significant effect for Map condition, $F(1, 44) = 0.542$, $\underline{p} = 0.468$), NACp condition ($F(1, 44) = 2.764$, $\underline{p} = 0.104$), or Map by NACp interaction ($F(1, 44) = 0.289$, $\underline{p} = 0.589$) (Appendix I, Table I.41). Pilots reported similar mean ratings for both the Map C ($\mu = 6.1$, $\sigma = 0.9$) and Map D ($\mu = 6.1$, $\sigma = 0.9$) conditions and for the NACp 9 ($\mu = 6.0$, $\sigma = 1.0$) and NACp 10 ($\mu = 6.2$, $\sigma = 0.7$) conditions (Appendix I, Table I.42). The number of responses for each rating value is presented in Figure 88.

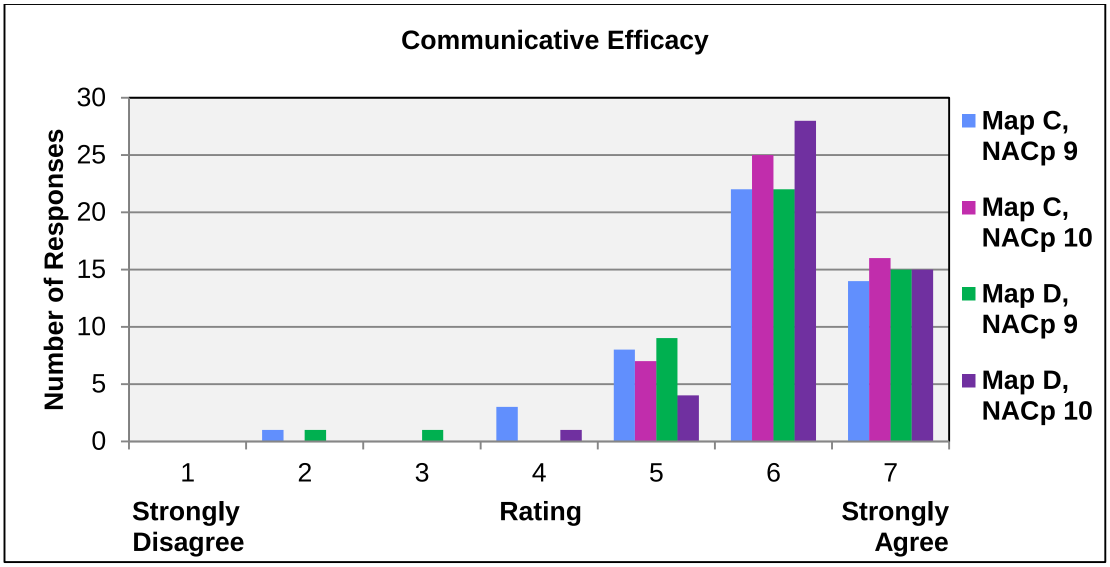


Figure 88. Communicative Efficacy Construct Data for Part 2 Off-Nominal Trials (N = 48).

Hazard Awareness

Flight crew responses to run questions H and I were combined to form the Hazard Awareness construct. The Hazard Awareness construct was only analyzed for the off-nominal (surface conflict) test trials. There was not a statistically significant effect for Map condition, $F(1, 44) = 0.392$, $p = 0.524$), NACp condition ($F(1, 44) = 2.681$, $p = 0.109$), or Map by NACp interaction ($F(1, 44) = 0.156$, $p = 0.687$) (Appendix I, Table I.43). Pilots reported similar mean ratings for both the Map C ($\mu = 5.9$, $\sigma = 1.4$) and Map D ($\mu = 6.2$, $\sigma = 0.9$) conditions and for the NACp 9 ($\mu = 5.8$, $\sigma = 1.2$) and NACp 10 ($\mu = 6.3$, $\sigma = 1.0$) conditions (Appendix I, Table I.44). The number of responses for each rating value is presented in Figure 89.

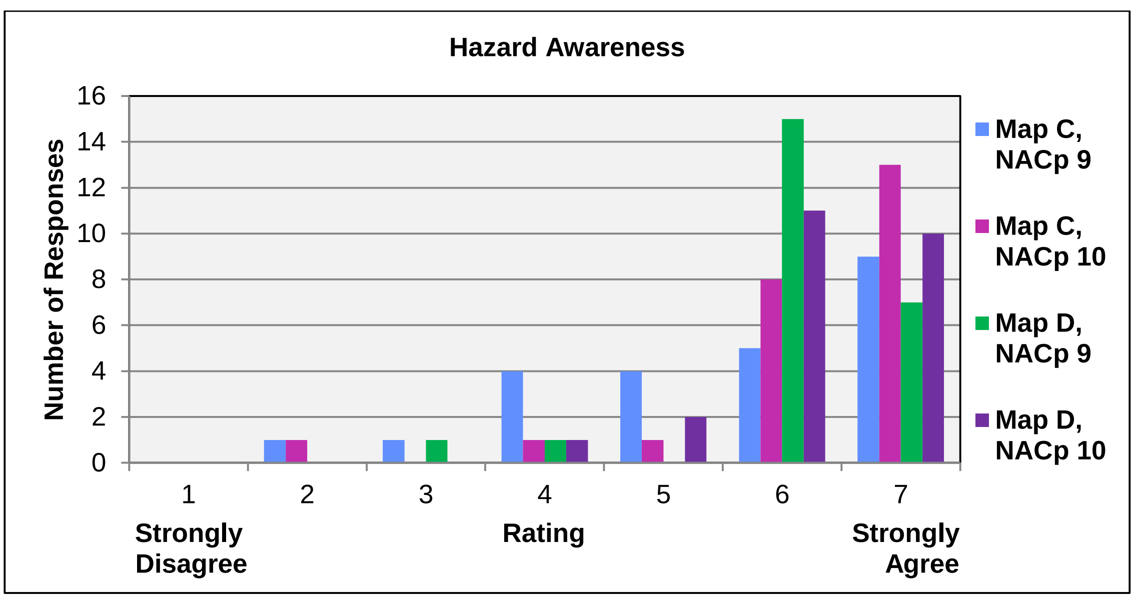


Figure 89. Hazard Awareness Construct Data for Part 2 Off-Nominal Trials (N = 24).

6.2.3.1.3 SART (Situational Awareness)

For the nominal test trials, there was not a significant main effect found for Map condition (F(1, 92) = 1.371, p = 0.245), HUD condition (F(1, 92) = 0.024, p = 0.876), or Map by HUD interaction (F(1, 92) = 1.030, p = 0.313) (Appendix I, Table I.45) for SART responses. The mean ratings for the Map and HUD conditions are as follows: Map C ($\mu = 7.3$, $\sigma = 3.0$), Map D ($\mu = 6.7$, $\sigma = 2.2$), HUD ($\mu = 6.9$, $\sigma = 2.7$), no HUD ($\mu = 7.0$, $\sigma = 2.5$) (Appendix I, Table I.46). The number of responses for each rating value is presented in Figure 90.

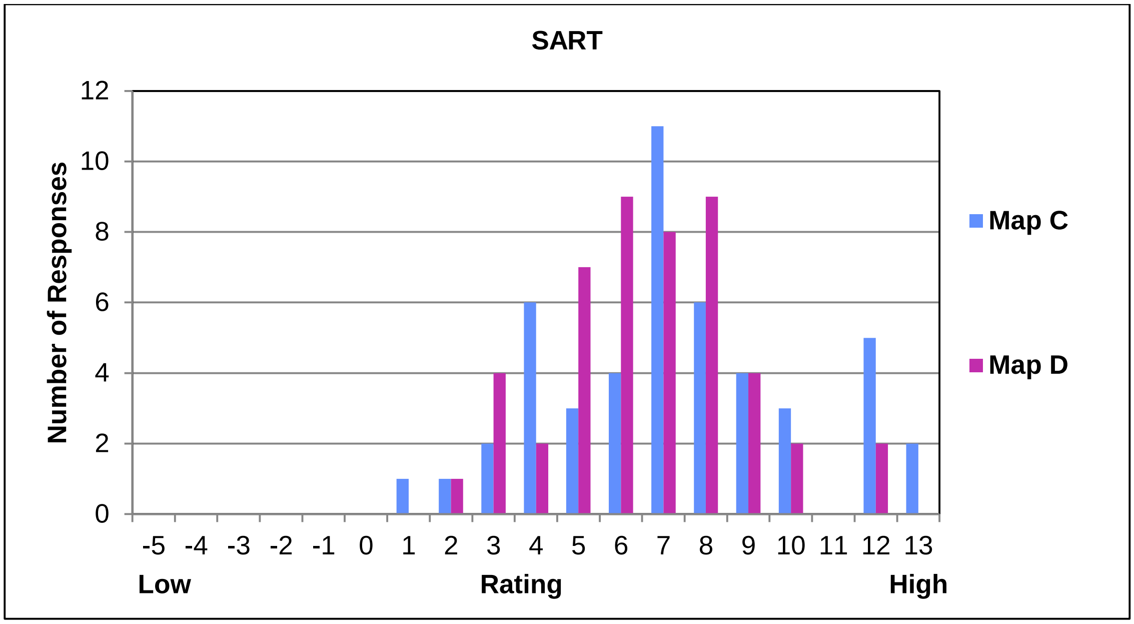


Figure 90. SART Situational Awareness Data for Part 2 Nominal Trials.

For the off-nominal trials, there was a statistically significant effect for Map condition, F(1, 44) = 7.432, p = 0.009) and a marginally significant effect for NACp condition (F(1, 44) = 3.997, p = 0.52). The Map by NACp interaction was not significant (F(1, 44) = 0.033, p = 0.857) (Appendix I, Table I.47). Pilots reported that the Map D condition ($\mu = 7.8$, $\sigma = 1.3$) was significantly higher for situation awareness than the Map C condition ($\mu = 6.5$, $\sigma = 1.8$) (Appendix I, Table I.48). Pilots also tended to report the NACp 9 condition ($\mu = 7.7$, $\sigma = 1.5$) higher for SART ratings compared to the NACp 10 condition ($\mu = 6.8$, $\sigma = 1.8$). The number of responses for each rating value is presented in Figure 91.

6.2.3.1.4 TLX (Workload)

For the nominal test trials, there was not a significant main effect for Map condition (F(1, 92) = 1.571, p = 0.213), HUD condition (F(1, 92) = 1.674, p = 0.199), or Map by HUD interaction (F(1, 92) = 0.301, p = 0.585) (Appendix I, Table I.49) for TLX responses. The mean ratings for the Map conditions (Map C ($\mu = 27.9$, $\sigma = 12.6$), Map D ($\mu = 31.1$, $\sigma = 12.5$) and HUD conditions (HUD ($\mu = 31.2$, $\sigma = 13.7$), no HUD ($\mu = 27.9$, $\sigma = 11.3$)) (Appendix I, Table I.50)) indicate the perceived overall mental workload was low to moderate. The number of responses for each rating value is presented in Figure 92.

For the off-nominal trials, there was a statistically significant effect for Map condition, F(1, 44) = 8.305, p = 0.006) and for the Map by NACp interaction (F(1, 44) = 4.478, p = 0.040) but not for the NACp condition (F(1, 44) = 2.647, p = 0.111) (Appendix I, Table I.51). Pilots tended to rate the Map D condition ($\mu = 48.0$, $\sigma = 11.9$) as higher in mental workload than the Map C condition ($\mu = 38.6$, $\sigma = 11.9$) (Appendix I, Table I.52); however, these TLX ratings are not practically significant as they both reflect a moderate level of mental workload. The more interesting finding is the Map by NACp interaction (Figure

93) which demonstrates that pilots significantly increased their mental workload ratings when using the Map D and NACp 9 condition, which was significantly different from all other Map by NACp conditions. The number of responses for each rating value is presented in Figure 94.

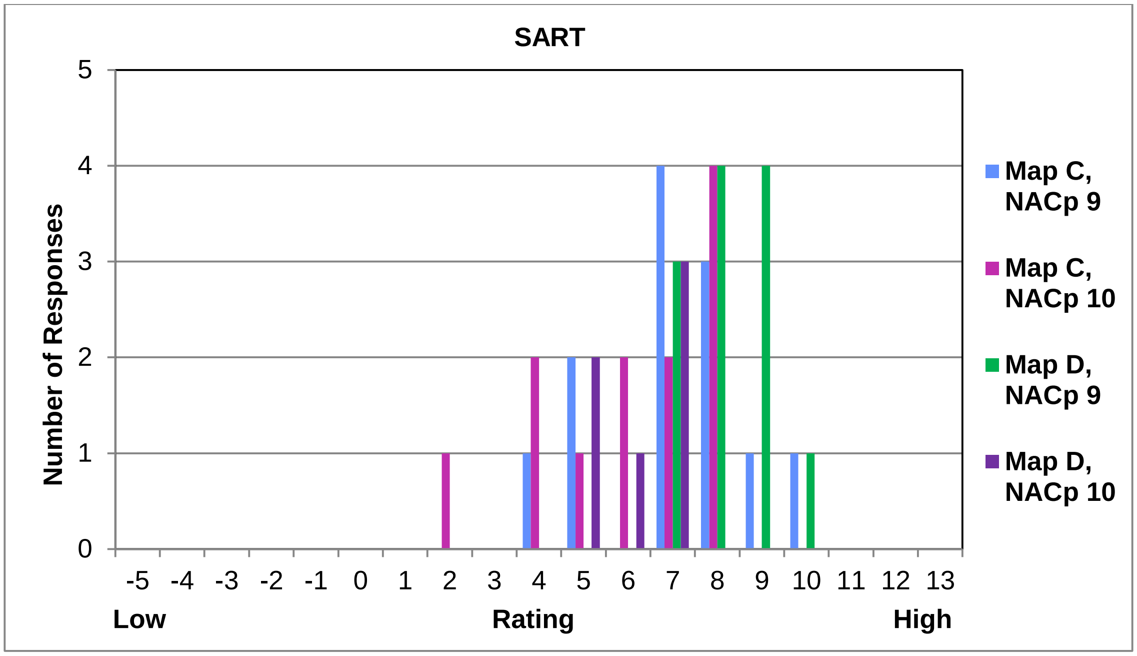


Figure 91. SART Situational Awareness Data for Part 2 Off-Nominal Trials.

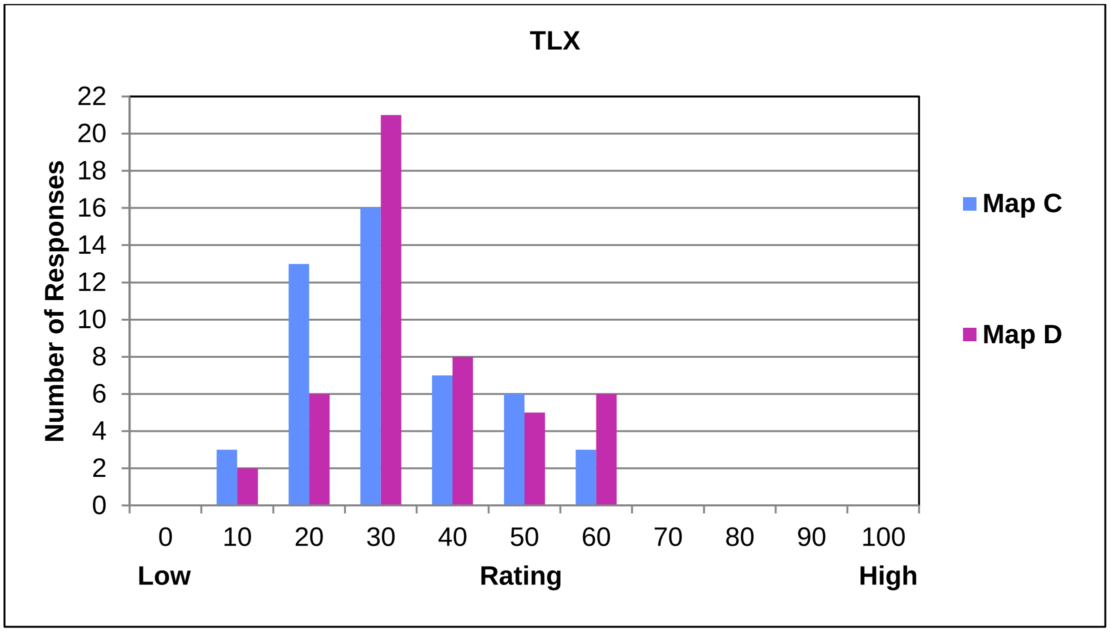


Figure 92. TLX Workload Data for Part 2 Nominal Trials.

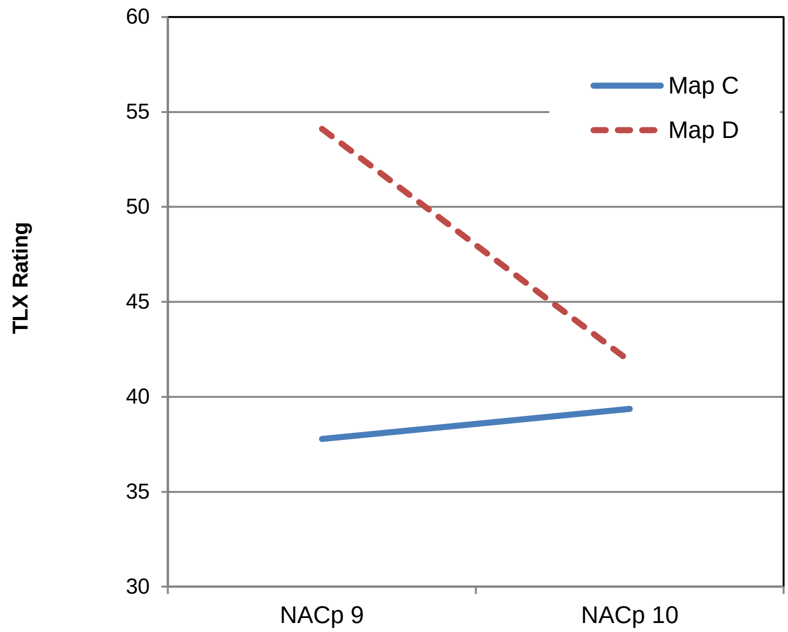


Figure 93. TLX Workload Map by NACp Interaction.

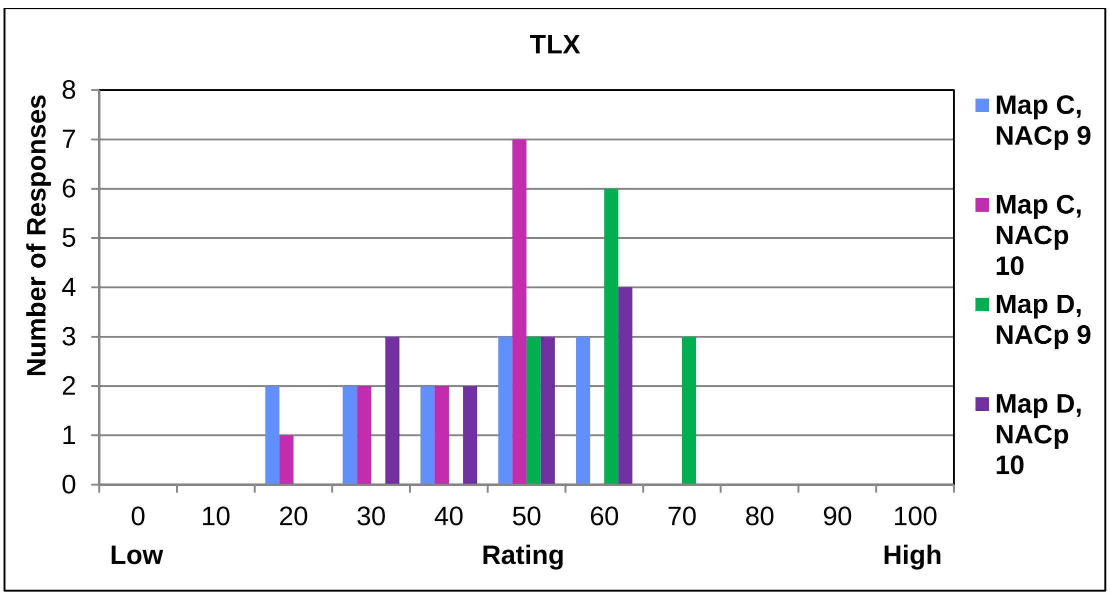


Figure 94. TLX Workload Data for Part 2 Off-Nominal Trials.

6.2.3.2 <u>Part 2 Final Questionnaire Results</u>

At the conclusion of the testing, the evaluation pilots completed a final questionnaire. All questions along with the pilots' responses can be found in Appendix J.

6.2.3.2.1 STBO

The pilots were neutral in rating STBO for increasing workload compared to current surface operations ($\mu = 4.2$, $\sigma = 1.9$) (Figure J.11); however, they did feel that STBO would increase their general situation awareness ($\mu = 6.2$, $\sigma = 1.2$) (Figure J.12). They moderately agreed that STBO will increase efficiency ($\mu = 5.0$, $\sigma = 1.6$) (Figure J.13) and safety ($\mu = 5.1$, $\sigma = 2.0$) (Figure J.14) for ground movement of aircraft. Pilots generally commented that STBO negatively impacts workload and reduces the ability to watch for other traffic. Additional comments were that STBO can be distracting; takes one pilot out of the loop; realistic taxi speed and parameters should be utilized as aircraft performance differs, large aircraft must consistently manage their energy and momentum; and STBO works in a “sterile” environment; however, taxi operations differ among fleets and airports. Concerns were expressed regarding how the STBO system will account for routing modifications, STBO guidance non-compliance, and taxi errors. One pilot felt that STBO merely moves the queue from the runway to the very congested ramp area.

6.2.3.2.2 STBO Symbology

Pilot ratings indicated that STBO would cause a moderate increase in head-down time compared to current-day operations ($\mu = 4.8$, $\sigma = 2.0$) (Figure J.15). Pilots commented that STBO caused more heads-down time than normal. The pilots felt that STBO information should be located on the AMM on the ND display (18 pilots), HUD (15 pilots), and an AMM located on the EFB (14 pilots); however, they did not feel STBO information should be location on the PFD (3 pilots) (pilots were requested to select all that were required) (Figure J.16).

The Captains agreed that the advised ground speed information on the HUD was useful in helping meet the RTA ($\mu = 5.8$, $\sigma = 1.8$) (Figure J.18); however, they also felt that the advised ground speed alone, without any other STBO guidance information, was not optimal ($\mu = 3.6$, $\sigma = 2.0$) (Figure J.19). Many pilots recommended also displaying the RTA time deviation (seconds early/late) on the HUD. Other recommendations were adding a steering arrow below the aircraft symbol, vertical scale bar showing advised GS as a mark along the scale, or a bar that expands above/below wing symbol for early/late status. They did slightly agree that STBO taxi operations could be performed adequately without displaying STBO guidance information on the HUD ($\mu = 4.8$, $\sigma = 2.0$) (Figure J.21). Pilot comments on HUD use during STBO ranged from integrating as much as possible with the HUD to not believing the HUD is useful in taxi operations. One pilot recommended integration into wearable glasses for ground operations.

Pilots who used Map Condition C (see Appendix J, Question 31) indicated that it was easy to tell if they were going to reach the guidance end point on time, ahead of time, or behind schedule ($\mu = 6.4$, $\sigma = 0.9$) (Figure J.23). To improve this rating, pilots suggested using the words ‘early’/’late’ instead of +/-, blink the guidance end point symbol (green diamond) if off of STBO guidance, or include a verbal prompt if more than 15 seconds from STBO guidance. The pilots were asked to rate the usefulness of the STBO symbology elements for helping to meet the RTA. All symbology elements were rated as being useful: STBO time status (seconds early/late) ($\mu = 6.5$, $\sigma = 0.8$), advised ground speed ($\mu = 6.3$, $\sigma = 0.9$), guidance end point ($\mu = 6.0$, $\sigma = 1.6$), and selected traffic information ($\mu = 5.5$, $\sigma = 1.6$) (Figure J.24, Table J.6). They felt the selected traffic information (textual information) was somewhat useful in determining the intent of the aircraft ($\mu = 5.4$, $\sigma = 1.5$) (Figure J.25). Comments regarding Map Condition C included; selected traffic information was too cluttered; turn speeds were too slow (should not be below 8 kts); and would like to be provided graphical display of traffic’s cleared route, traffic’s projected location, and right-of-way information.

Pilots that used Map Condition D (see Appendix J, Question 35) also indicated that it was easy to tell if they were going to reach the guidance end point on time, ahead of time, or behind schedule ($\mu = 6.0$, $\sigma = 1.1$) (Figure J.28). To improve this rating, pilots suggested flashing the GS readout if excess GS is maintained for a certain period of time, add bar above/below wing symbol to indicate advised GS, and provide right-of-way information. The pilots were asked to rate the usefulness of the STBO symbology elements for helping to meet the RTA. The overall ratings were as follows: traffic intent information (graphical) ($\mu = 6.5$, $\sigma = 0.7$), advised ground speed ($\mu = 6.0$, $\sigma = 1.0$), graphical STBO guidance ($\mu = 5.8$, $\sigma = 1.5$), selected traffic information ($\mu = 5.3$, $\sigma = 1.6$), guidance end point ($\mu = 5.3$, $\sigma = 1.5$), and STBO time status (seconds early/late) (μ = 5.3, σ = 1.6) (Figure J.29, Table J.7). For the Map D condition, the symbology elements usefulness was rated differently between Captains and First Officers (Table 20), particularly for the selected traffic information. The Captain had to focus more attention out the window and was not able to read this head-down textual information as readily as the First Officer. The pilots were neutral regarding the usefulness of the selected (textual) traffic information (μ = 4.4, σ = 2.0) (Figure J.30); however, they felt that the graphical traffic intent information (traffic taxi route and guidance circles) was useful for determining the intent of aircraft (μ = 6.0, σ = 1.2) (Figure J.31), thus implying a preference for graphical information. It was observed during the testing that the graphical intent information was easier to use than the textual intent information. However, the graphical symbology was also confusing to some as evidence by two crews misinterpreting the symbology. Comments regarding Map Condition D included, increase turn speeds to 9 or 10 kts, use a status bar instead of the white open circle to show trend information, show taxi route for any traffic selected, and preferred graphical traffic route depiction.

Table 20. Usefulness of Map D STBO Symbology Elements per Pilot Position.

Captain		First Officer	
Traffic Intent Information,	μ = 6.33, σ = 0.82	Traffic Intent Information,	μ = 6.67, σ = 0.52
Advised Ground Speed,	μ = 5.83, σ = 1.33	Selected Traffic Information,	μ = 6.33, σ = 0.82
Guidance End Point,	μ = 5.83, σ = 1.47	Advised Ground Speed,	μ = 6.17, σ = 0.75
Graphical STBO Guidance,	μ = 5.67, σ = 1.97	Graphical STBO Guidance,	μ = 6.00, σ = 0.89
STBO Time Status,	μ = 4.50, σ = 1.64	STBO Time Status,	μ = 6.00, σ = 1.26
Selected Traffic Information,	μ = 4.33, σ = 1.51	Guidance End Point,	μ = 4.60, σ = 1.34

6.2.3.2.3 CD&R Symbology and STBO

The pilots agreed that the CD&R system was effectively integrated with the STBO display concepts (μ = 5.8, σ = 1.0) (Figure J.45) and that CD&R was effective during STBO (μ = 5.5, σ = 1.1) (Figure J.46). The pilots slightly agreed that the traffic intent information was useful in identifying traffic conflict situations when using either map condition (Map C, μ = 5.3, σ = 1.8 (Figure J.26); Map D, μ = 5.7, σ = 1.9 (Figure J.32)). Pilots commented that IA should be added to the HUD.

7 Conclusions

A piloted simulation study was conducted to evaluate the ability to conduct safe and efficient airport surface operations while utilizing an AMM displaying traffic of various position accuracies, as well as the effect of traffic position accuracy on airport CD&R capability. Also, the ability to safely conduct STBO was evaluated by assessing the impact of providing traffic intent information, CD&R system capability, and the display of STBO guidance to the flight crew on both a head-down display and HUD.

AMM, Traffic Position Accuracy, and CD&R Capability - Collisions and near collisions occurred more frequently when conflict traffic could only be viewed OTW, were reduced when conflict traffic could be view on an AMM, and were eliminated when CD&R capability was provided. A collision or near-collision occurred on each trial in which the conflict traffic was not displayed on the AMM (transmitting NACp 8 accuracy). The number of collisions and near-collisions were reduced when all traffic was displayed on the AMM, including traffic transmitting NACp 8 accuracy; however, collisions still occurred when the conflict traffic was not viewed on the AMM or the position accuracy was reduced, making the pilots unsure of the aircraft's true location. There were no collisions when IAs were generated on the conflict traffic (transmitting NACp $\geq$ 10 accuracy), notifying the flight crew of the potential conflict situation. These outcomes are supported by the qualitative results.

The test subjects thought that all the traffic should be displayed on the AMM, regardless of the position accuracy level, to provide a higher level of traffic awareness, increased safety, and to reduce the potential for accidents, but perhaps a distinction should be made in the symbology representing traffic transmitting a higher accuracy versus traffic transmitting a lower accuracy (NACp 8). There are some concerns with displaying traffic transmitting less accurate NACp 8 position accuracy, however. Due to the level of position uncertainty, pilots were sometimes unsure if the traffic was actually on the runway and continued the operation, resulting in collision. Further testing is required to determine the full effect of displaying less accurate data on an AMM for runway safety.

The CD&R system was very effective in preventing collisions; no collisions occurred when IAs were generated for conflicting traffic. With the current design, however, nuisance alerts were issued on traffic in the ramp area due to position accuracy, even at the NACp 10 level, suggesting CD&R alerting only be provided in the movement area due to the close proximity of aircraft in the ramp area. IA toggling also occurred. IA toggling happens when multiple instances of indications or alerts are generated as a result of position accuracy or aircraft maneuvering. Alert toggling can be a distraction to the flight crew and could cause mistrust in the technology.

Surface Trajectory-Based Operations - STBO was a new concept for the test subjects. On 98 percent of the trials, the flight crews met their RTA at the end of the taxi route within +/- 10 seconds, well within the acceptable performance bounds of +/- 15 seconds of RTA. They also had very good STBO conformance during straight taxi segments, on 93% of the trials the crews were within +/- 15 seconds of the planned guidance. However, some of the design aspects of STBO (slow start-up at the release time, slow speeds in turns) were quickly identified by the crews and some of the pilots started advancing the throttles slightly before the taxi release time and 'gaming' the turns (i.e., going into them late so the turn could be taken faster). Conformance, therefore, varied widely at these locations.

If compliance along the route is necessary, explicit intermediate RTAs/waypoints will be needed. Effective STBO will also need to account for SOPs, crew procedures, aircraft type and aircraft loadings, traffic, taxi route, prevailing visibility, and passenger comfort.

The display of traffic intent information was found to be helpful, particularly to the first officer. Graphical presentation of intent was preferred over textual presentation; however, the method of presentation must be optimized in either case. The current graphical implementation was the cause of three wrong turns because the pilot mistakenly thought that their aircraft was at the location of the intent symbology.

The CD&R system was minimally effective during STBO because the traffic was visible out-the-window (1,800 ft visibility). The flight crews were always aware of the traffic prior to any alerts being generated. Interestingly, two collisions occurred because the flight crews were early in reaching the intersection and turned in front of traffic; subsequently, the automated traffic taxied into the ownship as the crew was following their STBO guidance. Alerts were not generated on these aircraft, so perhaps the crew was more willing to proceed ahead of the traffic. In some instances, alerts were issued when the ownship was following the traffic after turning at the intersection.

Overall, the test subjects were neutral regarding the ability of STBO to increase efficiency but indicated STBO would increase situation awareness and safety. The pilots expressed concern for increased workload, the ability to watch for other traffic, and increased head-down time. Although not evaluated, pilots expressed concerns regarding how an STBO system will account for modifications to routing, STBO guidance non-compliance, and taxi errors.

Summary – A CD&R system can potentially eliminate runway collisions, while display of airport traffic on an AMM will help prevent collisions over the ability to only view traffic OTW. Although pilots prefer display of all traffic on an AMM for increased traffic awareness, further research is necessary to determine the effect on runway safety of displaying traffic that is transmitting less accurate data. A CD&R system can be very effective in preventing runway collisions; however, may not be as effective in the ramp area due to the close proximity of traffic.

The STBO concept tested showed potential for enabling the flight crew to safely conduct STBO operations. Additional research is needed to determine the most effective information and display method for STBO pilot conformance and the effectiveness of CD&R during STBO operations.

8 References

[ACSS, 2010] Aviation Communication & Surveillance Systems, *Flight Test Demonstration Report for Enhanced Situational Awareness on the Airport Surface with Indications and Alerts*, Document Number 8008170-001, Rev. A, 2010.

[ACSS, 2014] Aviation Communication & Surveillance Systems, *SafeRoute®, ADS-B in Avionics for NextGen Flight*, www.acss.com/products/saferoute, 2014.

[Airbus, 2015] Airbus, *Onboard Airport Navigation System*, http://robbi.free.fr/pilotlist/OANS.pdf, 2015.

[Ashley et al., 2011] Ashley, S. A., Audenaerd, L. F., Bales, R. A., Burr, C. S., Diffenderfer, P. A., and Morgan, C. E., *Surface Trajectory-Based Operations (STBO) Mid-Term Concept of Operations Overview and Scenarios*, Revision 2, MITRE, 2011.

[Bakowski et al., 2011] Bakowski, D. L., Foyle, D. C., Hooey, B. L., Kunkle, C. L., and Jordan, K. P., *NextGen Flight Deck Surface Trajectory-Based Operations (STBO): Speed-based Taxi Clearances*, Proceedings of the Sixteenth International Symposium on Aviation Psychology, 2011.

[Baxley et al., 2010] Baxley, B. T., Norman, R. M., Ellis, K. K., Latorella, K. A., and Adams, C. A., *Use of Data Comm by Flight Crews in High-Density Terminal Areas*, 10th AIAA Aviation Technology, Integration, and Operations Conference (ATIO), Fort Worth, TX, 2010.

[Boucek, 2002] Boucek, G. P., *Surface Accident and Incident Taxonomy and Mitigation Strategies*, Research Technical Institute, RTI/8348/003-01S, 2002.

[Brinton and Atkins, 2008] Brinton, C. and Atkins, S., *Local Data Exchange for Airport Surface Trajectory-Based Operations*, ICNS Conference, 2008.

[Cassell et al., 2003] Cassell, R., Ever, C., and Esche, J., *Safety Benefits of PathProx™ - A Runway Incursion Alerting System*. Proceedings of the 22nd Digital Avionics Systems Conference, 2003.

[Cheng, 2008] Cheng, V. H. L., Sweriduk, G. D., Yeh, J., Andre, A. D., and Foyle, D. C., *Flight-Deck Automation for Trajectory-Based Surface Operations*, AIAA Guidance, Navigation, and Control Conference and Exhibit, AIAA 2008-7401, Honolulu, HI, 2008.

[Cheng et al., 2009] Cheng, V. H. L., Andre, A. D., and Foyle, D. C., *Information Requirements for Pilots to Execute 4D Trajectories on the Airport Surface*. 2009 AIAA Aviation Technology, Integration, and Operations Conference, 2009.

[Cheng et al., 2011a] Cheng, V. H. L., Vaddi, V. V. S. S., and Sweriduk, G. D., *Concept and Requirements for Airport Surface Conflict Detection and Resolution*, Report submitted under NASA NRA Contract No. NNA10DE59C, 2011.

[Cheng et al., 2011b] Cheng, V. H. L., Vaddi, V. V. S. S., and Sweriduk, G. D., *Surface Conflict Detection and Resolution with Emphasis on Trajectory-Based Operations*, Base Year Final Report, NASA NRA Contract No. NNA10DE59C, 2011.

[Cheng et al., 2012] Cheng, V. H. L., Vaddi, V. V. S. S., Kwan, J., Wiraatmadja, S., Fong, A., Rife, J., and Saunders, F., *Surface Conflict Detection and Resolution with Emphasis on Trajectory-Based Operations*, Option Year 1 Final Report, NASA NRA Contract No. NNA10DE59C, 2012.

[Clark and Trampus, 2011] Clark, S. and Trampus, G., *Improving Runway Safety with Flight Deck Enhancements*, Aero Magazine, 41(1), 5-12, 2011.

[Diffenderfer and Morgan, 2010] Diffenderfer, P. A. and Morgan, C., *Mid-Term Surface Trajectory-Based Operations (STBO) Concepts of Use: Summary*, MTR 100269V1, MITRE, 2010.

[Diffenderfer and Morgan, 2011] Diffenderfer, P. A. and Morgan, C. E., *Surface Conformance Monitoring in the NextGen Timeframe,* Proceedings of the 2011 Integrated Communications Navigation and Surveillance (ICNS) Conference, 2011.

[FAA, 1999] Federal Aviation Administration, *FAA Airport Benefit-Cost Analysis Guide*, Washington, DC, 1999.

[FAA, 2003] Federal Aviation Administration, *Electronic Map Display Equipment for Graphical Depiction of Aircraft Position*, TSO-C165, Washington, DC, 2003.

[FAA, 2007a] Federal Aviation Administration, *Use of Class 1 or Class 2 Electronic Flight Bag (EFB),* Advisory Circular 91-78, Washington, DC, 2007.

[FAA, 2007b] *FAA Runway Safety Report*. Department of Transportation, Federal Aviation Administration, Office of Runway Safety, Washington DC, September 2007.

[FAA, 2007c] Federal Aviation Administration, *Electronic Flight Deck Displays,* Advisory Circular 25-11A, Washington, DC., 2007.

[FAA, 2009a] Federal Aviation Administration, *Project ManagementPlan for Airport Surface Trajectory-based Operations (STBO)* 1.0, Washington, DC, 2009.

[FAA, 2009b] Federal Aviation Administration, *Annual Runway Safety Report 2009,* Air Traffic Organization, Washington, DC, 2009.

[FAA, 2010] Automatic Dependent Surveillance – Broadcast (ADS-B) Out Performance Requirements to Support Air Traffic Control (ATC) Service, Final Rule, Docket No. FAA-2007-29305, Amdt. No. 91-314, Department of Transportation, Federal Aviation Administration, Washington DC, 2010.

[FAA, 2011] Federal Aviation Administration, *ATO Safety, National Runway Safety Plan, V 1.0,* Washington, DC, 2011.

[FAA, 2012] Federal Aviation Administration, *Runway Safety Report 2011-2012,* Washington, DC, 2012.

[FAA, 2014a] Federal Aviation Administration, *Guidelines for the Certification, Airworthiness, and Operational Use of Electronic Flight Bags,* Advisory Circular 120-76C, Washington, DC, 2014.

[FAA, 2014b] Federal Aviation Administration, *Aeronautical Information Manual*, Washington, DC, 2014.

[Foyle et al., 2009] Foyle, D. C., Hooey, B. L., Kunkle, C. L., Schwirzke, F. J., and Bakowski, D. L., *Piloted Simulation Of NextGen Time-based Taxi Clearances and Tailored Departures*. Proceedings of the 2009 IEEE/AIAA Integrated Communications, Navigation and Surveillance Conference, 2009.

[Foyle et al., 2011] Foyle, D. C., Hooey, B. L., Bakowski, D. L., Williams, J. L., and Kunkle, C. L., *Flight Deck Surface Trajectory-based Operations (STBO) Simulation Results and ConOps Implications.* Ninth USA/Europe Air Traffic Management Research and Development Seminar, ATM2011, 2011.

[Funk et al., 2008] Funk, K., Mauro, R., and Birdseye, H., *Identifying and Addressing Human Factors Issues of ADS-B and Cockpit Displays of Traffic Information,* (conference presentation), Human Factors and NextGen: The Future of Aviation, University of Texas, Arlington, Texas, May 28-29, 2008.

[Glass and Gawdiak, 1997] Glass, B. J. and Gawdiak, Y., *Integrated Navigation Applications in Airport Surface Traffic,* Saint Petersburg International Conference on Integrated Navigation Systems, 4th, A1997-30869 07-35, St. Petersburg, Russia, State Research Center of Russia Elektropribor, p. 105-113, 1997.

[Hart and Staveland, 1988] Hart, S. G. and Staveland, L. E., *Development of a multi-dimensional workload rating scale: Results of empirical and theoretical research*, P. A. Hancock and N. Meshkati, (Eds.), Human Mental Workload (pp. 139-183), Amsterdam, Elsevier, 1988.

[Hoang et al., 2011] Hoang, T., Jung, Y. C., Holbrook, J. B., and Malik, W. A., *Tower Controller's Assessment of the Spot and Runway Departure Advisor (SARDA) Concept*, Ninth USA/Europe Air Traffic Management Research and Development Seminar (ATM2011), 2011.

[Hoang et al., 2014] Hoang, T., Jung, Y. C., Gupta, G., Holbrook, J., Wang, E. M., Ingram, C., Waqar, M., Ray, K. A., Freedman, C. J., Tobias, L., and Wang, H., *Development and Findings From the Spot and Runway Departure Advisor (SARDA) Human-in-the-loop (HITL) Simulation Experiment*, NASA TM-2014-218383, 2014.

[Honeywell, 2010] Glover, J. H., *Development and Evaluation of a Conceptual Surface Traffic Display, Indicating and Alerting System (SURF IA)*, Honeywell International Inc., Rev. A, 2010.

[Honeywell, 2013] Honeywell International Inc., *Product Description SmartRunway™/SmartLanding™ Functions of the Enhanced Ground Proximity Warning System*, 2013.

[Hooey and Foyle, 2006] Hooey, B. L. and Foyle, D. C., *Pilot navigation errors on the airport surface: Identifying contributing factors and mitigating solutions*. The International Journal of Aviation Psychology, 2006.

[Hooey et al., 2014] Hooey, B. L., Cheng, V. H. L., and Foyle, D. C., *A Concept of Operations for Far-Term Surface Trajectory-Based Operations (STBO)*, NASA TM-2014-218354, June 2014.

[Hughes, 2007] Hughes, D., *Honeywell, Sensis Demonstrate Runway Incursion Warnings In the Cockpit*, Aviation Week, September 3, 2007, p. 67

[Jones et al, 2001] Jones, D. R., Quach, C. C., and Young, S. D., *Runway Incursion Prevention System – Demonstration and Testing at the Dallas/Fort Worth International Airport*, Proceedings of the 20th Digital Avionics Systems Conference, Daytona Beach, FL, 2001.

[Jones, 2002] Jones, D. R., *Runway Incursion Prevention System Simulation Evaluation*, Proceedings of the AIAA/IEEE 21st Digital Avionics Systems Conference. Irvine, CA, 2002.

[Jones, 2005] Jones, D. R., *Runway Incursion Prevention System Testing at the Wallops Flight Facility*, Proceedings of the SPIE Defense & Security Symposium. Enhanced and Synthetic Vision 2005. Editor(s): Jacques G. Verly. Vol. 5802, April 2005, pp. 47-58, 2005.

[Jones and Prinzel, 2006] Jones, D. R. and Prinzel, L. J., III, *Runway Incursion Prevention for General Aviation Operations*, Proceedings of the 25th Digital Avionics Systems Conference, Portland, OR, 2006.

[Jones et al, 2009] Jones, D. R.; Prinzel, L. J.; Otero, S. D.; and Barker, G. D., *Collision Avoidance for Airport Traffic Concept Evaluation*, Proceedings of the 28th Digital Avionics Systems Conference, Orlando, FL, 2009.

[Jones et al, 2010] Jones, D. R., Prinzel, L. J., Shelton, K. J., Bailey, R. E., Otero, S. D., and Barker, G. D., *Collision Avoidance for Airport Traffic Simulation Evaluation*, Proceedings of the 29th Digital Avionics Systems Conference, Salt Lake City, UT, 2010.

[Jones et al, 2012a] Jones, D. R., Chartrand, R. C., Wilson, S. R., Commo, S. A., Otero, S. D., and Barker, G. D., *Airport Traffic Conflict Detection and Resolution Algorithm Evaluation*, Proceedings of the 31st Digital Avionics Systems Conference, Williamsburg, VA, 2012.

[Jones et al, 2012b] Jones, D. R., Chartrand, R. C., Wilson, S. R., Commo, S. A., Otero, S. D., and Barker, G. D., *SURF IA Conflict Detection and Resolution Algorithm Evaluation*, Proceedings of the 31st Digital Avionics Systems Conference, Williamsburg, VA, 2012.

[JPDO, 2010] *Concept of Operations for the Next Generation Air Transportation System*, Joint Planning & Development Office, Washington, DC, Version 3.2, 2010.

[JPDO, 2011] *JPDO Trajectory-Based Operations (TBO) Study Team Report*, Joint Planning & Development Office, Washington, DC, 2011.

[Jung et al., 2010] Jung, Y. C., Hoang, T., Montoya, J., Gupta, G., Malik, W., and Tobias, L., *A Concept and Implementation of Optimized Operations of Airport Surface Traffic*, 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, 2010.

[Jung et al., 2011] Jung, Y., Hoang, T., Montoya, J., Gupta, G., Malik, W., Tobias, L, and Wang, H., *Performance Evaluation of a Surface Traffic Management Tool for Dallas/Fort Worth International Airport*, Ninth USA/Europe Air Traffic Management Research and Development Seminar (ATM2011), 2011.

[McGarry and Kerns, 2010] McGarry, K. A. and Kerns, K., *Results of a Second (Controller) Human-In-The-Loop Simulation Study of Automated Capabilities Supporting Surface Trajectory-Based Operations*, MITRE, 2010.

[Mohleji and Wang, 2010] Mohleji, S. C., and Wang, G., Modeling ADS-B Position and Velocity Errors for Airborne Merging and Spacing in Interval Management Application, MITRE release # 10-3026, 2010.

[Montoya et al., 2013] Montoya, J., Windhorst, R., Zhu, Z., Gridnev, S., Griffen, K. J., Saraf, A., and Stroiney, S., *Analysis of Airport Surface Schedulers Using Fast-Time Simulation*, 2013 Aviation Technology, Integration, and Operations Conference (ATIO), 2013.

[Morgan, 2010] Morgan, C. E., *A High-Level Description of Air Traffic Management Decision Support Tool Capabilities for NextGen Surface Operations: Results from the Surface Technical Team Working Group*, MP100131, MITRE, 2010.

[NTSB, 2000] *Safety Recommendation*, Letter to the FAA Administrator, A-00-66, National Transportation Safety Board, Washington, DC, 2000.

[NTSB, 2007] *Attempted Takeoff From Wrong Runway, Comair Flight 5191,Bombardier CL-600-2B19, N431CA, Lexington, Kentucky, August 27, 2007,* Accident Report, AAR-07-05, National Transportation Safety Board, Washington, DC, 2007.

[NTSB, 2012] *Most Wanted List - Transportation Safety Improvements*, National Transportation Safety Board, Washington, DC, www.ntsb.gov/safety/mwl1_2012.html, 2012.

[Otero et al, 2013] Otero, S. D., Barker, G. D., and Jones, D. R., *Initial Concept for Terminal Area Conflict Detection, Alerting, and Resolution Capability On or Near the Airport Surface*, Version 2.0, NASA Langley Research Center, Hampton, VA, NASA TM-2013-218052, 2013.

[Prevot et al., 2012] Prevot, T., Baxley, B. T., Callantine, T. J., Johnson, W. C., Quon, L. K., Robinson, J. E., and Swenson, H. N., *NASA's ATM Technology Demonstration-1: Transitioning Fuel Efficient, High Throughput Arrival Operations from Simulation to Reality*, Proceedings of the International Conference on Human-Computer Interaction in Aerospace (HCI-Aero), Brussels, Belgium, 2012.

[Prinzel et al., 2009] Prinzel, L. J., Jones, D. R., Shelton, K. J., Arthur, J. J., Bailey, R. E., Allamandola, A. S., Foyle, D. C., and Hooey, B. L., *Flight Deck Display Technologies for 4DT and Surface Equivalent Visual Operations*, Proceedings of the 15th International Symposium on Aviation Psychology, 2009.

[RTCA, 2001] *User Requirements for Aerodrome Mapping Information*, RTCA DO-272, RTCA, Inc., Washington, DC, 2001.

[RTCA, 2002] *Minimum Aviation System Performance Standards for Automatic Dependent Surveillance Broadcast (ADS-B)*, DO-242A, RTCA, Inc., Washington, DC, 2002.

[RTCA, 2003a] *Minimum Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps*, DO-257A, RTCA, Inc., Washington, DC, 2003.

[RTCA, 2003b] *Minimum Aviation System Performance Standards for Aircraft Surveillance Applications (ASA)*, DO-289, RTCA, Inc., Washington, DC, 2003.

[RTCA, 2010a] *Safety, Performance and Interoperability Requirements Document for ATSA-SURF Application*, DO-322, RTCA, Inc., Washington, DC, 2010.

[RTCA, 2010b] *Safety, Performance and Interoperability Requirements Document for Enhanced Traffic Situational Awareness on the Airport Surface with Indications and Alerts (SURF IA)*, DO-323, RTCA, Inc., Washington, DC, 2010.

[RTCA, 2011] *Recommendations for Implementing Trajectory Operations in the Mid-Term (2011-2018)*, A report of the NextGen Advisory Committee in response to Tasking from the FAA, 2011.

[RTCA, 2012] *Minimum Aviation System Performance Standards (MASPS) for ADS-B Traffic Surveillance Systems and Applications (ATSSA)*, DO-338, RTCA, Inc., Washington, DC, 2012.

[Shelton et al., 2009] Shelton, K. J.; Prinzel, L. J.; Jones, D. R.; Arthur, J. J.; Allamandola, A. S.; and Bailey, R. E., *Surface Map Traffic Intent Displays and Net-Centric Data-Link communications for NextGen*, Proceedings of the 28th Digital Avionics Systems Conference, 2009.

[Stelzer et al., 2010] Stelzer, E. K., *Human-In-The-Loop Concept Evaluation of Surface Conformance Monitoring Automation*, MTR100188, MITRE, 2010.

[Stelzer and Stanley, 2011] Stelzer, E. K. and Stanley, R.M., *Examination of Air Traffic Controller use of Surface Trajectory-Based Operations Decision Support Tools: Third Human-in-the-Loop Evaluation*, MTR110344, MITRE, 2011.

[Stelzer et al., 2011] Stelzer, E. K., Stanley, R. M., and Shepley, K .K. (2011). *Evaluating Surface Trajectory-Based Operations Concepts Through a Human-In-The-Loop Simualtion*, 30th Digital Avionics System Conference, Seattle, WA, 2011.

[Taylor, 1990] Taylor, R.M., *Situational Awareness Rating Technique (SART): The development of a tool for aircrew system design.* AGARD, Situational Awareness in Aerospace Operations (SEE N90-28972), pp. 17, 23-53, 1990.

[Verma et al., 2007] Verma, S., Kozon, T., Cheng, V., Ballinger, D., *Changes in Roles/Responsibilities of Air Traffic Control under Precision Taxiing*, 26th Digital Avionics Systems Conference, Dallas, TX, 2007.

[Williams et al., 2006] Williams, J. L., Hooey, B. L., and Foyle, D. C., *4-D Taxi Clearances: Pilot's Usage of Time- and Speed-based Formats*, Proceedings of the AIAA Modeling and Simulation Technologies Conference, 2006.

Appendix A: Part 1 Test Matrix

Crew	n (n = 1 to 12)	
Scenario	A1 (101)	= Nominal – 36C approach, land, taxi to ramp
	A2 (102)	= Nominal – 18C approach, land, taxi to ramp
	D1 (103)	= Nominal – taxi from ramp and depart 36C
	D2 (104)	= Nominal – taxi from ramp and depart 18C
	ONA (105)	= 36C Taxi conflict approach
	OND (106)	= 36C Departure/taxi conflict
	TA (901)	= Training – 36L approach, land, taxi to ramp
	TD (902)	= Training – taxi from ramp and depart 18R
	TONA (903)	= Training – 36L arrival/taxi conflict
Map Concept	A	= ownship, no route, qualified traffic
	B	= ownship, no route, unqualified & qualified traffic
HUD	No	= HUD not used
Conflict Traffic NACp	8	= unqualified traffic
	9	= qualified for SURF application
	10	= qualified for SURF and SURF IA applications
	N/A	= Not applicable
Visibility (Vis)	1 = 1800 ft RVR, day	
	2 = 3nm, day	

CD&R Indications and alerts on traffic with NACp 10 or 11 only

Wind:	0 = no winds
	1 = 10 kts at 020, for use with 36 runways
	2 = 15 kts at 150, for use with 18 runways

Definitions:
SURF qualified traffic = NACp 9+ accuracy
SURF IA qualified traffic = NACP 10+ accuracy
Unqualified traffic = NACp 8

Note:
Part 1 – traffic mix of NACp 8+

3 training scenarios before Part 1 - TA, TD, and TONA

Part 1 Test Matrix

Case No.	Crew	Scenario	Map Concept	HUD	Conflict Traffic NACp	Vis	Wind
1	All	A1	A	No	N/A	1	1
2	All	A2	A	No	N/A	1	2
3	All	D1	A	No	N/A	1	0
4	All	D2	A	No	N/A	1	0
5	All	A1	B	No	N/A	1	1
6	All	A2	B	No	N/A	1	2
7	All	D1	B	No	N/A	1	0
8	All	D2	B	No	N/A	1	0
9	1, 5, 9	ONA	A	No	8	1	0
10	3, 7, 11	ONA	B	No	8	1	0
11	3, 7, 11	OND	A	No	8	1	0
12	1, 5, 9	OND	B	No	8	1	0
13	2, 6, 10	ONA	A	No	9	1	0
14	4, 8, 12	ONA	A	No	10	1	0
15	4, 8, 12	OND	A	No	9	1	0
16	2, 6, 10	OND	A	No	10	1	0
Training Scenarios							
Case No.	Crew	Scenario	Map Concept	HUD	Conflict Traffic NACp	Vis	Wind
41	All	TA	A	No	N/A	2	1
42	All	TD	B	No	N/A	2	0
43	All	TONA	A	No	10	2	1

Appendix B: Part 1 Nominal Scenarios

Two approach and two departure nominal scenarios were used for Part 1 testing. All nominal scenarios were designed to be conflict free, provided the crew followed the ATC instructions and executed them in a timely manner.

Part 1 Nominal Scenario – Approach Runway 36C

An approach and departure flow was implemented as follows. Traffic were approaching Runway 36C (Figure B.1, magenta route) and Runway 36L (Figure B.1, orange route), spaced 5 nm apart and staggered between runways. This traffic landed, exited the runway, and taxied to the terminal via the routes shown in Figure B.1. There was a departure flow to Runway 36R via the blue colored route shown in Figure B.1. The traffic held at Runway 36C until after an aircraft landed, then crossed to Runway 36R for departure approximately every 3 minutes. One aircraft would cross Runway 36C after every other arrival, for a rate of 1 departure for every 2 arrivals. Other static traffic was placed in strategic locations to add interest to the scenario.

At the beginning of this scenario, the ownship was approximately 5 nm from the runway threshold on approach to Runway 36C. The flight crew was cleared to land, exit the runway at Taxiway C5, and taxi to the terminal via Taxiways C5, K, and J (Figure B.1, magenta route).

Part 1 Nominal Scenario – Approach Runway 18C

An approach and departure flow was implemented as follows. Traffic were approaching Runway 18R (Figure B.2, orange route) and Runway 18C (Figure B.1, magenta route), spaced 5 nm apart and staggered between runways. This traffic landed, exited the runway, and taxied to the terminal via the routes shown in Figure B.2. There was a departure flow to Runway 18L via the blue colored route shown in Figure B.2. The traffic would depart approximately every 3 minutes, for a rate 1 departure for every 2 arrivals. Other static traffic was placed in strategic locations to add interest to the scenario.

At the beginning of this scenario, ownship was approximately 5 nm from the runway threshold on approach to Runway 18C. The flight crew was cleared to land, exit the runway at Taxiway C2, and taxi to the terminal via Taxiways C2, P, and P1 (Figure B.2, magenta route).

Part 1 Nominal Scenario – Departure Runway 36C

An approach and departure flow was implemented as follows. Traffic were approaching Runway 36R (Figure B.3, blue route) and Runway 36L (Figure B.3, orange route), spaced 5 nm apart and staggered between runways. This traffic landed, exited the runway, and taxied to the terminal via the routes shown in Figure B.3. There was a departure flow to Runway 36C via the magenta colored route shown in Figure B.3. The traffic would depart approximately every 3 minutes, for a rate 1 departure for every 2 arrivals. Other static traffic was placed in strategic locations to add interest to the scenario.

At the beginning of this scenario, the ownship was on the ramp near Taxiway J. The flight crew was cleared to taxi to Runway 36C via Taxiways J and R for departure (Figure B.3, magenta route).

Part 1 Nominal Scenario – Departure Runway 18C

An approach and departure flow was implemented as follows. Traffic were approaching Runway 18R (Figure B.4, orange route) and Runway 18L (Figure B.4, blue route), spaced 5 nm apart and staggered between runways. This traffic landed, exited the runway, and taxied to the terminal via the routes shown in Figure B.4. There was a departure flow to Runway 18C via the magenta colored route shown in Figure B.4. The traffic would depart approximately every 3 minutes, for a rate 1 departure for every 2 arrivals. Other static traffic was placed in strategic locations to add interest to the scenario.

At the beginning of this scenario, the ownship was on the ramp near Taxiway J. The flight crew was cleared to taxi to Runway 18C via Taxiways J, K, C and C8 for departure (Figure B.4, magenta route).

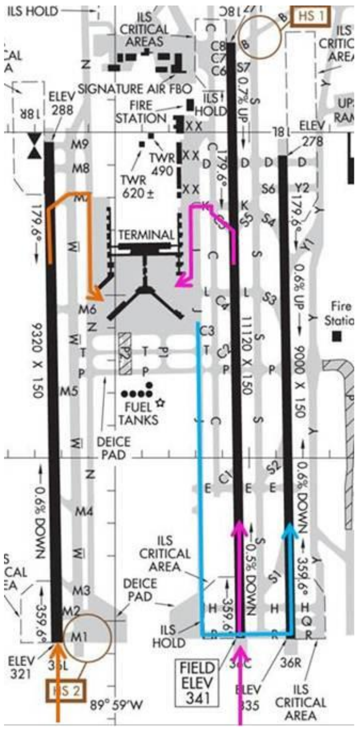


Figure B.1. 36C Approach Scenario.

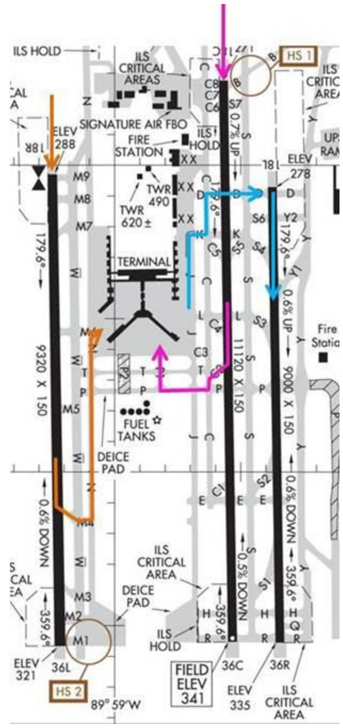


Figure B.2. 18C Approach Scenario.

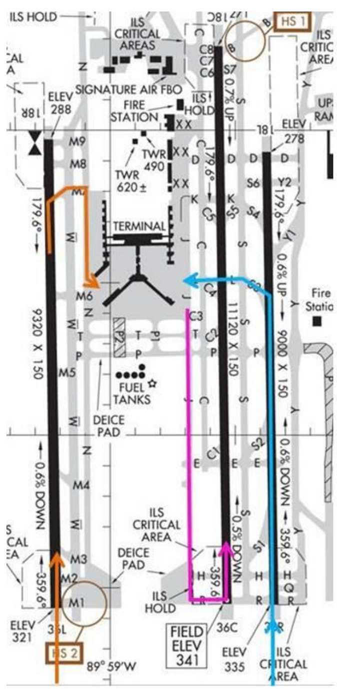


Figure B.3. 36C Departure Scenario.

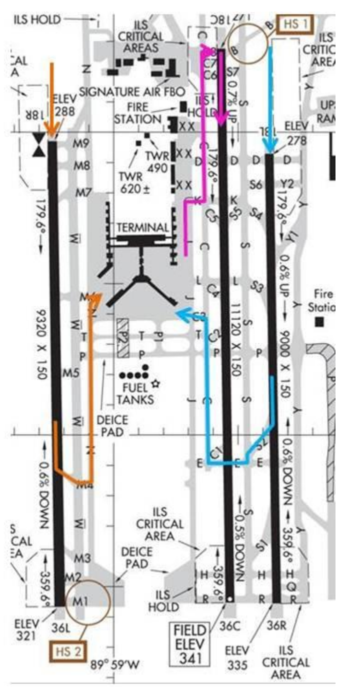


Figure B.4. 18C Departure Scenario.

Appendix C: Part 1 Case Lists

The experimental case order for each crew for Part 1 testing is listed in Tables C.1 and C.2. Refer to Appendix A for a detailed description of each case.

Table C.1. Part 1 Case Order for Crews 1 through 6.

	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5	Crew 6
Run 1	5	7	8	6	6	8
Run 2	2	5	1	7	2	5
Run 3	1	6	4	8	3	7
Run 4	4	8	3	5	1	6
Run 5	3	3	2	4	4	3
Run 6	9	13	11	14	9	16
Run 7	7	2	5	3	8	4
Run 8	8	4	6	2	7	1
Run 9	6	1	7	1	5	2
Run 10	12	16	10	15	12	13

Table C.2. Part 1 Case List for Crews 7 through 12.

	Crew 7	Crew 8	Crew 9	Crew 10	Crew 11	Crew 12
Run 1	3	5	1	6	2	8
Run 2	6	6	7	5	8	7
Run 3	7	8	5	7	5	6
Run 4	8	7	6	8	6	5
Run 5	5	3	8	1	7	2
Run 6	10	15	12	13	10	14
Run 7	4	2	2	3	3	1
Run 8	2	1	3	2	1	4
Run 9	9	4	4	4	4	3
Run 10	11	14	9	16	11	15

Appendix D: Part 2 Test Matrix

Crew	n (n = 1 to 12)	
Scenario	4D1a (201)	= 4D taxi from ramp to departure runway
	4D1b (202)	= 4D taxi from ramp to departure runway
	4D2a (203)	= 4D taxi from ramp to departure runway
	4D2b (204)	= 4D taxi from ramp to departure runway
	ONT (205)	= Taxi conflict
	ONT2 (206)	= Taxi conflict
	T4D (904)	= Training – 4D taxi from ramp to departure runway
	TONT (905)	= Training – taxi conflict on SURF IA qualified traffic
Map Concept	C	= ownship, route, traffic, ownship 4D text
	D	= Map C + ownship & traffic graphical 4D
HUD	No	= HUD not used
	Yes	= 4D text + standard symbology
Conflict Traffic NACp	9	= qualified for SURF application
	10	= qualified for SURF and SURF IA applications
	N/A	= Not applicable
Visibility (Vis)	1 = 1800 ft RVR, day	
	2 = 3nm, day	

CD&R Indications and alerts on traffic with NACp 10 or 11 only

Wind: 0 = no winds

Definitions:
SURF qualified traffic = NACp 9+ accuracy
SURF IA qualified traffic = NACP 10+ accuracy
Unqualified traffic = NACp 8

Note:
Part 2 – traffic mix of NACp 9+

3 training scenarios before Part 2 - T4D with Map C, T4D with Map D, and TONT

Part 2 Test Matrix

Run No.	Crew	Scenario	Map Concept	HUD	Conflict Traffic NACp	Vis	Wind
17	1, 5, 9	4D1a	C	No	N/A	1	0
18	1, 5, 9	4D1b	C	Yes	N/A	1	0
19	1, 5, 9	4D2a	C	Yes	N/A	1	0
20	1, 5, 9	4D2b	C	No	N/A	1	0
21	1, 5, 9	ONT	C	No	9	1	0
22	1, 5, 9	ONT2	C	No	10	1	0
23	3, 7, 11	4D1a	C	Yes	N/A	1	0
24	3, 7, 11	4D1b	C	No	N/A	1	0
25	3, 7, 11	4D2a	C	No	N/A	1	0
26	3, 7, 11	4D2b	C	Yes	N/A	1	0
27	3, 7, 11	ONT	C	No	10	1	0
28	3, 7, 11	ONT2	C	No	9	1	0
29	2, 6, 10	4D1a	D	No	N/A	1	0
30	2, 6, 10	4D1b	D	Yes	N/A	1	0
31	2, 6, 10	4D2a	D	Yes	N/A	1	0
32	2, 6, 10	4D2b	D	No	N/A	1	0
33	2, 6, 10	ONT	D	No	9	1	0
34	2, 6, 10	ONT2	D	No	10	1	0
35	4, 8, 12	4D1a	D	Yes	N/A	1	0
36	4, 8, 12	4D1b	D	No	N/A	1	0
37	4, 8, 12	4D2a	D	No	N/A	1	0
38	4, 8, 12	4D2b	D	Yes	N/A	1	0
39	4, 8, 12	ONT	D	No	10	1	0
40	4, 8, 12	ONT2	D	No	9	1	0
Training Scenarios							
Run No.	Crew	Scenario	Map Concept	HUD	Conflict Traffic NACp	Vis	Wind
44	1, 5, 9, 3, 7, 11	T4D	C	Yes	10	2	0
45	1, 5, 9, 3, 7, 11	T4D	C	No	10	2	0
46	1, 5, 9, 3, 7, 11	TONT	C	No	10	2	0
47	2, 6, 10 4, 8, 12	T4D	D	Yes	10	2	0
48	2, 6, 10 4, 8, 12	T4D	D	No	10	2	0
49	2, 6, 10 4, 8, 12	TONT	D	No	10	2	0

Appendix E: Part 2 Nominal Scenarios

Four STBO taxi nominal scenarios were used for Part 2 testing. All nominal scenarios were designed to be conflict free, provided the crew followed the ATC instructions and STBO guidance. A detailed description of the STBO taxi procedure is given in the *Part 2 Procedure* section above.

Part 2 Nominal Scenarios – STBO Taxi Runway 36C

Two STBO taxi scenarios were conducted to Runway 36C. These two scenarios were the same except that ownship had a different starting location so the flight crews would not learn to anticipate the clearance. This was done in order to have similar scenarios for analysis purposes

An approach and departure flow was implemented as follows. Traffic were approaching Runway 36R (Figure E.1 and E.2, blue route) and Runway 36L (Figure E.1 and E.2, orange route), spaced 5 nm apart and staggered between runways. This traffic landed, exited the runway, and taxied to the terminal via the routes shown in Figures E.1 and E.2. There were two departure flows to Runway 36C via the green and magenta colored routes shown in Figures E.1 and E.2. The traffic would depart approximately every 3 minutes, for a rate 1 departure for every 2 arrivals. Other static traffic was placed in strategic locations to add interest to the scenario.

At the beginning of these scenarios, the ownship was parked in the ramp facing Taxiway L and was then cleared to GPM 32. For each scenario, the crew was given taxi clearance and STBO guidance to taxi to Runway 36C. In one scenario, the taxi clearance was via Taxiways L, S, and R (Figure E.1, magenta route). For the other scenario, the taxi clearance was via Taxiways J, P, S, and R (Figure E.2, magenta route).

Part 2 Nominal Scenarios – STBO Taxi Runway 18R

Two STBO taxi scenarios were conducted to Runway 18R. Again, these two scenarios were the same except that the ownship had a different starting location.

An approach and departure flow was implemented as follows. Traffic was approaching Runway 18C (Figure E.3 and E.4, orange route), spaced 5 nm apart. This traffic landed, exited the runway, and taxied to the terminal. There were departure flows to Runway 18R via Taxiway A, N, and M9 and from the terminal ramp via Taxiway N and M9. The traffic would depart approximately every 3 minutes, for a rate 1 departure for every arrival. Other static traffic was placed in strategic locations to add interest to the scenario.

One aircraft taxied along Taxiway A, toward the Taxiway A/C intersection. The aircraft turned south onto Taxiway C following the green route shown in Figures E.3 and E.4. This aircraft appeared as if it could be a potential threat for the ownship; however, as long as the flight crew followed the STBO taxi guidance, the traffic aircraft would trail ownship, giving the subject crew plenty of time to turn in front of the aircraft.

For one of the scenarios, the ownship started at the ramp near GPM 13 and was given clearance to Runway 18R via Taxiways C, A, N, and M9 (Figure E.3). For the other scenario, the ownship began on the ramp near GPM 14 and was given clearance to Runway 18R via Taxiways V, C, A, N, and M9 (Figure E.4).

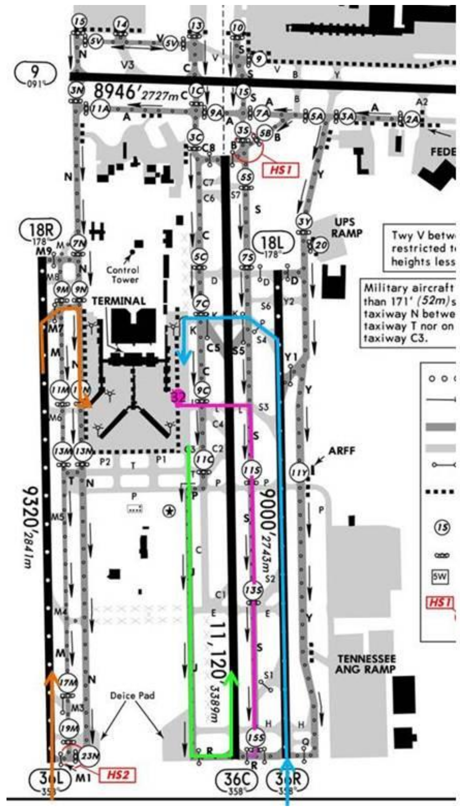


Figure E.1. STBO 36C Taxi Scenario.

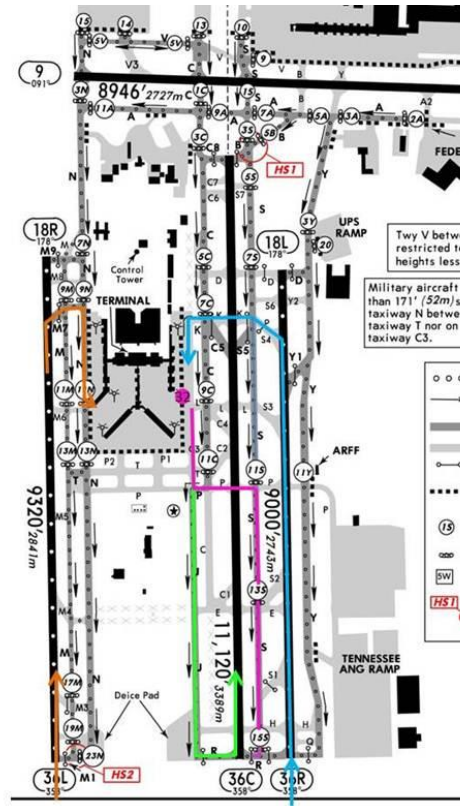


Figure E.2. STBO 36C Taxi Scenario.

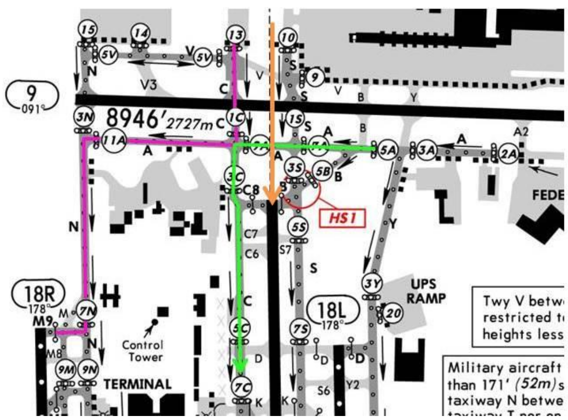


Figure E.3. STBO 18R Taxi Scenario.

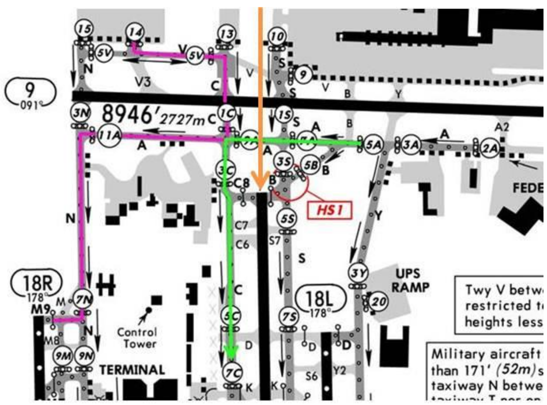


Figure E.4. STBO 18R Taxi Scenario.

Appendix F: Part 2 Case Lists

The experimental case order for each crew for Part 2 testing is listed in Tables F.1 and F.2. Refer to Appendix D for a detailed description of each case.

Table F.1. Part 2 Case List for Crews 1 through 6.

	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5	Crew 6
Run 1	18	31	23	38	19	30
Run 2	19	30	26	35	18	31
Run 3	22	34	28	40	22	34
Run 4	17	32	25	36	20	29
Run 5	20	29	24	37	17	32
Run 6	21	33	27	39	21	33

Table F.2. Part 2 Case List for Crews 7 through 12.

	Crew 7	Crew 8	Crew 9	Crew 10	Crew 11	Crew 12
Run 1	24	37	17	32	25	36
Run 2	25	36	20	29	24	37
Run 3	28	40	22	34	28	40
Run 4	26	35	18	31	26	38
Run 5	23	38	19	30	23	35
Run 6	27	39	21	33	27	39

Appendix G: Post Run Questionnaires

At the end of each test trial, the evaluation pilots completed a post run questionnaire (Tables G.1 and G.2), a Situation Awareness Rating Technique (SART) questionnaire to evaluate situation awareness (Table G.3), and a Task Load Index (TLX) questionnaire to rate workload (Table G.4).

Table G.1. Part 1 Post Run Questionnaire.

Post-Run Ratings Please rate agreement with statements based on display condition just evaluated	Strongly Disagree	Disagree	Slightly Disagree	Neither agree or disagree	Slightly Agree	Agree	Strongly Agree
A. I was aware of ownship position.							
B. I was aware of traffic and other vehicles during operations.		Task Management					
C. The display concepts were effective for management of mental workload.							
D. The display concepts contributed to communication effectiveness (ATC and Flight Crew).		Communicative Efficacy					
E. The display promoted effective crew resource management, coordination, and cohesion.							
F. The display concepts contributed to perceived safety during operation (if unsafe, please state to researcher and reason why).		Hazard Awareness					
G. The display concepts were effective for detection of potential surface conflicts.	.						

Table G.2. Part 2 Post Run Questionnaire.

Post-Run Ratings Please rate agreement with statements based on display condition just evaluated	Strongly Disagree	Disagree	Slightly Disagree	Neither agree or disagree	Slightly Agree	Agree	Strongly Agree
A. I was aware of ownship position.							
B. The display concepts were effective for maintaining my situation awareness of ownship.		Task Management					
C. I was aware of traffic and other vehicles during operations.							
D. The display concepts provided effective awareness of traffic intent information.							
E. The display concepts were effective for required time-of-arrival taxi conformance.		Communicative Efficacy					
F. The display location of STBO taxi guidance information was effective for situation awareness.							
G. The display location of STBO taxi guidance information was effective for mental workload.							
H. The display concepts contributed to perceived safety during operation (if unsafe, please state to researcher and reason why).		Hazard Awareness					
I. The display concepts were effective for detection of potential surface conflicts during STBO taxi.							

Table G.3. Situation Awareness Rating Technique (SART).

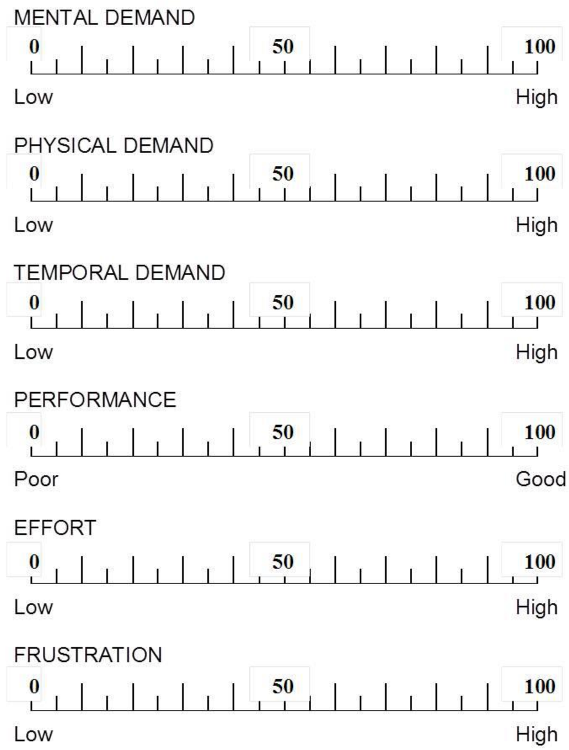
Situation Awareness Ratings	Low....................................High						
	1	2	3	4	5	6	7
SART #1 Demand on Attentional Resources How much demand was placed on attention due to complexity and variability of the task?							
SART #2 Supply of Attentional Resources How much spare attention and mental ability was available during the task?							
SART #3 Understanding What was the level of understanding of information and familiarity of the situation?							

Table G.4. Task Load Index (TLX).

Rating Scale Definitions

Title	Descriptions
MENTAL DEMAND	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Verbalize your rating for each scale:



Appendix H. Part 1 Run Questionnaire Results

Part 1 Post Run Questionnaire Results

Question A. I was aware of ownship position.

Table H.1. Question A ANOVA Statistics for Part 1 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.800	1	0.800	2.707	0.102
Error	55.563	188	0.296		
Total	8693.000	190			

Table H.2. Question A Descriptive Statistics for Part 1 Nominal Trials.

MAP	Mean	SD	N
A	6.8	0.5	96
B	6.5	0.7	94
Total	6.6	0.6	190

Table H.3. Question A ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.375	1	0.375	3.667	0.069
Error	2.250	22	0.102		
Total	1137.000	24			

Table H.4. Question A Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	7.0	0.0	12
B	6.8	0.5	12
Total	6.9	0.3	24

Table H.5. Question A ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	2.667	2	1.333	3.882	0.031
Error	11.333	33	0.343		
Total	1614.000	36			

Table H.6. Question A Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	7.0	0.0	12
9	6.3	0.9	12
10	6.7	0.5	12
Total	6.7	0.6	36

Question B. I was aware of traffic and other vehicles during operations.

Table H.7. Question B ANOVA Statistics for Part 1 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.590	1	0.590	0.466	0.496
Error	238.063	188	1.266		
Total	7742.000	190			

Table H.8. Question B Descriptive Statistics for Part 1 Nominal Trials.

MAP	Mean	SD	N
A	6.1	0.8	96
B	6.1	1.0	94
Total	6.1	0.9	190

Table H.9. Question B ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	35.042	1	35.042	7.954	0.010
Error	96.917	22	4.405		
Total	557.000	24			

Table H.10. Question B Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	3.0	2.1	12
B	5.4	2.1	12
Total	4.2	2.4	24

Table H.11. Question B ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	57.167	2	28.583	10.271	0.000
Error	91.833	33	2.783		
Total	878.000	36			

Table H.12. Question B Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	3.0	2.1	12
9	4.4	1.7	12
10	6.1	1.1	12
Total	4.5	2.1	36

Question C. The display concepts were effective for management of mental workload.

Table H.13. Question C ANOVA Statistics for Part 1 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.343	1	0.343	0.338	0.562
Error	191.110	188	1.017		
Total	7298.000	190			

Table H.14. Question C Descriptive Statistics for Part 1 Nominal Trials.

MAP	Mean	SD	N
A	6.1	0.8	96
B	6.0	1.1	94
Total	6.1	0.9	190

Table H.15. Question C ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	3.375	1	3.375	1.665	0.210
Error	44.583	22	2.027		
Total	785.000	24			

Table H.16. Question C Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	5.2	1.8	12
B	5.9	1.0	12
Total	5.5	1.4	24

Table H.17. Question C ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	4.667	2	2.333	1.179	0.320
Error	65.333	33	1.980		
Total	1094.000	36			

Table H.18. Question C Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	5.2	1.8	12
9	5.0	1.4	12
10	5.8	0.9	12
Total	5.3	1.4	36

Question D. The display concepts contributed to communication effectiveness (ATC and flight crew).

Table H.19. Question D ANOVA Statistics for Part 1 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.001	1	0.001	0.001	0.981
Error	192.868	188	1.026		
Total	6973.000	190			

Table H.20. Question D Descriptive Statistics for Part 1 Nominal Trials.

MAP	Mean	SD	N
A	6.1	0.7	96
B	6.0	1.1	94
Total	6.1	0.9	190

Table H.21. Question D ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	4.167	1	4.167	1.774	0.196
Error	51.667	22	2.348		
Total	804.000	24			

Table H.22. Question D Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	5.2	1.8	12
B	6.0	1.3	12
Total	5.6	1.6	24

Table H.23. Question D ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	7.389	2	3.694	2.049	0.145
Error	59.500	33	1.803		
Total	1134.000	36			

Table H.24. Question D Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	5.2	1.8	12
9	5.1	1.4	12
10	6.1	0.7	12
Total	5.4	1.4	36

Question E. The display promoted effective crew resource management, coordination, and cohesion.

Table H.25. Question E ANOVA Statistics for Part 1 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	2.531	1	2.531	2.843	0.093
Error	167.411	188	0.890		
Total	7387.000	190			

Table H.26. Question E Descriptive Statistics for Part 1 Nominal Trials.

MAP	Mean	SD	N
A	6.2	0.8	96
B	5.9	1.1	94
Total	6.1	0.9	190

Table H.27. Question E ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	5.042	1	5.042	1.276	0.271
Error	86.917	22	3.951		
Total	743.000	24			

Table H.28. Question E Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	4.8	2.1	12
B	5.7	1.8	12
Total	5.2	2.0	24

Table H.29. Question E ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	20.722	2	10.361	3.878	0.031
Error	88.167	33	2.672		
Total	1176.000	36			

Table H.30. Question E Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	4.8	2.1	12
9	5.1	1.7	12
10	6.5	0.7	12
Total	5.4	1.8	36

Question F. The display concepts contributed to perceived safety during operation.

Table H.31. Question F ANOVA Statistics for Part 1 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.241	1	0.241	0.268	0.605
Error	168.938	188	0.899		
Total	7448.000	190			

Table H.32. Question F Descriptive Statistics for Part 1 Nominal Trials.

MAP	Mean	SD	N
A	6.2	0.8	96
B	6.0	1.0	94
Total	6.1	0.9	190

Table H.33. Question F ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	12.042	1	12.042	2.179	0.154
Error	121.583	22	5.527		
Total	647.000	24			

Table H.34. Question F Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition..

MAP	Mean	SD	N
A	3.9	2.5	12
B	5.3	2.2	12
Total	4.6	2.4	24

Table H.35. Question F ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	48.667	2	24.333	8.023	0.001
Error	100.083	33	3.033		
Total	1141.000	36			

Table H.36. Question F Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	3.9	2.5	12
9	5.1	1.6	12
10	6.8	0.5	12
Total	5.3	2.1	36

Question G. The display concepts were effective for detection of potential surface conflicts.

Table H.37. Question G ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	100.042	1	100.042	53.790	0.000
Error	40.917	22	1.860		
Total	401.000	24			

Table H.38. Question G Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	1.3	0.5	12
B	5.3	1.9	12
Total	3.3	2.5	24

Table H.39. Question G ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	176.056	2	88.028	50.229	0.000
Error	57.833	33	1.753		
Total	794.000	36			

Table H.40. Question G Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	1.3	0.5	12
9	3.9	2.2	12
10	6.7	0.5	12
Total	3.9	2.6	36

Part 1 Questionnaire Constructs Results

Task Management

Table H.41. Task Management Construct ANOVA Statistics for Part 1 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.023	1	0.023	0.042	0.837
Error	103.661	188	0.551		
Total	7839.222	190			

Table H.42. Task Management Construct Descriptive Statistics for Part 1 Nominal Trials.

MAP	Mean	SD	N
A	6.3	0.8	288
B	6.2	1.0	282
Total	6.3	0.9	570

Table H.43. Task Management Construct ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	5.671	1	5.671	4.481	0.046
Error	27.843	22	1.266		
Total	770.556	24			

Table H.44. Task Management Construct Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	5.1	2.3	36
B	6.0	1.4	36
Total	5.5	1.9	72

Table H.45. Task Management Construct ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	8.907	2	4.454	4.228	0.023
Error	34.759	33	1.053		
Total	1132.667	36			

Table H.46. Task Management Construct Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	5.1	2.3	36
9	5.3	1.6	36
10	6.2	0.9	36
Total	5.5	1.7	108

Communicative Efficacy

Table H.47. Communicative Efficacy Construct ANOVA Statistics for Part 1 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.614	1	0.614	0.777	0.379
Error	148.496	188	0.790		
Total	7146.000	190			

Table H.48. Communicative Efficacy Construct Descriptive Statistics for Part 1 Nominal Trials.

MAP	Mean	SD	N
A	6.2	0.7	192
B	6.0	1.1	188
Total	6.1	0.9	380

Table H.49. Communicative Efficacy Construct ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
MAP	4.594	1	4.594	1.620	0.216
Error	62.396	22	2.836		
Total	765.750	24			

Table H.50. Communicative Efficacy Construct Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	5.0	1.9	24
B	5.8	1.6	24
Total	5.4	1.8	48

Table H.51. Communicative Efficacy Construct ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	13.214	2	6.607	3.304	0.049
Error	66.375	33	2.011		
Total	1146.500	36			

Table H.52. Communicative Efficacy Construct Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	5.0	1.9	24
9	5.1	1.5	24
10	6.3	0.7	24
Total	5.4	1.6	72

Hazard Awareness

Table H.53. Hazard Awareness Construct ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	45.375	1	45.375	15.106	0.001
Error	66.083	22	3.004		
Total	487.500	24			

Table H.54. Hazard Awareness Construct Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	2.6	2.2	24
B	5.3	2.0	24
Total	4.0	2.5	48

Table H.55. Hazard Awareness Construct ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	102.264	2	51.132	33.649	0.000
Error	50.146	33	1.520		
Total	913.250	36			

Table H.56. Hazard Awareness Construct Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	2.6	2.2	24
9	4.5	2.0	24
10	6.7	0.5	24
Total	4.6	2.4	72

Part 1 SART Results

Table H.57. SART ANOVA Statistics for Part 1 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	16.942	1	16.942	3.198	0.075
Error	996.052	188	5.298		
Total	9785.000	190			

Table H.58. SART Descriptive Statistics for Part 1 Nominal Trials.

MAP	Mean	SD	N
A	6.6	2.3	120
B	7.2	2.2	70
Total	6.8	2.3	190

Table H.59. SART ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.167	1	0.167	0.051	0.823
Error	71.667	22	3.258		
Total	960.000	24			

Table H.60. SART Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	6.0	1.8	12
B	6.2	1.9	12
Total	6.1	1.8	24

Table H.61. SART ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	77.167	2	38.583	7.508	0.002
Error	169.583	33	5.139		
Total	2409.000	36			

Table H.62. SART Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	6.0	1.8	12
9	7.7	1.9	12
10	9.6	2.9	12
Total	7.8	2.7	36

Part 1 TLX Results

Table H.63. TLX ANOVA Statistics for Part 1 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	253.139	1	253.139	1.085	0.299
Error	43850.446	188	233.247		
Total	271806.250	190			

Table H.64. TLX Descriptive Statistics for Part 1 Nominal Trials.

MAP	Mean	SD	N
A	35.5	15.8	120
B	33.1	14.3	70
Total	34.6	15.3	190

Table H.65. TLX ANOVA Statistics for Part 1 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	81.279	1	81.279	0.524	0.477
Error	3410.359	22	155.016		
Total	22522.917	24			

Table H.66. TLX Descriptive Statistics for Part 1 Off-Nominal Trials for Map Condition.

MAP	Mean	SD	N
A	26.3	11.4	12
B	30.0	13.4	12
Total	28.7	12.3	24

Table H.67. TLX ANOVA Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
NACp	134.144	2	67.072	0.430	0.654
Error	5145.023	33	155.910		
Total	34748.611	36			

Table H.68. TLX Descriptive Statistics for Part 1 Off-Nominal Trials for NACp (8, 9, 10) Condition.

NACp	Mean	SD	N
8	26.3	11.4	12
9	31.0	14.6	12
10	28.5	11.1	12
Total	28.6	12.3	36

Appendix I: Part 2 Run Questionnaire Results

Part 2 Post Run Questionnaire Results

Question A. I was aware of ownship position.

Table I.1. Question A ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	1.406	1	1.406	2.265	0.136
HUD	0.951	1	0.951	1.531	0.219
MAPxHUD	0.156	1	0.156	0.252	0.617
Error	57.122	92	0.621		
Total	4103.000	96			

Table I.2. Question A Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	6.9	0.3	24
C	Y	6.9	0.3	24
	Total	6.9	0.3	48
D	N	6.6	1.1	24
D	Y	6.6	0.7	24
	Total	6.6	0.9	48
C+D	N	6.8	0.8	48
C+D	Y	6.8	0.5	48
	Total	6.8	0.7	96

Table I.3. Question A ANOVA Statistics for Part 2 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.083	1	0.083	0.246	0.622
Error	15.583	46	0.339		
Total	2096.000	48			

Table I.4. Question A Descriptive Statistics for Part 2 Off-Nominal Trials for NACp Condition.

MAP	NACp	Mean	SD	N
C	9	6.9	0.3	12
C	10	6.8	0.4	12
	Total	6.9	0.3	24
D	9	6.6	0.8	12
D	10	6.7	0.7	12
	Total	6.6	0.7	24
C+D	9	6.8	0.6	24
C+D	10	6.8	0.5	24
	Total	6.8	0.6	48

Question B. The display concepts were effective for maintaining my situation awareness of ownship.

Table I.5. Question B ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.006	1	0.006	0.006	0.938
HUD	0.084	1	0.084	0.082	0.775
MAPxHUD	2.256	1	2.256	2.215	0.140
Error	93.722	92	1.019		
Total	3661.000	96			

Table I.6. Question B Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	6.6	0.5	24
C	Y	6.6	0.5	24
	Total	6.6	0.5	48
D	N	6.6	0.7	24
D	Y	6.5	0.7	24
	Total	6.5	0.7	48
C+D	N	6.6	0.6	48
C+D	Y	6.5	0.6	48
	Total	6.6	0.6	96

Table I.7. Question B ANOVA Statistics for Part 2 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	3.221	1	3.221	0.899	0.342
Error	164.81	46	3.5882		
Total	1675.000	48			

Table I.8. Question B Descriptive Statistics for Part 2 Off-Nominal Trials for NACp Condition.

MAP	NACp	Mean	SD	N
C	9	6.4	0.7	12
C	10	6.5	0.5	12
	Total	6.5	0.6	24
D	9	6.4	0.8	12
D	10	6.7	0.7	12
	Total	6.5	0.7	24
C+D	9	6.4	0.7	24
C+D	10	6.6	0.6	24
	Total	6.5	0.7	48

Question C. I was aware of traffic and other vehicles during operations.

Table I.9. Question C ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	1.534	1	1.534	2.362	0.128
HUD	0.951	1	0.951	1.464	0.229
MAPxHUD	1.951	1	1.951	3.004	0.086
Error	59.744	92	0.649		
Total	3801.000	96			

Table I.10. Question C Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	6.5	0.6	24
C	Y	6.4	0.6	24
	Total	6.5	0.6	48
D	N	6.5	0.5	24
D	Y	6.3	0.6	24
	Total	6.4	0.6	48
C+D	N	6.5	0.6	48
C+D	Y	6.4	0.6	48
	Total	6.4	0.6	96

Table I.11. Question C ANOVA Statistics for Part 2 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	4.433	1	4.433	1.250	0.272
Error	163.502	46	3.554		
Total	1332.000	48			

Table I.12. Question C Descriptive Statistics for Part 2 Off-Nominal Trials for NACp Condition.

MAP	NACp	Mean	SD	N
C	9	5.8	1.3	12
C	10	6.3	0.8	12
	Total	6.1	1.1	24
D	9	6.4	0.8	12
D	10	6.2	0.9	12
	Total	6.3	0.9	24
C+D	9	6.1	1.1	24
C+D	10	6.3	0.9	24
	Total	6.2	1.0	48

Question D. The display concepts provided effective awareness of traffic intent information.

Table I.13. Question D ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.336	1	0.336	0.419	0.519
HUD	0.278	1	0.278	0.346	0.558
MAPxHUD	2.336	1	2.336	2.910	0.091
Error	73.844	92	0.803		
Total	3678.000	96			

Table I.14. Question D Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	6.3	0.8	24
C	Y	6.0	0.9	24
	Total	6.1	0.8	48
D	N	6.4	0.7	24
D	Y	6.1	0.6	24
	Total	6.3	0.6	48
C+D	N	6.3	0.7	48
C+D	Y	6.1	0.8	48
	Total	6.2	0.74	96

Table I.15. Question D ANOVA Statistics for Part 2 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	3.521	1	3.521	1.824	0.183
Error	88.792	46	1.930		
Total	1645.000	48			

Table I.16. Question D Descriptive Statistics for Part 2 Off-Nominal Trials for NACp Condition.

MAP	NACp	Mean	SD	N
C	9	5.3	1.5	12
C	10	6.3	0.6	12
	Total	5.8	1.2	24
D	9	5.2	1.5	12
D	10	5.9	0.9	12
	Total	5.5	1.3	24
C+D	9	5.3	1.5	24
C+D	10	6.1	0.8	24
	Total	5.7	1.2	48

Question E. The display concepts were effective for required time-of-arrival taxi conformance.

Table I.17. Question E ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	1.344	1	1.344	1.680	0.198
HUD	0.011	1	0.011	0.014	0.906
MAPxHUD	2.178	1	2.178	2.721	0.102
Error	73.644	92	0.800		
Total	3678.000	96			

Table I.18. Question E Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	6.4	0.8	24
C	Y	6.4	0.6	24
	Total	6.4	0.7	48
D	N	6.4	0.7	24
D	Y	6.4	0.8	24
	Total	6.4	0.7	48
C+D	N	6.4	0.7	48
C+D	Y	6.4	0.7	48
	Total	6.4	0.7	96

Table I.19. Question E ANOVA Statistics for Part 2 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	6.750	1	6.750	2.793	0.101
Error	111.167	46	2.417		
Total	1822.000	48			

Table I.20. Question E Descriptive Statistics for Part 2 Off-Nominal Trials for NACp Condition.

MAP	NACp	Mean	SD	N
C	9	6.1	0.9	12
C	10	6.2	0.6	12
	Total	6.1	0.7	24
D	9	6.3	0.6	12
D	10	6.4	0.7	12
	Total	6.3	0.6	24
C+D	9	6.2	0.8	24
C+D	10	6.3	0.6	24
	Total	6.2	0.7	48

Question F. The display location of STBO taxi guidance information was effective for situation awareness.

Table I.21. Question F ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.306	1	0.306	0.232	0.631
HUD	0.584	1	0.584	0.443	0.507
MAPxHUD	1.056	1	1.056	0.801	0.373
Error	121.256	92	1.318		
Total	3567.000	96			

Table I.22. Question F Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	6.3	0.6	12
C	Y	6.5	0.5	12
	Total	6.4	0.5	24
D	N	6.0	1.3	12
D	Y	6.2	0.8	12
	Total	6.1	1.0	24
C+D	N	6.2	1.0	48
C+D	Y	6.3	0.7	48
	Total	6.3	0.8	96

Table I.23. Question F ANOVA Statistics for Part 2 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	6.021	1	6.021	2.507	0.120
Error	110.458	46	2.401		
Total	1715.000	48			

Table I.24. Question F Descriptive Statistics for Part 2 Off-Nominal Trials for NACp Condition.

MAP	NACp	Mean	SD	N
C	9	6.2	0.6	12
C	10	6.3	0.8	12
	Total	6.2	0.7	24
D	9	6.3	0.7	12
D	10	6.3	0.5	12
	Total	6.3	0.6	24
C+D	9	6.3	0.6	24
C+D	10	6.3	0.6	24
	Total	6.3	0.6	48

Question G. The display location of STBO taxi guidance information was effective for mental workload.

Table I.25. Question G ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	1.176	1	1.176	1.365	0.246
HUD	0.608	1	0.608	0.705	0.403
MAPxHUD	2.535	1	2.535	2.942	0.090
Error	79.276	92	0.862		
Total	3672.825	96			

Table I.26. Question G Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	6.3	0.6	24
C	Y	6.3	0.6	24
	Total	6.3	0.6	48
D	N	6.0	1.2	24
D	Y	6.0	0.8	24
	Total	6.0	1.0	48
C+D	N	6.2	0.9	48
C+D	Y	6.1	0.7	48
	Total	6.2	0.8	96

Table I.27. Question G ANOVA Statistics for Part 2 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	7.212	1	7.212	0.951	0.329
Error	735.49	46	15.991		
Total	1032.415	48			

Table I.28. Question G Descriptive Statistics for Part 2 Off-Nominal Trials for NACp Condition.

MAP	NACp	Mean	SD	N
C	9	6.1	0.8	12
C	10	6.1	0.8	12
	Total	6.1	0.8	24
D	9	6.2	0.7	12
D	10	6.1	0.5	12
	Total	6.1	0.6	24
C+D	9	6.1	0.7	24
C+D	10	6.1	0.7	24
	Total	6.1	0.7	48

Question H. The display concepts contributed to perceived safety during operations.

Table I.29. Question H ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.178	1	0.178	0.232	0.631
HUD	1.878	1	1.878	2.452	0.121
MAPxHUD	0.011	1	0.011	0.015	0.904
Error	70.444	92	0.766		
Total	3674.000	96			

Table I.30. Question H Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	6.5	0.6	24
C	Y	6.4	0.6	24
	Total	6.5	0.6	48
D	N	6.3	1.1	24
D	Y	6.3	0.7	24
	Total	6.3	0.9	48
C+D	N	6.4	0.9	48
C+D	Y	6.4	0.6	48
	Total	6.4	0.8	96

Table I.31. Question H ANOVA Statistics for Part 2 Off-Nominal Trials for Map Condition.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	41.217	1	14.217	1.465	0.229
Error	38.212	46	0.831		
Total	943.560	48			

Table I.32. Question H Descriptive Statistics for Part 2 Off-Nominal Trials for NACp Condition.

MAP	NACp	Mean	SD	N
C	9	6.0	1.2	12
C	10	6.3	0.7	12
	Total	6.2	1.0	24
D	9	6.3	0.5	12
D	10	6.3	0.8	12
	Total	6.3	0.6	24
C+D	9	6.2	0.9	24
C+D	10	6.3	0.7	24
	Total	6.3	0.8	48

Question I. The display concepts were effective for detection of potential surface conflicts during STBO taxi.

Table I.33. Question I ANOVA Statistics for Part 2 Off-Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	2.083	1	2.083	1.310	0.258
Error	73.167	46	1.591		
Total	1594.000	48			

Table I.34. Question I Descriptive Statistics for Part 2 Off-Nominal Trials.

MAP	NACp	Mean	SD	N
C	9	5.2	1.6	12
C	10	6.2	1.6	12
	Total	5.7	1.7	24
D	9	5.8	1.2	12
D	10	6.2	0.8	12
	Total	6.0	1.0	24
C+D	9	5.5	1.4	24
C+D	10	6.2	1.2	24
	Total	5.8	1.4	48

Part 2 Questionnaire Constructs Results

Task Management

Table I.35. Task Management Construct ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	2.344	1	2.344	2.728	0.102
HUD	0.260	1	0.260	0.303	0.583
MAPxHUD	0.094	1	0.094	0.109	0.742
Error	79.042	92	0.859		
Total	3671.000	96			

Table I.36. Task Management Construct Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	6.7	0.5	72
C	Y	6.6	0.5	72
	Total	6.6	0.5	144
D	N	6.6	0.8	72
D	Y	6.5	0.7	72
	Total	6.5	0.7	144
C+D	N	6.6	0.7	144
C+D	Y	6.5	0.6	144
	Total	6.6	0.6	288

Table I.37. Task Management Construct ANOVA Statistics for Part 2 Off-Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.642	1	0.642	0.165	0.689
NACp	1.157	1	1.157	0.179	0.675
MAPxNACp	0.554	1	0.554	0.145	0.712
Error	351.532	44	3.821		
Total	1994.562	48			

Table I.38. Task Management Construct Descriptive Statistics for Part 2 Off-Nominal Trials for NACp (8, 9, 10) Condition.

MAP	NACp	Mean	SD	N
C	9	6.4	1.0	36
C	10	6.6	0.6	36
	Total	6.5	0.8	72
D	9	6.5	0.8	36
D	10	6.5	0.8	36
	Total	6.5	0.8	72
C+D	9	6.4	0.9	72
C+D	10	6.5	0.7	72
	Total	6.5	0.8	144

Communicative Efficacy

Table I.39. Communicative Efficacy Construct ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	3.760	1	3.760	2.505	0.117
HUD	3.010	1	3.010	2.005	0.160
MAPxHUD	1.760	1	1.760	1.173	0.282
Error	138.125	92	1.501		
Total	3425.000	96			

Table I.40. Communicative Efficacy Construct Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	6.3	0.7	96
C	Y	6.3	0.7	96
	Total	6.3	0.7	192
D	N	6.2	1.0	96
D	Y	6.2	0.8	96
	Total	6.2	0.9	192
C+D	N	6.3	0.8	192
C+D	Y	6.2	0.7	192
	Total	6.3	0.8	384

Table I.41. Communicative Efficacy Construct ANOVA Statistics for Part 2 Off-Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	1.089	1	1.089	0.542	0.468
NACp	4.030	1	4.030	2.764	0.104
MAPxNACp	0.580	1	0.580	0.289	0.589
Error	184.920	44	2.010		
Total	2258.300	48			

Table I.42. Communicative Efficacy Construct Descriptive Statistics for Part 2 Off-Nominal Trials for NACp (8, 9, 10) Condition.

MAP	NACp	Mean	SD	N
C	9	5.9	1.0	48
C	10	6.2	0.7	48
	Total	6.1	0.9	96
D	9	6.0	1.0	48
D	10	6.2	0.7	48
	Total	6.1	0.9	96
C+D	9	6.0	1.0	96
C+D	10	6.2	0.7	96
	Total	6.1	0.9	192

Hazard Awareness

Table I.43. Hazard Awareness Construct ANOVA Statistics for Part 2 Off-Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	0.501	1	0.501	0.392	0.524
NACp	3.001	1	3.001	2.681	0.109
MAPxNACp	0.215	1	0.215	0.156	0.687
Error	49.243	44	1.119		
Total	1793.500	48			

Table I.44. Hazard Awareness Construct Descriptive Statistics for Part 2 Off-Nominal Trials for NACp (8, 9, 10) Condition.

MAP	NACp	Mean	SD	N
C	9	5.6	1.5	24
C	10	6.3	1.2	24
	Total	5.9	1.4	48
D	9	6.1	0.9	24
D	10	6.3	0.8	24
	Total	6.2	0.9	48
C+D	9	5.8	1.2	48
C+D	10	6.3	1.0	48
	Total	6.0	1.1	96

Part 2 SART Results

Table I.45. SART ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	9.375	1	9.375	1.371	0.245
HUD	0.167	1	0.167	0.024	0.876
MAPxHUD	7.042	1	7.042	1.030	0.313
Error	629.250	92	6.840		
Total	5294.000	96			

Table I.46. SART Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	7.6	2.8	24
C	Y	7.0	3.1	24
	Total	7.3	3.0	48
D	N	6.4	2.2	24
D	Y	6.9	2.3	24
	Total	6.7	2.2	48
C+D	N	7.0	2.5	48
C+D	Y	6.9	2.7	48
	Total	7.0	2.6	96

Table I.47. SART ANOVA Statistics for Part 2 Off-Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	18.750	1	18.750	7.432	0.009
NACp	10.08	1	10.083	3.997	0.052
MAPxNACp	0.083	1	0.083	0.033	0.857
Error	111.000	44	2.523		
Total	2634.000	48			

Table I.48. SART Descriptive Statistics for Part 2 Off-Nominal Trials for NACp (9, 10) Condition.

MAP	NACp	Mean	SD	N
C	9	7.1	1.7	12
C	10	6.1	1.9	12
	Total	6.5	1.8	24
D	9	8.3	1.0	12
D	10	7.4	1.5	12
	Total	7.8	1.3	24
C+D	9	7.7	1.5	24
C+D	10	6.8	1.8	24
	Total	7.2	1.7	48

Part 2 TLX Results

Table I.49. TLX ANOVA Statistics for Part 2 Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	247.577	1	247.577	1.571	0.213
HUD	263.896	1	263.896	1.674	0.199
MAPxHUD	47.461	1	47.461	0.301	0.585
Error	14501.823	92	157.629		
Total	98732.639	96			

Table I.50. TLX Descriptive Statistics for Part 2 Nominal Trials.

MAP	HUD	Mean	SD	N
C	N	25.6	11.6	24
C	Y	30.3	13.4	24
	Total	27.9	12.6	48
D	N	30.2	10.7	24
D	Y	32.1	14.2	24
	Total	31.1	12.5	48
C+D	N	27.9	11.3	48
C+D	Y	31.2	13.7	48
	Total	29.5	12.6	96

Table I.51. TLX ANOVA Statistics for Part 2 Off-Nominal Trials.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
MAP	1062.514	1	1062.514	8.305	0.006
NACp	338.672	1	338.672	2.647	0.111
MAPxNACp	572.931	1	572.931	4.478	0.040
Error	5629.225	44	127.937		
Total	97520.139	48			

Table I.52. TLX Descriptive Statistics for Part 2 Off-Nominal Trials for NACp (8, 9, 10) Condition.

MAP	NACp	Mean	SD	N
C	9	37.8	13.6	12
C	10	39.4	10.6	12
	Total	38.6	11.9	24
D	9	54.1	7.3	12
D	10	41.9	12.8	12
	Total	48.0	11.9	24
C+D	9	45.9	13.5	24
C+D	10	40.6	11.5	24
	Total	43.3	12.7	48

Appendix J: Final Questionnaire Results

A post-test questionnaire was administered to each of the 24 test subjects.

General Safety

1. Rate the level of perceived safety you believe you would experience if you did not have this system (i.e., what you have today) onboard your aircraft during similar operations.
   1 = Not Safe; 7 = Completely Safe

2. Rate the level of perceived safety you believe you would experience if you had this system (CD&R system) onboard your aircraft during similar operations.   1 = Not Safe; 7 = Completely Safe

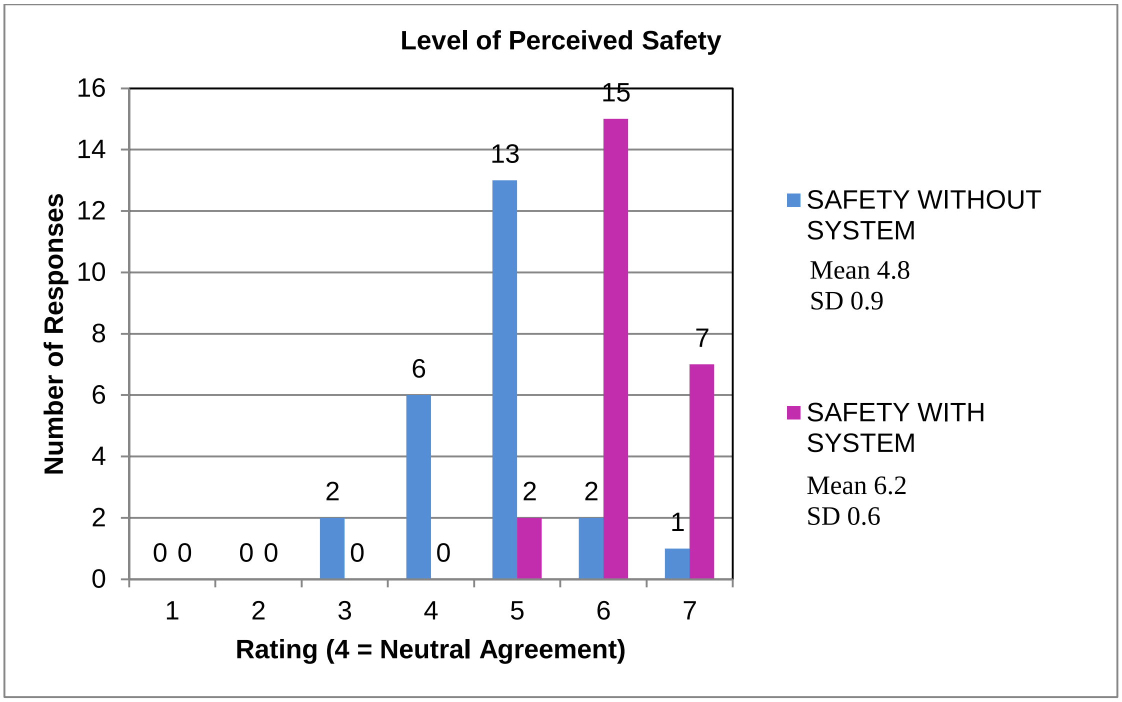


Figure J.1. Level of Perceived Safety Responses.

Table J.1. ANOVA Statistics for Level Of Perceived Safety.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
CDR	Sphericity Assumed	25.521	1	25.521	65.371	.000
	Greenhouse-Geisser	25.521	1.000	25.521	65.371	.000
	Huynh-Feldt	25.521	1.000	25.521	65.371	.000
	Lower-bound	25.521	1.000	25.521	65.371	.000
Error(CDR)	Sphericity Assumed	8.979	23	.390		
	Greenhouse-Geisser	8.979	23.000	.390		
	Huynh-Feldt	8.979	23.000	.390		
	Lower-bound	8.979	23.000	.390		

3. Rate the level of safety you felt during *runway* conflict incidents. 1 = Not Safe; 7 = Completely Safe

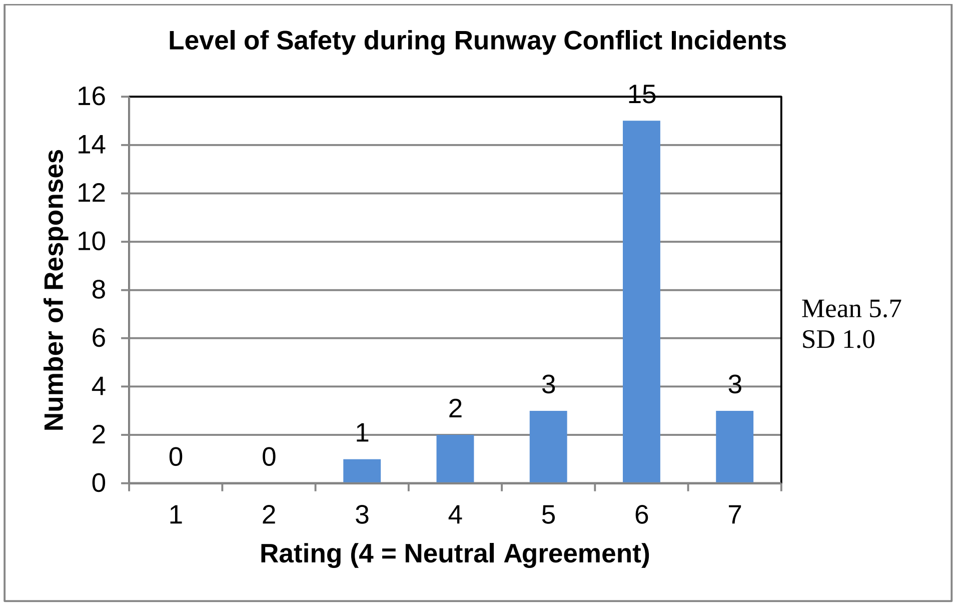


Figure J.2. Level of Safety During Runway Conflict Incidents Responses.

If not completely safe, please provide suggesions for improvements that may potentially increase perceived level of safety to "completely safe".

Subject	Suggestions
1	Not enough experience with the system to suggest improvements to what you have designed.
2	It was hard to understand. The symbology – especially for "off-scale" aircraft conflicts.
3	Perhaps a caution a little earlier when another aircraft approaches the runway, thereby, reminding the aircraft taking off to expand their scale and search for conflicts outside visual range.
4	(no answer)
5	Label possible conflicting aircraft with their NAC number to let pilots know if they will get auto-warnings.
6	Not necessaryily the system, but the operators (users) comfort level.
7	Level 10 or better.
8	Require all aircraft and operators to be equipped and trained at the highest level.
9	(no answer)
10	Ground speed/acceleration information of target aircraft.
11	Need distance from conflicting airplane.
12	(no answer)
13	Make sure all movement at those conditions are a 10 or higher. A FLIR backup would help.
14	No suggestions – one can never eliminate risk, only identify potential areas for problems and employ risk management techniques. Ex. SOP's, policies, and procedures.
15	Question of participating vs non-participating adds to mental workload and uncertainty.
16	Maybe an idea of distance, i.e. 1.0 nm not a good idea to cross, 5.0 nm its ok to cross. ATC cleared us to cross today at 0.9 nm, we questioned that.
17	Safety is relative to the number of reporting aircraft. 100% reporting = 100% +/- safety.
18	Show all traffic.
19	Procedures to allow CA or taxi pilot to observe conflict without looking down to moving map. At least one pilot should be outside at all times.
20	(no answer)

21	1. While I do believe this adds an additional layer of safety to avoid conflicts, the words "completely safe" implies to me "perfection" which in my opinion may lead to slight dependency and/or complacency while using such systems. The trust but verify the method could be slightly diminished thereby adding false security in operations. 2. No interaction by ATC or did other aircraft have similar equipment? Don't know.
22	Detailed training on what scale to use during different types of operations. Our crew missed a conflict that may have been avoided had we been on the proper screen scale.
23	(no answer)
24	Better resolution or more experience with current system. I spent a lot of attention looking at aircraft in hold short situations wondering if there were an incursion or if it was display/resolution issue.

4. Rate the level of safety you felt during _taxi_ conflict incidents. 1 = Not Safe; 7 = Completely Safe

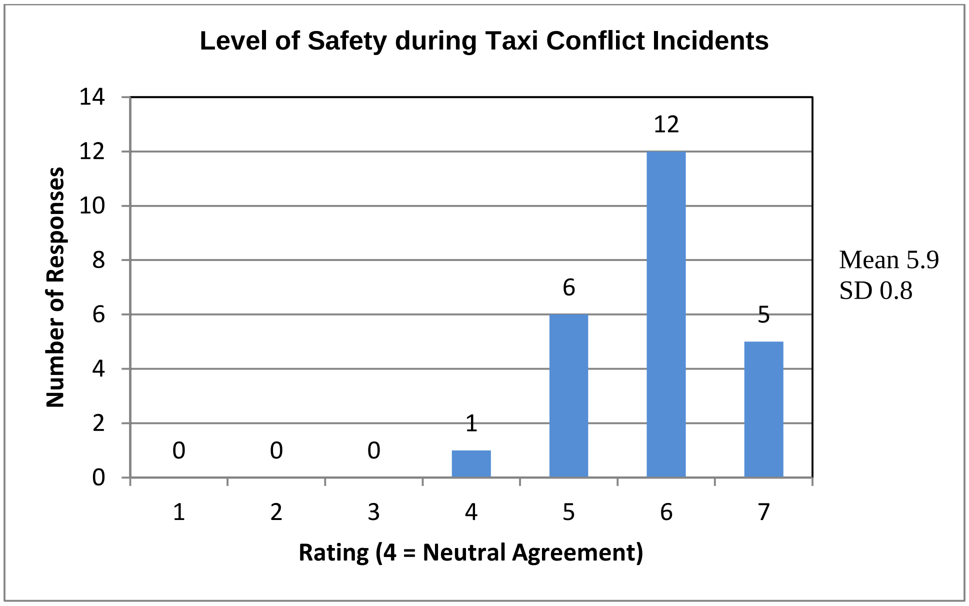


Figure J.3. Level of Safety During Taxi Conflict Incidents Responses.

If not completely safe, please provide suggesions for improvements that may potentially increase perceived level of safety to "completely safe".

Subject	Suggestions
1	Increase the distance between conflicting aircraft wherein a caution is annunciated – Increase would be minimal however many times I thought the impending conflict got too close before aural caution.
2	On several of the other targets their taxi clearance information wasn't available. Even when it was displayed, we still didn't know if the other aircraft would follow its guidance.
3	Perhaps a system to send a "stop" signal to one of the aircraft in a conflict situation.
4	More connectivity (either voice or data link) verifying critical clearance items, i.e. runway crossing or merging traffic.
5	Same as #3
6	(no answer)
7	(no answer)
8	Increase radius of warning.
9	Not all obesrved potential conflicts were identified by the system. No warning (or caution) was

	displayed for some "close calls". Have different collision algorithms been tested?
10	Prefer to set my own taxi speed with respect to other constraints on THS operations, i.e. final numbers, weather conditions.
11	(no answer)
12	(no answer)
13	Somehow alert us if a traffic has the same clearance and is +/- 15 seconds of us. A FLIR backup would help.
14	Same as #3
15	Same as #3
16	(no answer)
17	All aircraft reporting exact position in the best.
18	Show all traffic.
19	If 1800 RVR, emphasis should be visual confirmation of conflict.
20	(no answer)
21	Other airplance involved in conflict had no ATC questioning as did we, were not sure if aircraft was also conflict equipped. The human factor was removed making myself unconfortable with the situation.
22	Although it's a great system, I would never totally trust a system into feeling "completely safe". I believe that a certain element of risk will always remain despite our best efforts.
23	(no answer)
24	As with the runway, we don't receive an advisory with every traffic occurrence and we didn't get a path from every symbol I highlighted. So…. I try to watch visually and clear verbally all traffic. No system will make me feel completely safe.

General Advantages and Disadvantages

5. What do you consider the <u>best</u> feature of the displays/technology you evaluated today? Can the feature be improved? If so, how?

Subject	Best Feature	Improvement
1	Real time imagery with ability to deter route of confict aircraft.	Routing of conflict aircraft displayed instead of just having taxiways listed.
2	Visual of traffic and ability to ID them.	Put moving map on ND display. I have to go to a lot of other pages on the EFB, so I couldn't be tracking traffic as easily.
3	The projected taxi path was very helpful.	Not sure.
4	Traffic following beyond the visual range.	(no answer)
5	Shows taxi route graphically.	No suggestions.
6	The warning system of impending conflict was an excellent tool.	(no answer)
7	Taxi route.	Yes, my aircraft chevron symbol yellow and closer to the ring – it gets lost at bottom plus further to scan.
8	Visual taxi path. Possible early awareness of conflicts.	(no answer)
9	The ability to observe the aircraft position and direction of travel in real-time on the moving map display.	Show the ground speed next to the aircraft symbol.
10	When all aircraft have the NACp 11.	When all aircraft have the NACp 11.
11	Colored taxi route.	(no answer)
12	Display of unnoticed traffic.	(no answer)
13	IFR.	Make all tolerences NACp 10 or better.
14	CPDLC eliminates readback/hearback	Too cumbersome to "Wilco" on this device.

	errors.	
15	Traffic location.	Hollow widget for NACp 8 and below. Solid for higher NACp.
16	Datalink taxi instructions and traffic awareness symbology.	Maybe an auto-scale feature that when a traffic symbol is off scale, and it might conflict, it scales out so you can see it.
17	SA in low visibility.	Seems to be real close to perfect.
18	Display. Confidence that we can see all of the traffic.	Show all traffic regardless of accuracy!
19	Moving map with real-time position awareness.	Using position awareness similar to ground roll guidance in HUD during takeoff roll.
20	Being able to identify conflicting aircraft routes.	No.
21	1. Adds a new dimension to situational awareness. 2. Ease of use.	Definitely needs a touch screen availability while in the moving map mode to quickly gain overall SA at airport.
22	Audio call-outs of the conflicts.	Yes, it should offer a more concise resolution. Such as “STOP” or “GO AROUND”.
23	One more level of higher safety – especially for operations during reduced visibility.	Yes, have the cautions and warnings show on the primary flight display and HUD.
24	Like TCAS, the visual depictions and predictive advisories increase situational awareness, even if occasionally we get nuisance alerts.	I don’t think we should worry about displaying too many aircraft even if their exact location isn’t perfect. Especially when in taxi operations. Again, some of this is learning on operator part, what resolution we are seeing. I.e., is that symbol with his nose touching the runway a threat? Otherwise its distracting.

6. What do you consider to be the <u>worst</u> feature of the displays/technology you evaluated today? Can the feature be improved? If so, how?

Subject	Worst Feature	Improvement
1	(no answer)	(no answer)
2	Never heard an “aural” alert for runway conflicts. You had to be looking at moving map.	For runway conflicts, provide aural alerts. Move the moving map display to the ND.
3	No deconfliction guidance.	A simple “stop” command to at least one of the aircraft.
4	(no answer)	(no answer)
5	The arrival time prediction display (+/- ETAs).	Switch the signs so that if you’re early, the display shows a minus value and vice-versa for late arrivals.
6	NACp scale was a little confusing when an 8 or 9 level aricraft caused a conflict. Was not sure if it would be an issue or not.	Not sure.
7	Scale of map on approach.	Yes, able to slew it with the smaller scales.
8	Takes a lot of time of at least one pilot during busy period.	Not sure.
9	Movement information for targets (speed) was not displayed for ground targets next to their symbols.	(no answer)
10	Seeing some targets not all.	To have the confidence of TCAS… will take some time.
11	Arrows for all aircraft need to be smaller and taxiways larger.	Self explanatory.
12	Some traffic not displayed.	(no answer)

13	Not all traffic shown, thus you cannot trust it completely.	Be able to see traffic say on a 7-8 mile final and be told what runway he is cleared for.
14	Too much head-down and button pushing. Plus, first officers have to input weight and balance data, make radio calls, run checklists, etc. No time to look outside, expecially if a short taxi.	Task loading can send a first officer from the green into the red quickly. Must reduce tasks. Fewer button pushes would help somewhat.
15	Uncertainty of NACp 8-9 aircraft.	See #5.
16	Ground RTAs.	A update feature / function. If you cannot make an RTA you let ATC know and revise.
17	Unreported and uncertain aircraft.	Yes, increased required position certainty.
18	N/A	N/A
19	Symbology. Could be confused easily. Timed departure taxi. Puts pressure on pilot to achieve a schedule during taxi. Some pilots simply need more time during low vis taxi.	(no answer)
20	Learning curve is fast. No bad feature.	(no answer)
21	1. There was a few times when I wanted to see and verify my magenta taxi route 100%, and due to aircraft position even on full zoom out could not see entire airport (the direction arrows seem to not work in this moving map display). 2. Removal of the human element as this took out knowing the intentions of conflicting traffic and situations that could lead to sooner resolutions.	By adding a conventional touch/pinch feature to moving map or by activating the pan arrows to see around airport without changing the zoom or size of runway/taxiway.
22	Requires more heads down time.	A more automated system that required less crew monitoring would help the crew.
23	1. Causes pilots to be "heads down" during critical taxi operations. 2. Does not identify all conflicts (vehicles and some aircraft).	1. Overlaying the "moving map" display onto the field diagram chart. 2. See question #5.
24	Definitely the layering of the moving map, comm, checklists, charts. I think this is a safety problem from the workload management perspective. The system is good enough to give a false sense of safety "perception". In reality if you add 2D (?) engine start, PA's, new ATIS, T/O data, runway change to the problem of being off moving map page, you have a safety problem.	Move comm panel CPDLC to a different screen like 777. Get the checklist to a different screen like 777 and either use datalink comm which I prefer to voice but not both. The duplication is distracting and you already have enough distraction in the system.

7. What other suggestions, comments, etc. can you provide that may potentially enhance the displays/technology you evaluated today?

Subject	Comments
1	(no answer)
2	(no answer)
3	See above.
4	(no answer)
5	See comment on displaying NACp values.
6	None
7	1. Slew approach. 2. Yellow my aircraft pulsing. 3. Closer to ring – easy scan.
8	(no answer)
9	Version “A” allowed a false sense of security since not all traffic was able to be observed. I think that only version B should be considered for implementation.
10	Being able to “pinch” and/or slide screen view.
11	I would recommend using TCAS symbology. It’s simple, accurate, and understandable.
12	Smaller aircraft symbols.
13	If you have a HUD, couple it with a FLIR like system.
14	Ground display improvement – when about to cross a runway or taxi onto a runway, nice to zoom out to see traffic landing in reduced visibility, including night. The display should be able to have your position in the center of the screen, so you can see full-scale zoom out for the runway. Can it incorporate ramp and taxiway closures/construction? Linked to Jeppesen updates?
15	(no answer)
16	(no answer)
17	(no answer)
18	(no answer)
19	(no answer)
20	None
21	I think in a real world environment that ATC/human elements might have resolved the conflicts “sooner than later” if they had been available; however, as a stand alone system it was a great backup to SA. The above human factors should be factored in somwhow!
22	Assign one pilot the task of focusing outside, and the other pilot the task of monitioring the dispalys inside.
23	Voice guidance would be very helpful. When I use my I-phone as a navigation system, the voice prompts are easy to understand – even with other background noise (radio/wife and/or daughter talking). Could work well.
24	I think we need to increase the consistancy of alerts and warnings vs filter. I felt like we spent a lot of time heads down looking at symbols on the moving map and wondering if they were going to become a factor. The vast majority did not.

Traffic Awareness

8. Rate your level of overall traffic awareness when ALL traffic was displayed on the airport moving map. 1 = Low; 7 = High

9. Rate your level of overall traffic awareness when only qualified traffic (NACp 9 and higher) was displayed on the airport moving map. 1 = Low; 7 = High

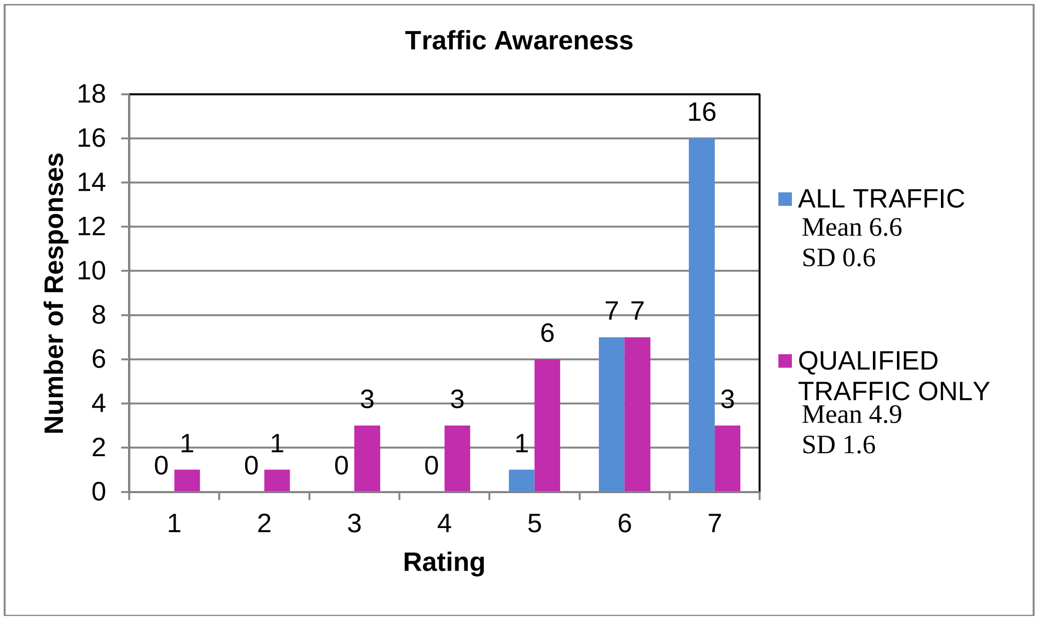


Figure J.4. Traffic Awareness Responses.

Table J.2. ANOVA Statistics for Traffic Responses.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Traffic	Sphericity Assumed	36.750	1	36.750	21.535	.000
	Greenhouse-Geisser	36.750	1.000	36.750	21.535	.000
	Huynh-Feldt	36.750	1.000	36.750	21.535	.000
	Lower-bound	36.750	1.000	36.750	21.535	.000
Error(Traffic)	Sphericity Assumed	39.250	23	1.707		
	Greenhouse-Geisser	39.250	23.000	1.707		
	Huynh-Feldt	39.250	23.000	1.707		
	Lower-bound	39.250	23.000	1.707		

10. The presentation of ALL traffic on the airport moving map represents a safety issue (i.e., qualified and unqualified traffic). 1 = Strongly Disagree; 7 = Strongly Agree

11. The presentation of only qualified traffic on the airport moving map represents a safety issue (i.e., aircraft reporting less accurate data not shown). 1 = Strongly Disagree; 7 = Strongly Agree

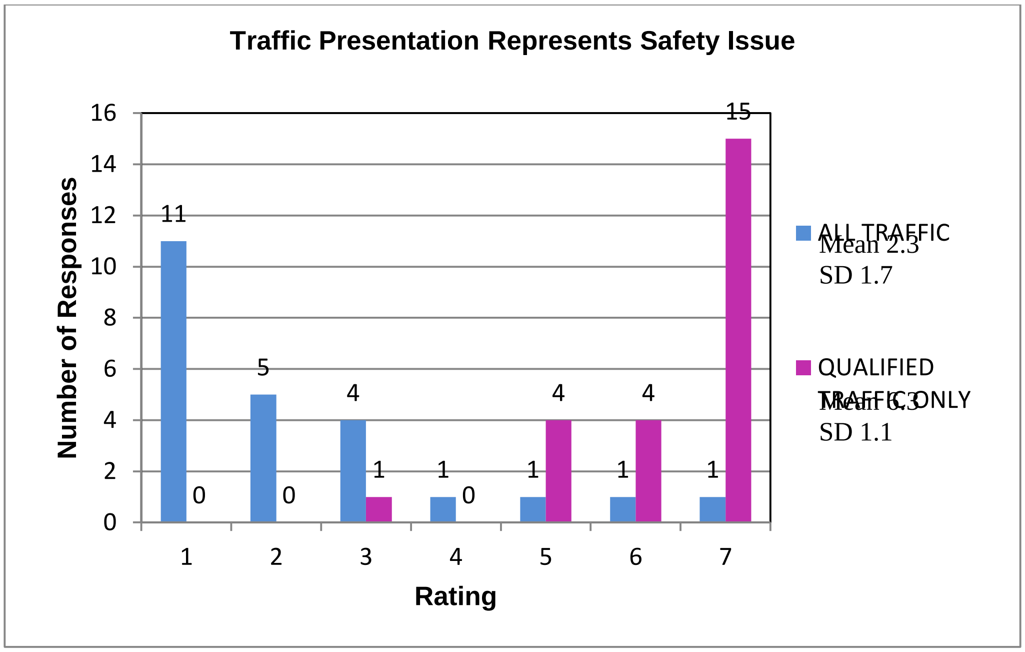


Figure J.5. Traffic Presentation Represents Safety Issue Responses.

Table J.3. ANOVA Statistics for Traffic Presentation Represents Safety Issue.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Traffic	Sphericity Assumed	196.021	1	196.021	68.854	.000
	Greenhouse-Geisser	196.021	1.000	196.021	68.854	.000
	Huynh-Feldt	196.021	1.000	196.021	68.854	.000
	Lower-bound	196.021	1.000	196.021	68.854	.000
Error(Traffic)	Sphericity Assumed	65.479	23	2.847		
	Greenhouse-Geisser	65.479	23.000	2.847		
	Huynh-Feldt	65.479	23.000	2.847		
	Lower-bound	65.479	23.000	2.847		

12. The presentation of ALL traffic on the airport moving map will increase the potential for accidents (i.e., qualified and unqualified traffic). 1 = Strongly Disagree; 7 = Strongly Agree

13. The presentation of only qualified traffic on the airport moving map will increase the potential for accidents (i.e., aircraft reporting less accurate data not shown). 1 = Strongly Disagree; 7 = Strongly Agree

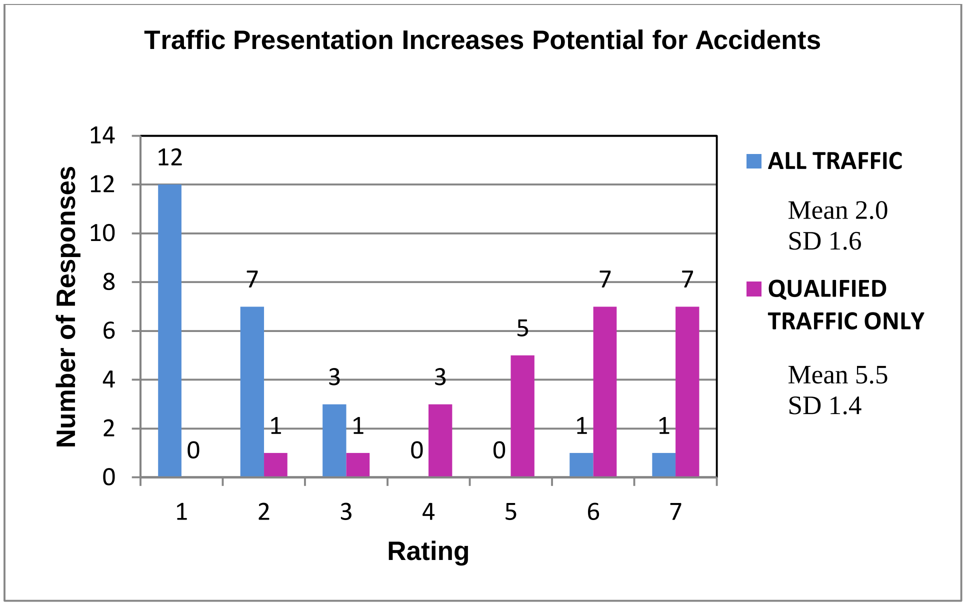


Figure J.6. Traffic Presentation Increases Potential for Accidents Responses.

Table J.4. ANOVA Statistics for Traffic Presentation Increases Potential for Accidents.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Traffic	Sphericity Assumed	126.750	1	126.750	33.800	.000
	Greenhouse-Geisser	126.750	1.000	126.750	33.800	.000
	Huynh-Feldt	126.750	1.000	126.750	33.800	.000
	Lower-bound	126.750	1.000	126.750	33.800	.000
Error(Traffic)	Sphericity Assumed	86.250	23	3.750		
	Greenhouse-Geisser	86.250	23.000	3.750		
	Huynh-Feldt	86.250	23.000	3.750		
	Lower-bound	86.250	23.000	3.750		

Displays

14. The location of the EFB was optimal for viewing the airport moving map.
    1 = Strongly Disagree; 7 = Strongly Agree

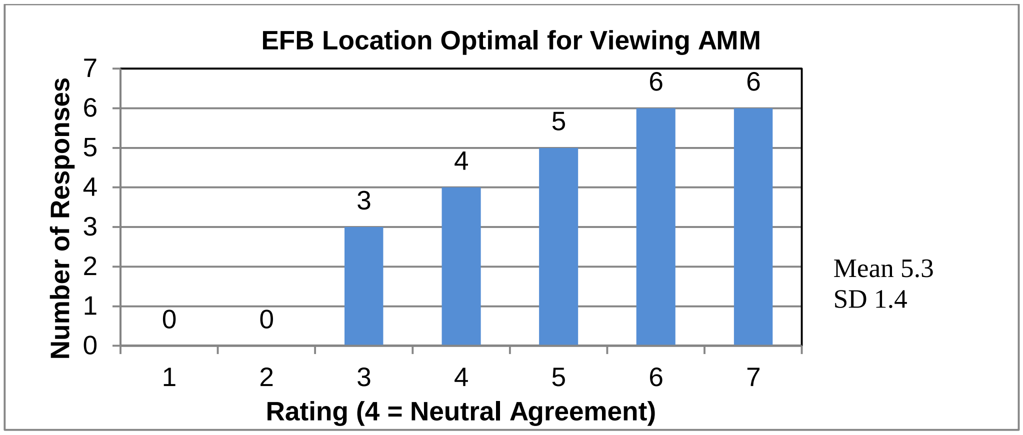


Figure J.7. EFB Location Optimal for Viewing AMM Responses.

If you disagree, what location/display is preferable for locating the airport moving map.

Subject	Suggestions
1	(no answer)
2	The location of the EFB was really good. But there are multiple other pages that we need to look at on the EFB (charts, checklists, etc.).
3	With my longer legs, the location was not optimal. I frequently banged my knee on the EFB. The viewing angle was good, however.
4	Add moving map to ND in certain range settings.
5	(no answer)
6	(no answer)
7	ND page on ground.
8	Not sure it was optimal – But sure it is better than by side window.
9	(no answer)
10	Center console/pedestal … where both pilots can point to display
11	It should be on PFD for better scan.
12	Put it in the NAV display.
13	Possible HUD but it could get cluttered.
14	On the ND. Too many screens.
15	(no answer)
16	(no answer)
17	AMM should be on forward display.
18	(no answer)
19	(no answer)
20	(no answer)
21	(no answer)
22	Elevated to eye level would be ideal.
23	Maybe on a movable "arm" to put a display more in center of pilots view. Then the EFB can be "stowed" out of the center of view when not required.
24	Physically I think its fine and I hate to keep looping on layering but how about a hard button to go straight to the moving map.

Displays - Traffic Symbology

15. Should all traffic be displayed on the airport moving map or only the traffic that meets NACp 9 and higher position accuracy levels?

    23 for All traffic
    1 for NACp 9+

    Rate the level of confidence in the answer provided above. 1 = None (0%), 7 = Completely (100%)

Pilot	1	2	3	4	5	6	7	8	9	10	11	12
	6	5	6	7	7	6	6	7	6	7	6	6
Pilot	13	14	15	16	17	18	19	20	21	22	23	24
	6	7	6	6		7	6	7	7	6	7	6

Mean	6.35
Std. Dev.	0.57

16. Displaying all traffic using the <u>same</u> map symbol (even for traffic with less accurate position information (NACp 8 or less)) would <u>not</u> provide hazardously misleading information.
    1 = Strongly Disagree; 7 = Strongly Agree

17. Displaying all traffic using <u>different</u> map symbols for unqualified (NACp 8 or less) and qualified (NACp 9 or higher) traffic would <u>not</u> provide hazardously misleading information.
    1 = Strongly Disagree; 7 = Strongly Agree

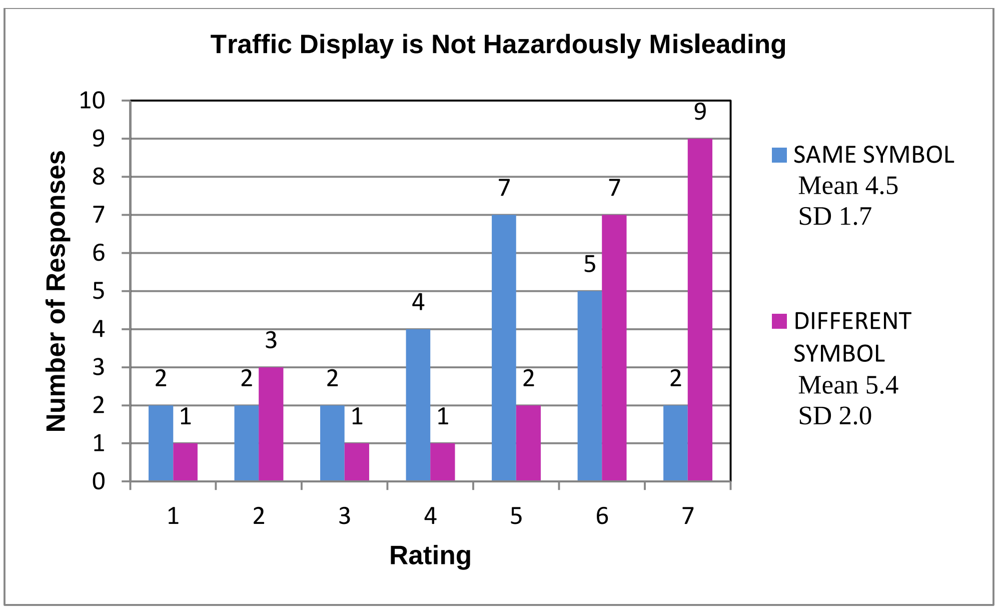


Figure J.8. Traffic Display is Not Hazardously Misleading Responses.

Table J.5. ANOVA Statistics for Traffic Display is Not Hazardously Misleading.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Symbol	Sphericity Assumed	10.083	1	10.083	3.096	.092
	Greenhouse-Geisser	10.083	1.000	10.083	3.096	.092
	Huynh-Feldt	10.083	1.000	10.083	3.096	.092
	Lower-bound	10.083	1.000	10.083	3.096	.092
Error(symbol)	Sphericity Assumed	74.917	23	3.257		
	Greenhouse-Geisser	74.917	23.000	3.257		
	Huynh-Feldt	74.917	23.000	3.257		
	Lower-bound	74.917	23.000	3.257		

18. There should be a distinction (difference) between the symbology representing qualified traffic (traffic with NACp 9 or higher) and unqualified traffic (NACp 8 or less).
    1 = Strongly Disagree; 7 = Strongly Agree

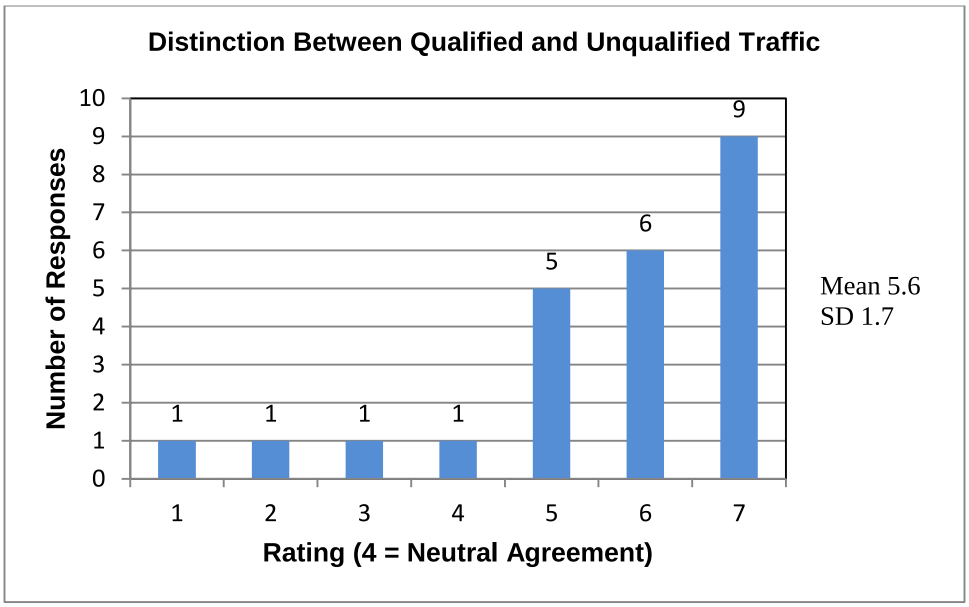


Figure J.9. Distinction Between Qualified and Unqualified Traffic Responses.

If you agree, which symbology do you feel would be most effective (choose one):

Different symbol – such as rounded chevron – 12 votes
Accuracy range ring around symbol – 5 votes
Other – 4 votes, segmented/dashed chevron, hollow widget, by selecting by touch to see NACp of signal, different color
* 4 pilots did not respond, 1 pilot made 2 selections

19. There should be a distinction (difference) between the symbology representing traffic qualified for the CD&R indication and alerting function (traffic with NACp 10 or 11) vs traffic not qualified for that function (NACp 9 or less). 1 = Strongly Disagree; 7 = Strongly Agree

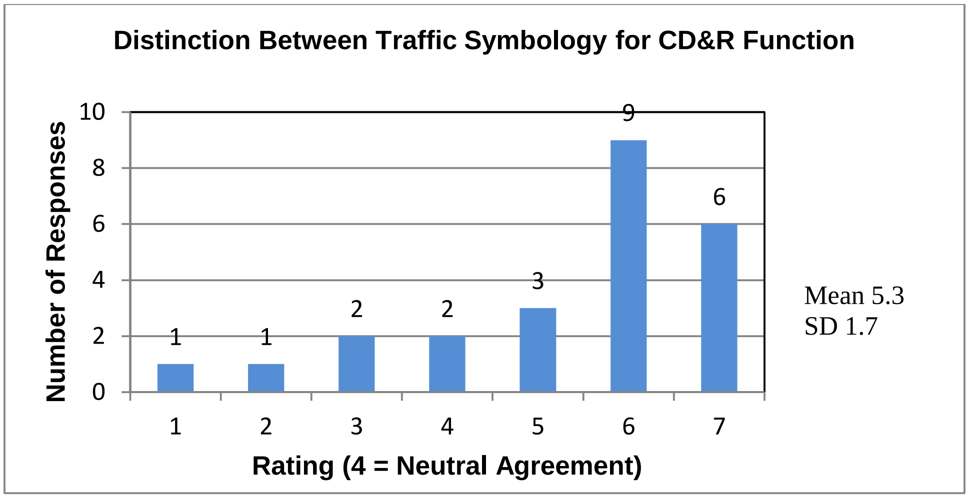


Figure J.10. Distinction Between Traffic Symbology for CD&R Function Responses.

If you agree, which symbology do you feel would be most effective (choose one):

Different symbol – 11 votes
Accuracy range ring around symbol – 6 votes
Other – 4 votes, symbol in different color, hollow widget, symbol strength measured by NACp by touch on screen
* 4 pilots did not respond, 1 pilot made 2 selections

Surface Trajectory-Based Operations (STBO)

20. STBO will <u>increase</u> my <u>workload</u> compared to current surface operational procedures.
1 = Strongly Disagree; 7 = Strongly Agree

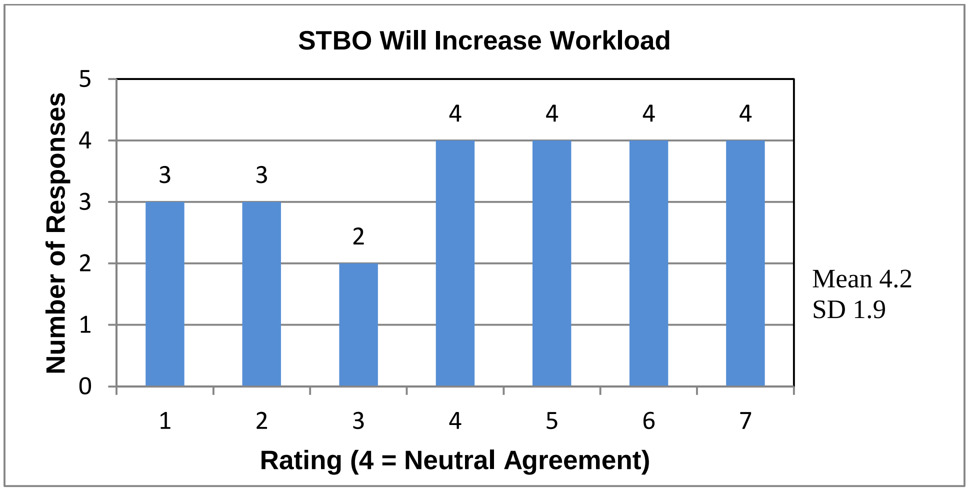


Figure J.11. STBO Will Increase Workload Responses.

21. STBO will increase my situation awareness compared to current surface operational procedures.
1 = Strongly Disagree; 7 = Strongly Agree

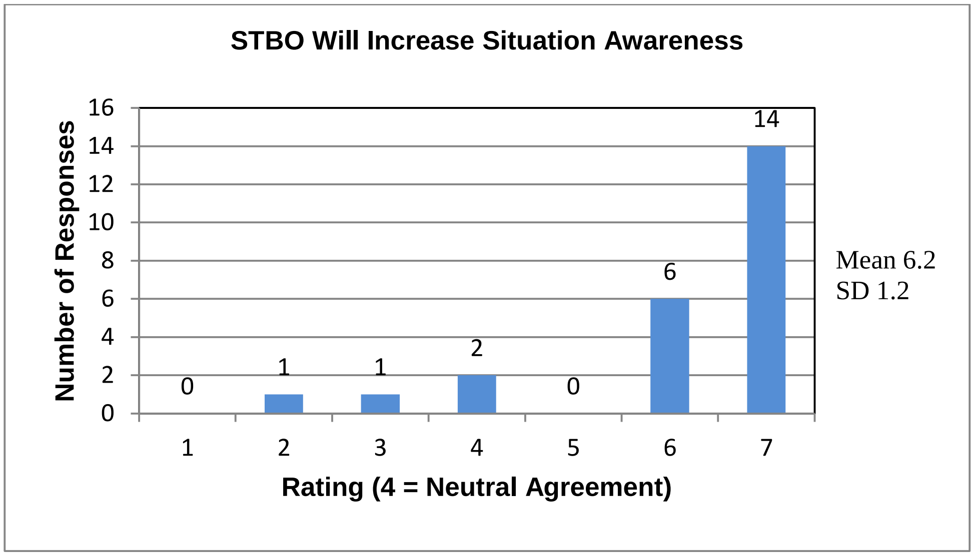


Figure J.12. STBI Will Increase Situation Awareness Responses.

Please comment on STBO and how it should be integrated into current procedures:

Subject	Suggestions
1	With increased SA, cockpit CRM and communication will become enhanced if crews commit to a dialogue that continually updates new situations and awareness.
2	I don't know the benefit. It seems your are merely moving the queue from the end of the runway to the very congested ramp area.
3	I found it quite helpful, especially the moving map display. But, it does increase the workload/scan rate.
4	It should be dynamic vice static. If the RTA is paramount, it should rule. If not, it should be updated as the situation evolves.
5	STBO greatly reduces the chances of an error in route while taxiing. The conflict features will be very useful during low vis applications. I feel the aural caution and warning or at least a visual indication should be given for aircraft below NACp 9 when crossing runways and an aircraft collision hazard exists.
6	Trying to incorporate it into the current SMGCS system would be a benefit. It can be difficult to taxi with just a paper chart in low vis.
7	Normal flows and checklist, training in class room, sim is vital not home computer self taught.
8	Cumbersome – takes one pilot out of loop.
9	The workload associated with maintaining appropriate RTA had a significant impact on my ability to watch for other traffic, even with the HUD in use. I believe the system should use only a taxi start time derived from an approximate total taxi time based on an average speed.
10	Any attempt to show ground traffic (of any kind/type) is fine by me.
11	In low visibility situations, night and rain or snow.
12	Put it on the NAV display and merge it with the TCAS.
13	You do focus on it a lot which could lead to distraction, i.e. checklists, but I feel the benefits outweigh the negatives by a wide margin.
14	Excellent tool. Could seamlessly be incorporated into current procedures.
15	Some crew training will be required to understand high and low NACp traffic. Realistic taxi speed and parameters need to be loaded as aircraft performance differs if having to use excessive braking will increase wear and heating hazards on long taxi.

16	Only proximity traffic should be able to display. When another traffic is selected, then previous traffic turns off trajectory and truns on new traffic selected.
17	Works in a "sterile" environment. Taxi speeds, and traffic sequencng differ among fleets and airports.
18	Text is ideal. Excellent.
19	(no answer)
20	(no answer)
21	It definitely adds to SA increases, and it almost self integrates itself into your scan normally. I think that part comes naturally, what took a little more time was defining what it would be like using only this system and no normal ATC communications. So this would require some training on removal of human factors elements.
22	It needs to account for poor surface conditions such as snow and ice.
23	Great system to provide more SA to pilots – it can be distracting at times. Should be utilized as a safety tool for special utilization for weather/traffic events. Should not be used every day/every flight.
24	Any info we get on what other aircraft are doing on the ground is most helpful, especially at busy airports or during international ops. But as helpful as the speed and desequencing can be, we also saw potential problems when attention gets prioritized on speed and spacing and not on routing and safety, i.e. spacing. Interesting to see warnings when we snugged up behind prededing aircraft which lots of captains like to do.

22. STBO will increase efficiency for ground movement of aircraft.
    1 = Strongly Disagree; 7 = Strongly Agree

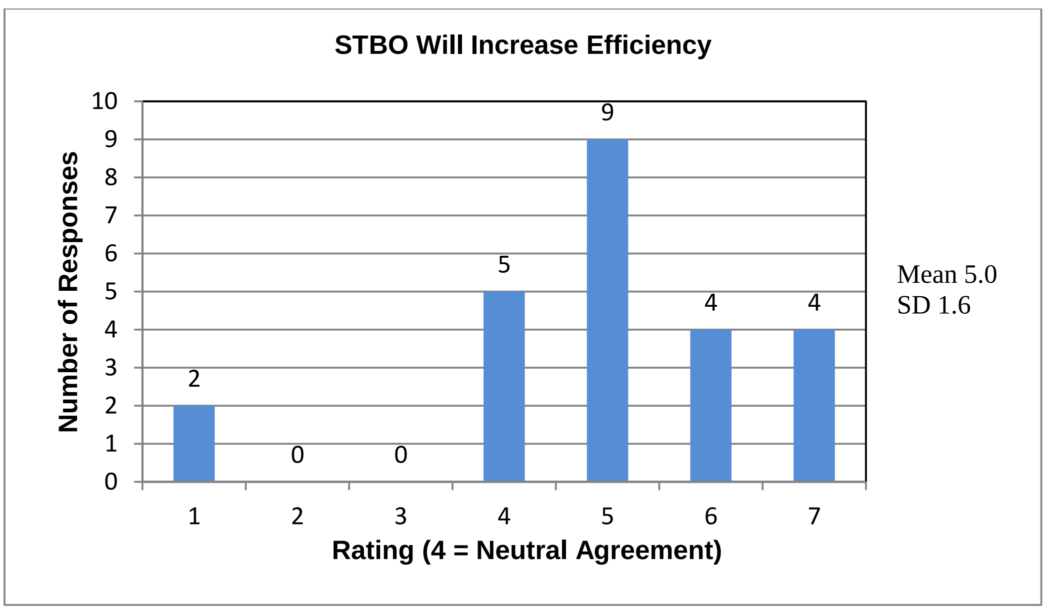


Figure J.13. STBO Will Increase Efficiency Responses.

23. STBO will <u>increase</u> <u>safety</u> for ground movement of aircraft.
    1 = Strongly Disagree; 7 = Strongly Agree

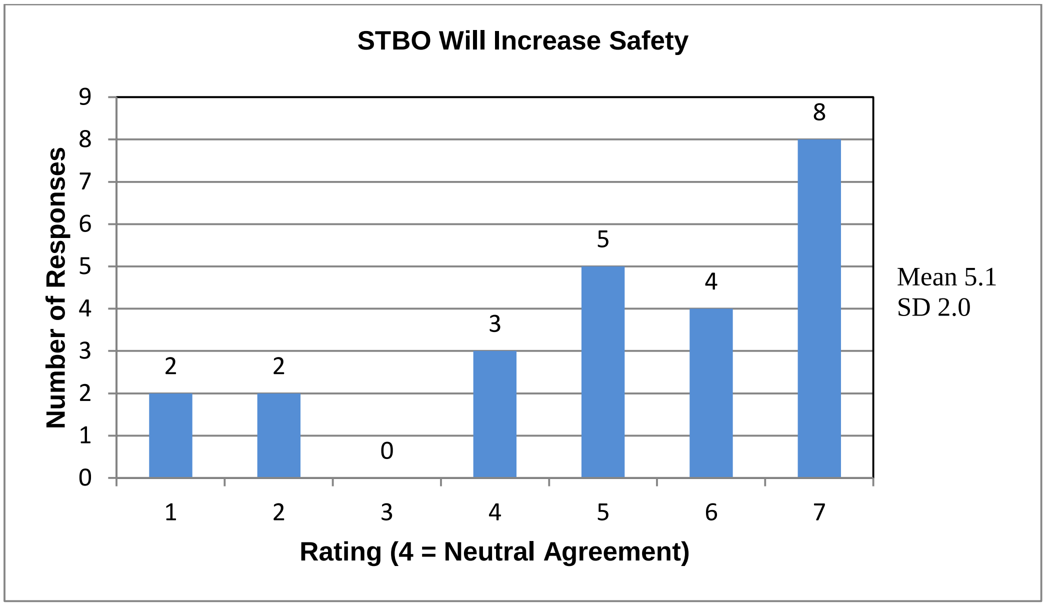


Figure J.14. STBO Will Increase Safety Responses.

24. STBO <u>did not increase</u> my subjective estimate of head-down time compared to current-day operations.
    1 = Strongly Disagree; 7 = Strongly Agree

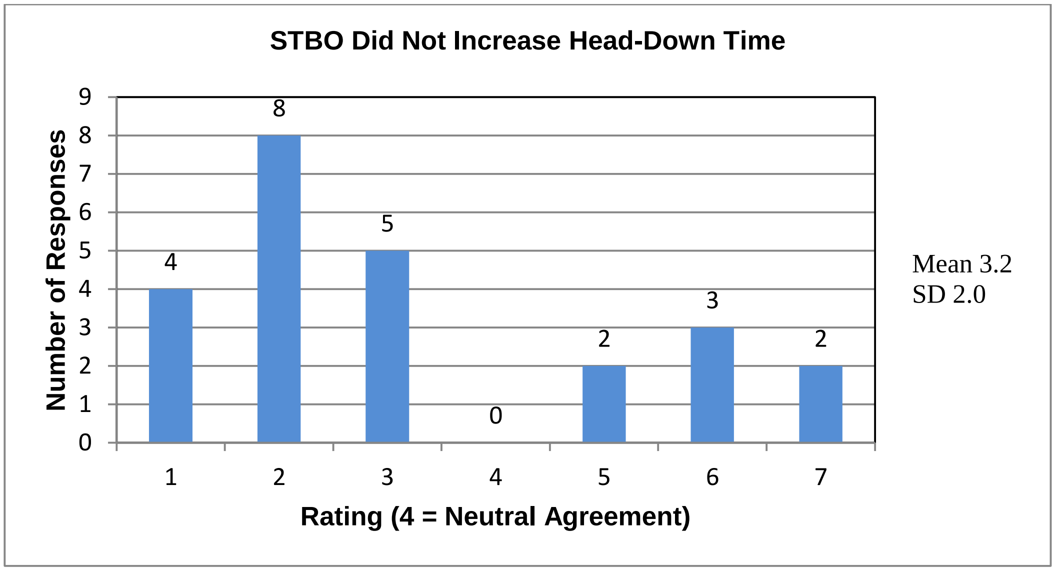


Figure J.15. STBO Did Not Increase Head-Down Time Responses.

Please comment on the reason for the rating above:

Subject	Suggestions
1	Yes – my head was down more; however, when it came back up I had a much clearer idea of what was happening around me – great trade off.
2	It caused me to be far more heads-down than I normally would be.
3	It was necessary to increase the head down time/EFB scan while taxiing.
4	We currently do not compute estimate to an RTA on the ground. We are more interested in time to takeoff and that is done outside not inside head down.
5	A portion of my attention was needed to monitor speed and ETA estimates which would put more reliance on the FO to apprise me of other possible threats.
6	I personally scanned inside/outside as a normal procedure (or at least tried to!).
7	Watching time circles.
8	Increased head-down time for both.
9	Much higher taxi workload.
10	Timing taxi is a bad idea. Too many other tasks to set up for flight.
11	A lot of "heads-down" is required. Can it be trained to efficiency – yes.
12	(no answer)
13	You do look down more, but the payoff of no wrong taxi and seeing your taxi clearance in word and map = Fantastic!
14	Too much button pushing – moving map, checklists, CPDLC, map zoom, etc.
15	Much more heads down time even with HUD.
16	I found, at times, to be heads down more than I would without this technology.
17	Increases "head-down" time since most pilots would strive to be +/- 0. Perfection takes extra attention.
18	(no answer)
19	Pilot needs to be head-up. So symbols in HUD may be alternative to moving map.
20	You are constantly checking your 10-9 page (airport). You have your route. Just need to follow it.
21	The time I use head-down on airport diagram is/was about the same while incorporating my scan down into EFB.
22	It became the focus of my attention, and could easily distract a crew from performing essential safety items and procedures.
23	It definitely increased my "heads-down" time.
24	We are pilots. If you give us a target, we will try to hit it. Our fear of failure is greater than our fear of death. I watched my captain taxi over all creation and darn near ram 2 other planes trying to keep the "circle on the disk". Its going to be distracting and really only beneficial at airports with relatively long unrestricted runs, not like JFK.

25. To perform STBO adequately, information is required to be located on the following displays: (Check all that are required.)

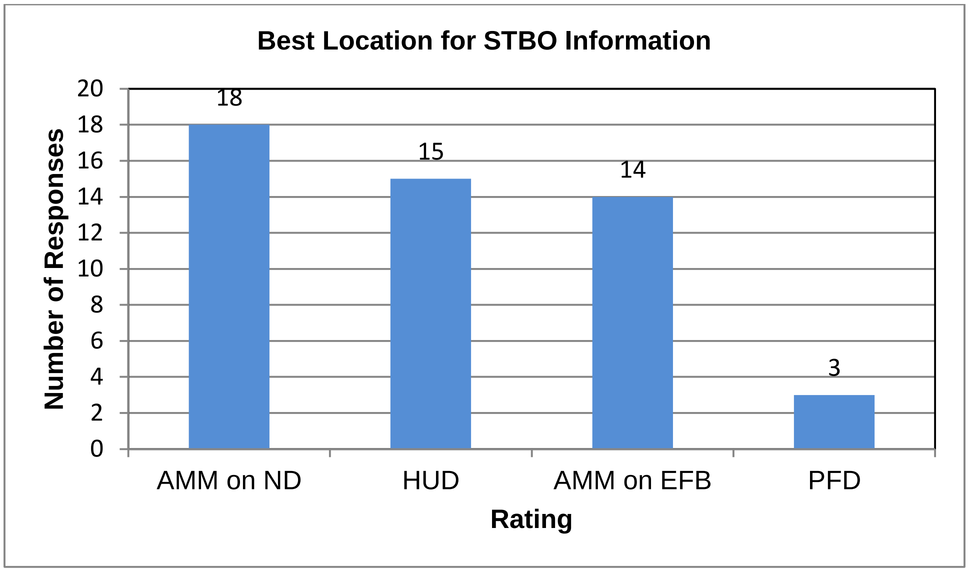


Figure J.16. Best Location for STBO Information Responses.

Head-Up Display (HUD) STBO Guidance

If you used the HUD during STBO, answer questions in this section.

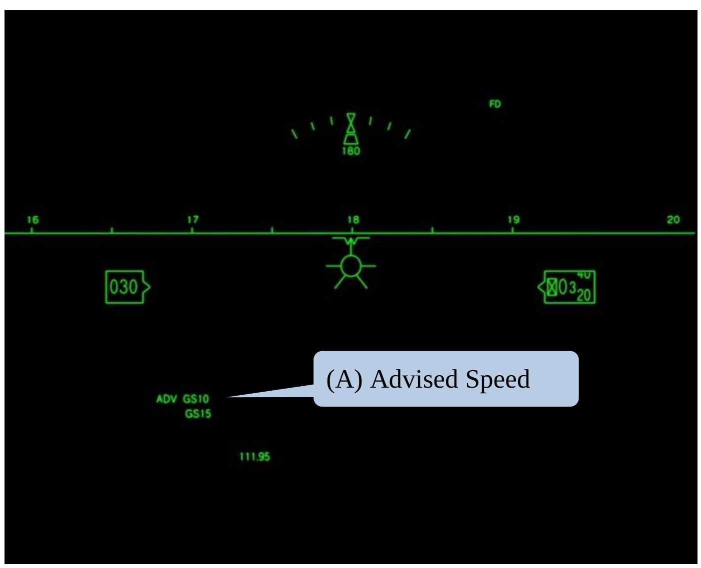


Figure J.17. HUD Displaying STBO Guidance.

26. Refer to the item labeled (A) on Figure J.17. Please rate the usefulness of the advised ground speed displayed on the HUD in helping you to meet the RTA. 1 = Not Useful; 7 = Very Useful

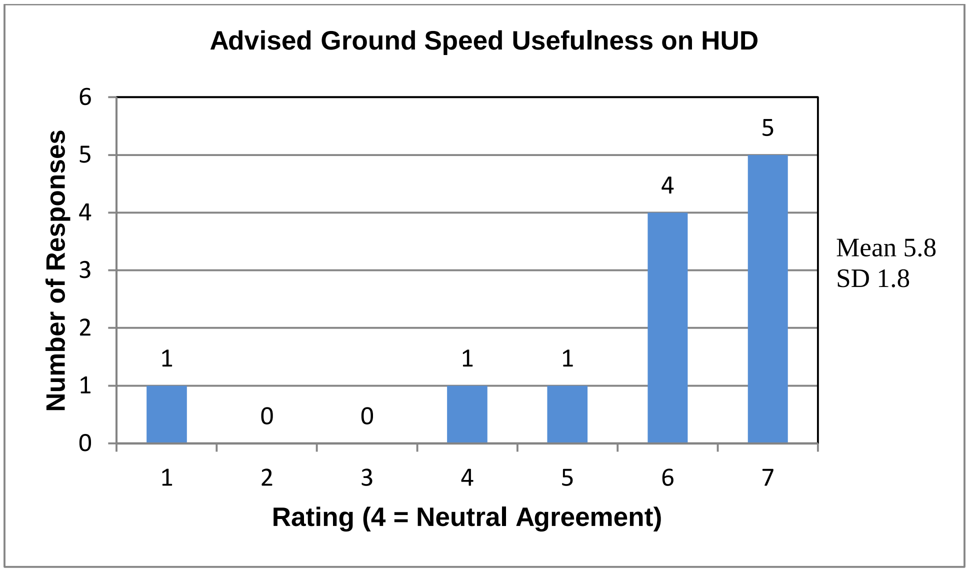


Figure J.18. Advised Ground Speed Usefulness on HUD Responses.

27. The display of advised ground speed on the HUD, without any other STBO guidance information, is suficient for helping me meet the RTA. 1 = Strongly Disagree; 7 = Strongly Agree

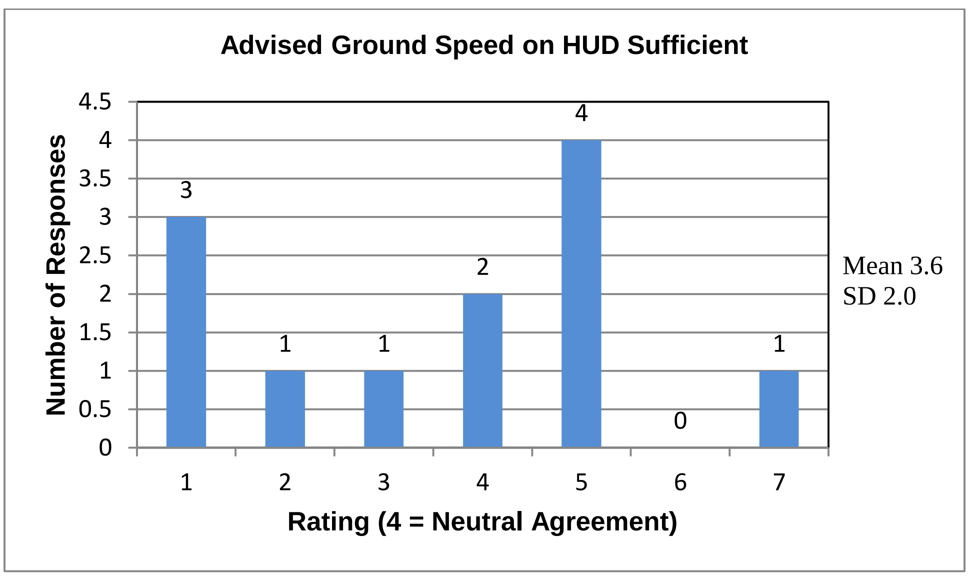


Figure J.19. Advised Ground Speed on HUD Sufficient Responses.

If you disagree, which other symbology should be shown on the HUD.

Subject	Other Symbology Suggestions
1	Plus/minus time to RTA would be nice.
3	Perhaps a steering arrow could be incorporated.
5	The ETA +/- display would be useful to avoid heads-down time to check progress on the EFB.
7	(no answer)
9	Time deviation in seconds.
11	(no answer)
13	You might as well put the clock showing how many seconds ahead/behind on HUD. I kept looking down to reference that.
15	(no answer)
17	Need to look "heads-down" for actual GS decreases situation awareness.
19	My experience is that the HUD is a distratction when taxiing during low vis ops. So pilots are inclined to ignore.
21	The early/late scale shown on bottom of EFB should be on HUD as well!
23	Current GS. Cautions/warnings.

28. Please indicate on the figure below where you would locate the "advised ground speed" symbology. Feel free to change the format of the symbology if necessary.

29. Please indicate on the figure below any additional symbology you feel is required on the HUD for STBO.

Images showing pilots marking on the figures are not included in this document.

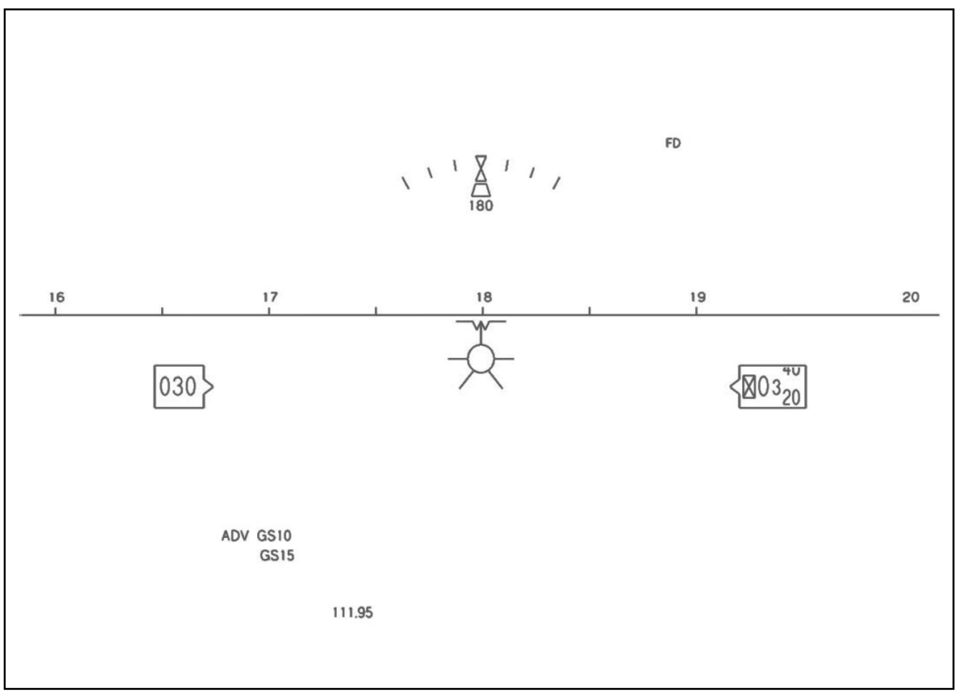


Figure J.20. HUD Symbology.

Subject	Symbology Location on Figure
1	Plus/minus time to RTA in seconds near ADV GS.
3	Steering arrow in center below aircraft symbol (flasher when approaching turn). Move ADV GS/GS to middle of HUD.
5	ETA and +/- seconds beside ADV GS/GS. Under heading scale at top, Caution/Warning Traffic with left/right arrow below.
7	Distance in feet to next turn.
9	Add +/- time below ADV GS/GS. Move that block of data above horizon line to left of heading scale.
11	Move ADV GS/GS up to the left of the aircraft symbol.
13	Add +/- time to right of ADV GS. Show current taxiway and next turn on HUD, i.e., on "Alpha left turn Bravo".
15	Add +/- target time near ADV GS.
17	Put ground speed in box to left, add vertical scale bar showing ADV GS as mark along scale.
19	Move ADV GS/GS up to upper left of HUD. Add taxi route to HUD. Add bar above/below wing symbol for early/late.
21	ADV GS location is good where it is. Add +/- scale below GS.
23	Move ADV GS/GS up to left of heading. Add words "Caution", "Warning".

30. STBO taxi operations can be performed adequately without displaying STBO guidance information on the HUD. 1 = Strongly Disagree; 7 = Strongly Agree

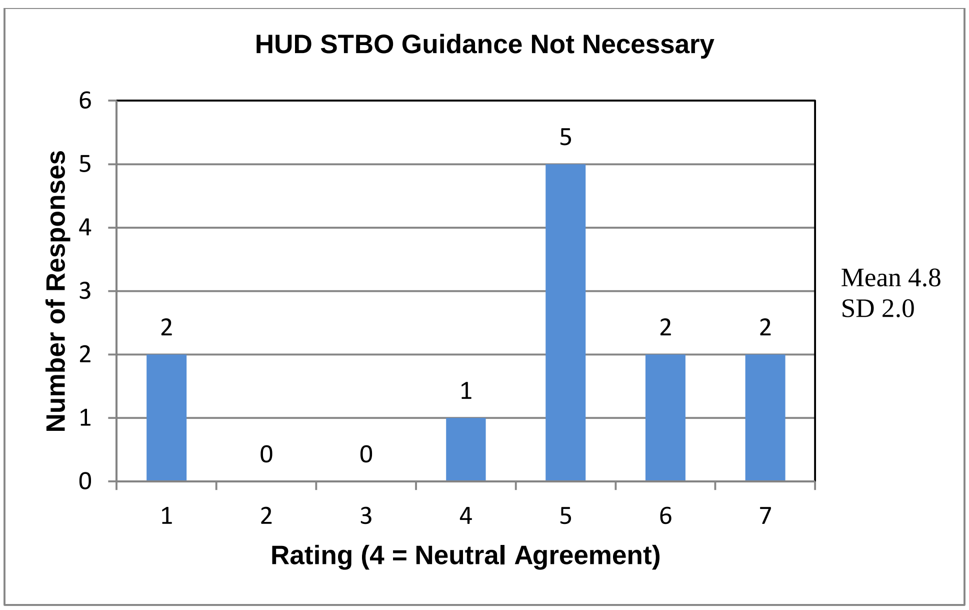


Figure J.21. HUD STBO Guidance Not Necessary Responses.

<u>Map C Condition</u> – STBO Guidance Textually Only

If you used the Map C condition, answer questions in this section.

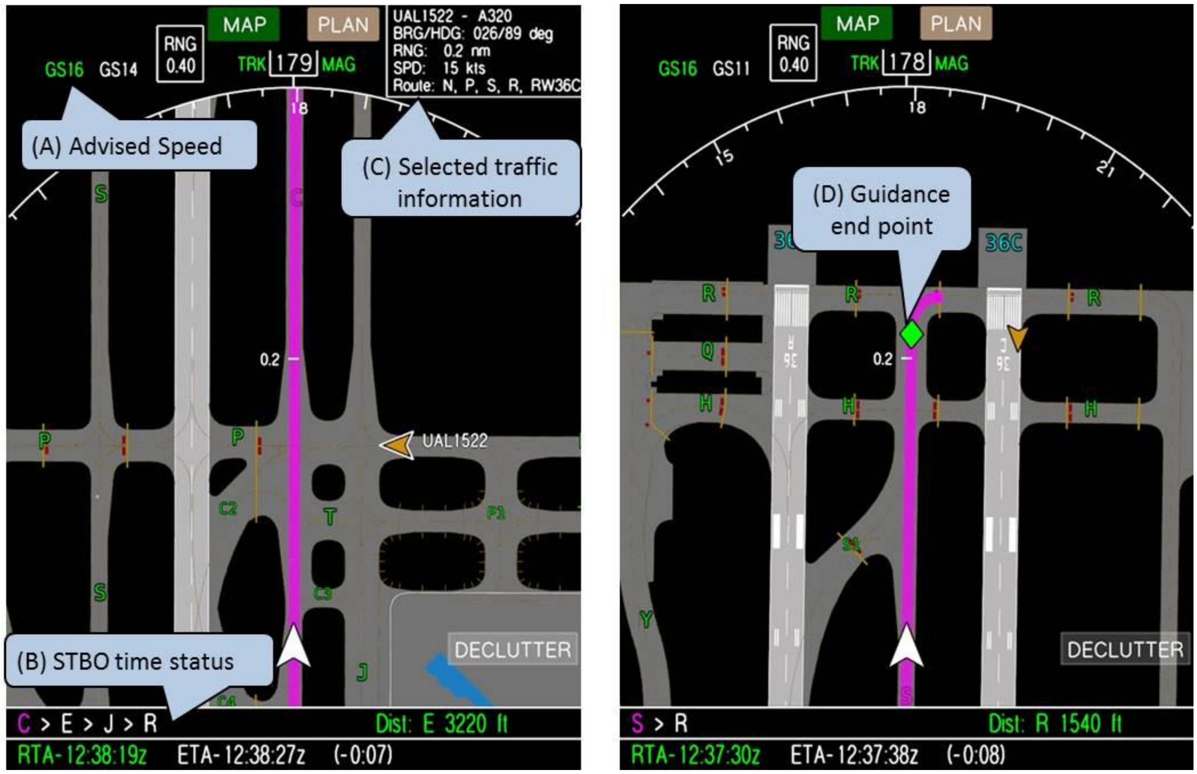


Figure J.22. Map C Condition.

31. While taxiing during the STBO scenarios using Map Condition C, it was easy to tell if I was going to reach my guidance end point on time, ahead of time, or behind schedule.
    1 = Strongly Disagree, 7 = Strongly Agree

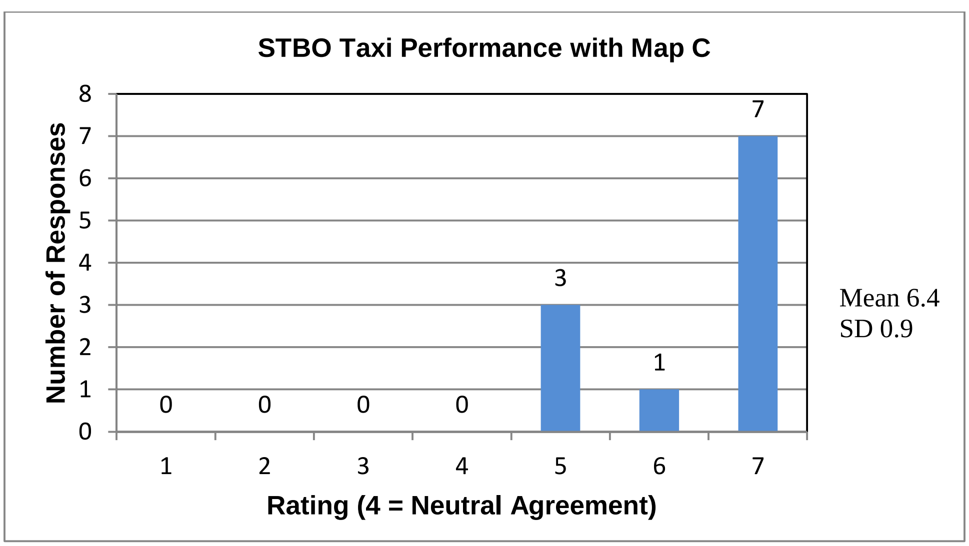


Figure J.23. STBO Taxi Performance with Map C Responses.

What, if anything, could be changed or modified to increase the rating?

Subject	Suggested Changes
1	Replace +/- with E (early) or L (late)
2	There is no more than a 7.
5	See previous note on changing +/- symbology for showing ahead or behind ETA.
6	It was a very good system. Straight forward to read data.
9	The information provided was excellent.
10	N/A Captain used this…. I was traffic and radio man!!
13	Maybe put the + or – beside the symbol of the airplane.
14	Put a second display of time error, ex. (-0:07) under the GS in the upper left hand corner.
17	Always display 'EARLY' or 'LATE'. Change the display "if greater than +/- 10" to a color change.
18	Works great!
21	If off of ETA the diamond should blink at you. For HUD and graphics above: Note: Also the max ADV GS of 30 kts would have to be modified so as to avoid violations of rules. For example, the max GS of taxiing aircraft in China according to their ATC manuals is 22 kts!
22	Include a verbal prompt if > 15 seconds of the required time.

32. Refer to the items labeled (A), (B), (C), and (D) on the figures above. Please rate the usefulness of each item in helping you to meet the RTA. 1 = Not Useful; 7 = Very Useful

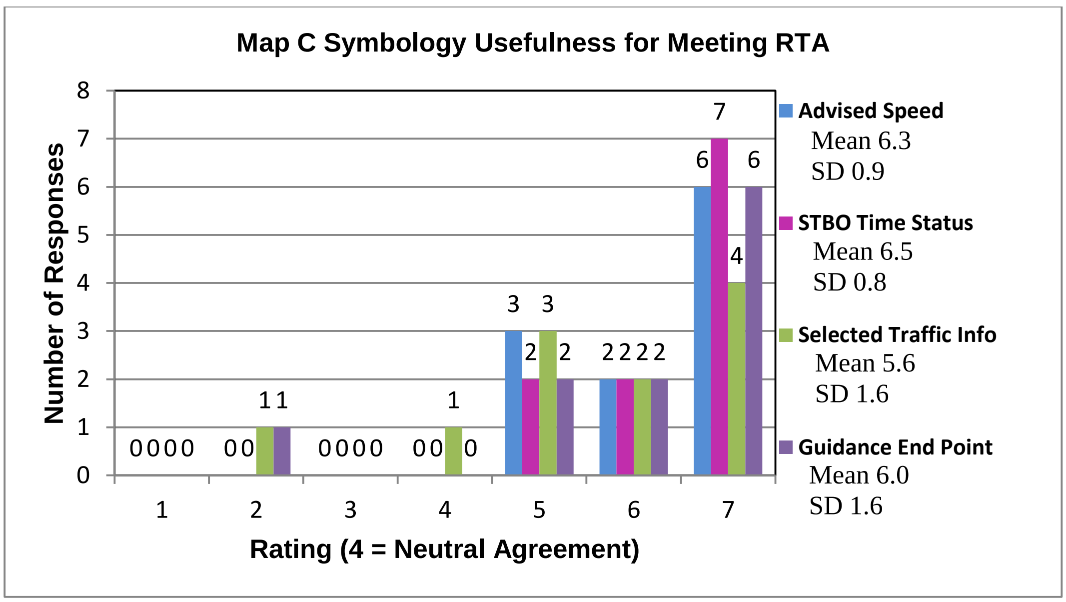


Figure J.24. Map C Symbology Usefulness for Meeting RTA Responses.

Table J.6. ANOVA Statistics for Map C Symbology Usefulness for Meeting RTA.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
STBO_ELEMENTS	Sphericity Assumed	5.159	3	1.720	1.429	.254
	Greenhouse-Geisser	5.159	2.305	2.239	1.429	.261
	Huynh-Feldt	5.159	3.000	1.720	1.429	.254
	Lower-bound	5.159	1.000	5.159	1.429	.259
Error(STBO_ELEMENTS)	Sphericity Assumed	36.091	30	1.203		
	Greenhouse-Geisser	36.091	23.046	1.566		
	Huynh-Feldt	36.091	30.000	1.203		
	Lower-bound	36.091	10.000	3.609		

What, if anything, could be changed or modified to increase the rating?

Subject	Suggested Changes
1	(no answer)
2	Regarding Map C, putting other traffic's RTA would help us know if we should try to go in front of or behind conflicting traffic that is going to our same runway (or similar route to ours).
5	(no answer)
6	Traffic information was good with a route, but also was sometimes more clutter on the screen.
9	Too much time was alloted for the completion of turns. Turn speeds should probably not be below 8 kts.
10	N/A Captain used this…. I was traffic and radio man!!
13	Airliners do not turn as slow as you have it calibrated.
14	See #31. Selected traffic information – too much information clutter.
17	(no answer)
18	(no answer)
21	If conflict target shows holding for you or not in data block.
22	Make the display slightly larger to make it more noticable.

33. Refer to the item labeled (C) on Figure J.22. Rate the usefulness of the selected traffic information in determining the intent of that aircraft. 1 = Not Useful; 7 = Very Useful

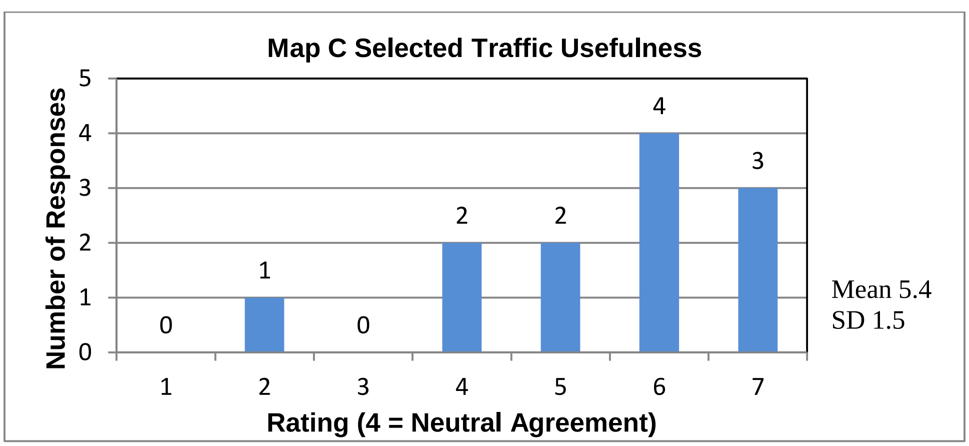


Figure J.25. Map C Selected Traffic Usefulness Responses.

What information could be added or deleted to enhance the quality and value of the selected traffic information (item C)?

Subject	Suggested Changes
1	Graphic depiction of intended taxi route, not just taxi letter designators.
2	See #32. Add their RTA if going to the same or nearby (runway with simialr track). Also, when traffic is selected, show their route on the moving map in a different color/width or some visual way to see where they are cleared.
5	Delete the portions of the cleared route of the selected traffic which have already been completed.
6	(no answer)
9	Add ground speed next to aircraft symbol.
10	I like it as is.
13	Maybe a projected line of where he will be in the next 20 seconds?
14	See #32. Cluttered display. Also, pilots frequently make taxi errors – what ATC cleared him to do isn't always what they do do - unfamiliar airport, reduced visibility, hear back/read back errors, expected clearances.
17	What the pilot was actually going to do – but you can never display that.
18	Very helpful.
21	Adding information in data block to target. If both aircraft are to cross paths, I needed to know who has give-way instructions, couldn't determine this easily.
22	The system should make it clear who has the right of way, and who should yield.

34. The traffic intent information was useful in identifying traffic conflict situations.
 1 = Not Useful; 7 = Very Useful

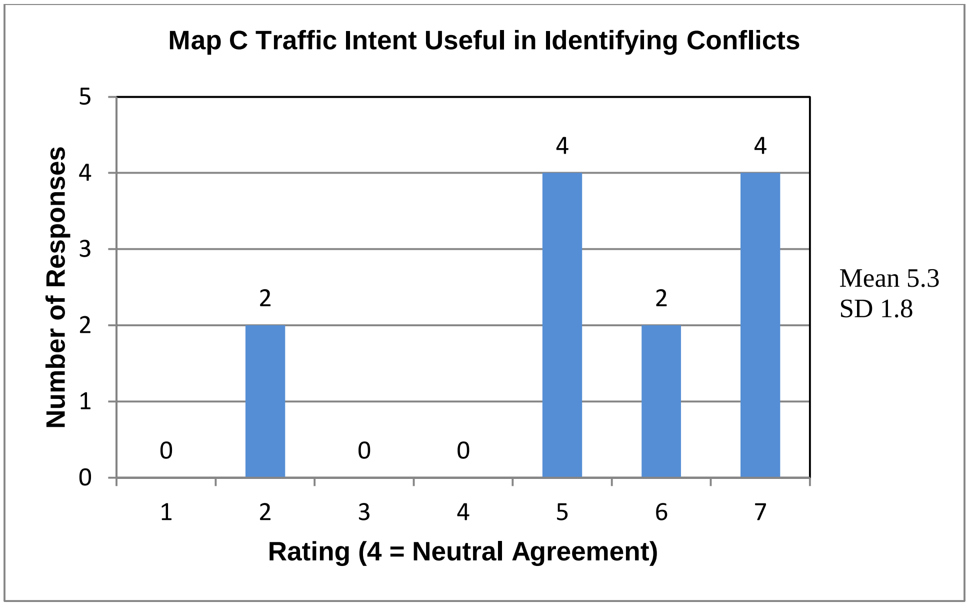


Figure J.26. Map C Traffic Intent Useful in Identifying Conflicts Responses.

How may the traffic intent information be improved to increase traffic conflict situation identification?

Subject	Suggested Changes
1	Earlier warning – expand the caution/warning bubbles around conflict aircraft minimally.
2	Same as above in #33.
5	See previous note about showing NACp 8 traffic when in runway crossing situation.
6	Could it be available for more than one potential traffic conflict?
9	It's a great system but the possibility that other aircraft will not make the required turns still exists.
10	I like it as is.
13	See above (#33).
14	Look out the window. Caution and warning messages excellent and well displayed (CD&R).
17	(no answer)
18	Enhance the color of crossing taxiways.
21	See answer #33 above please.
22	Aircraft with the right of way should flash and/or blink.

<u>Map D Condition</u> – STBO Guidance Textually and Graphically

If you used the Map D condition, answer questions in this section.

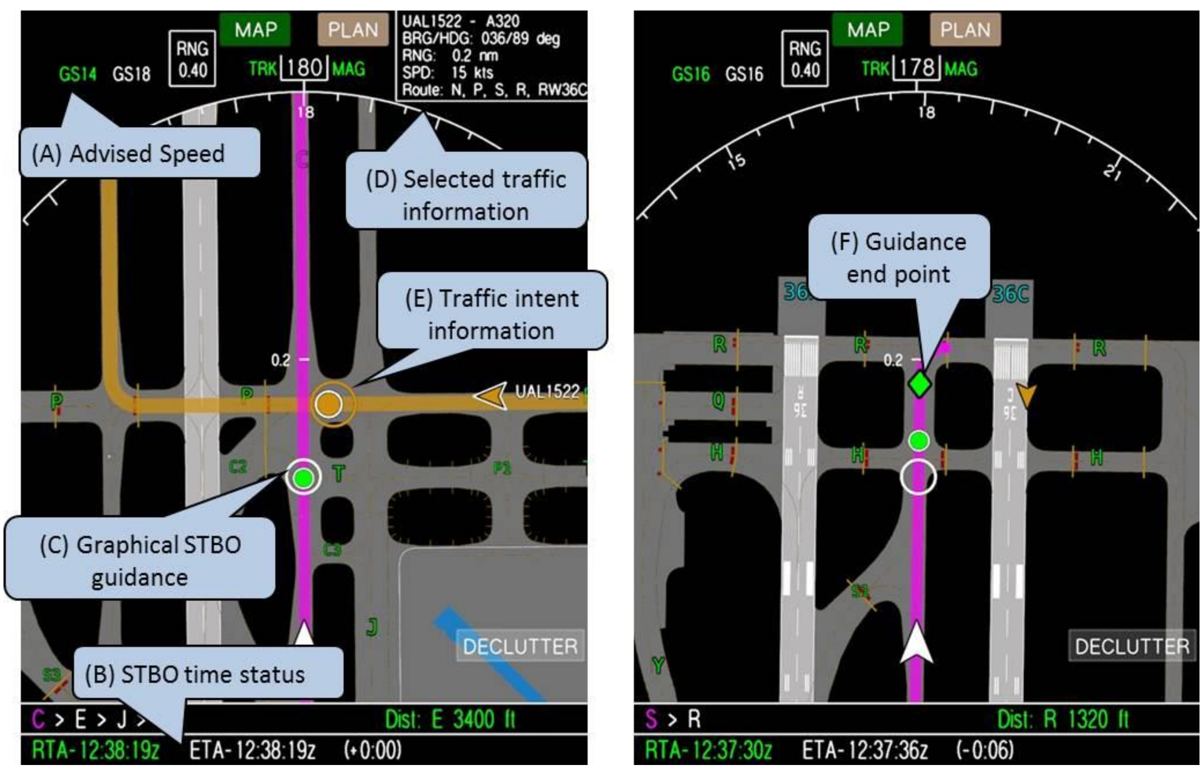


Figure J.27. Map D Condition.

35. While taxiing during the STBO scenarios using Map Condition D, it was easy to tell if I was going to reach my guidance end point on time, ahead of time, or behind schedule.
    1 = Strongly Disagree; 7 = Strongly Agree

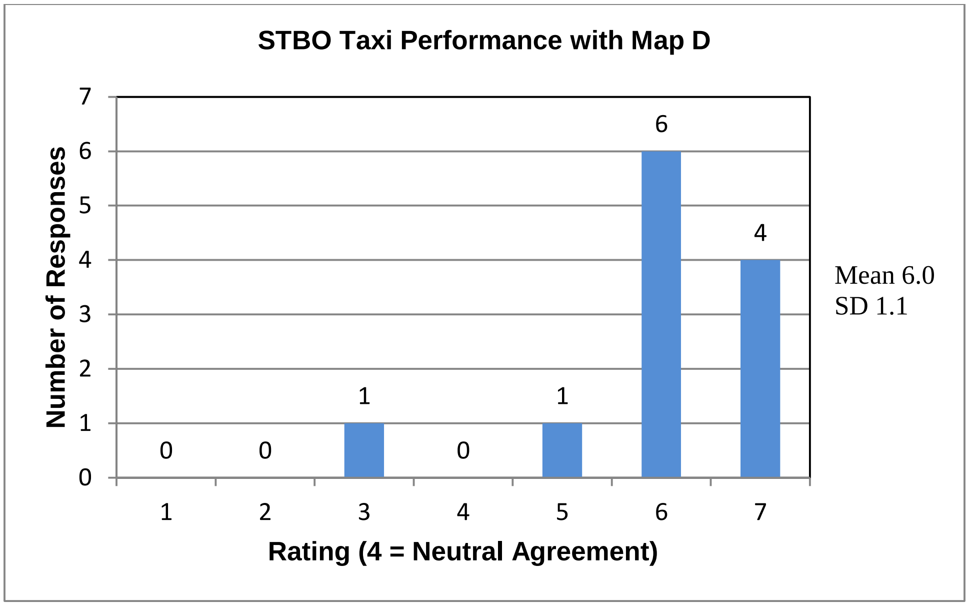


Figure J.28. STBO Taxi Performance with Map D Responses.

What, if anything, could be changed or modified to increase the rating?

Subject	Suggested Changes
3	I didn't use the RTA/ETA figures at the bottom until close to the guidance end point and the graphical STBO guidance was parked there. I must admit I did not notice (D) the selected traffic information.
4	No
7	Change color of my aircraft yellow – plus move close to time rings.
8	(no answer)
11	Nothing!
12	(no answer)
15	Too much heads down especially in busy airport scenario.
16	I think maybe a flashing GS readout if excess GS is maintained for a certain period of time.
19	How about using known symbols for speed and thrust vector. Added bar above/below wing symbol. I just don't think pilot wants to use HUD during low vis taxi!
20	(no answer)
23	Give pilots capability to move EFB more to the center of view (attached to swingable arm).
24	Yes easy to tell, no touch to manage. I think you should eliminate the turn speed correction for one. Its easy to catch up but hard to slow down. I'm honestly not sure what we are trying to achieve here. All it takes is one hold short of – for traffic entering/exiting ramp to really muck this up, and I don't see any real deconfliction of traffic like the above left secenario which we need. We still don't know who is supposed to go first at intersection as both jets chase the puck with the circle.

36. Refer to the items labeled (A), (B), (C), (D), (E), and (F) on the figures above. Please rate the usefulness of each item in helping you to meet the RTA. 1 = Not Useful; 7 = Very Useful

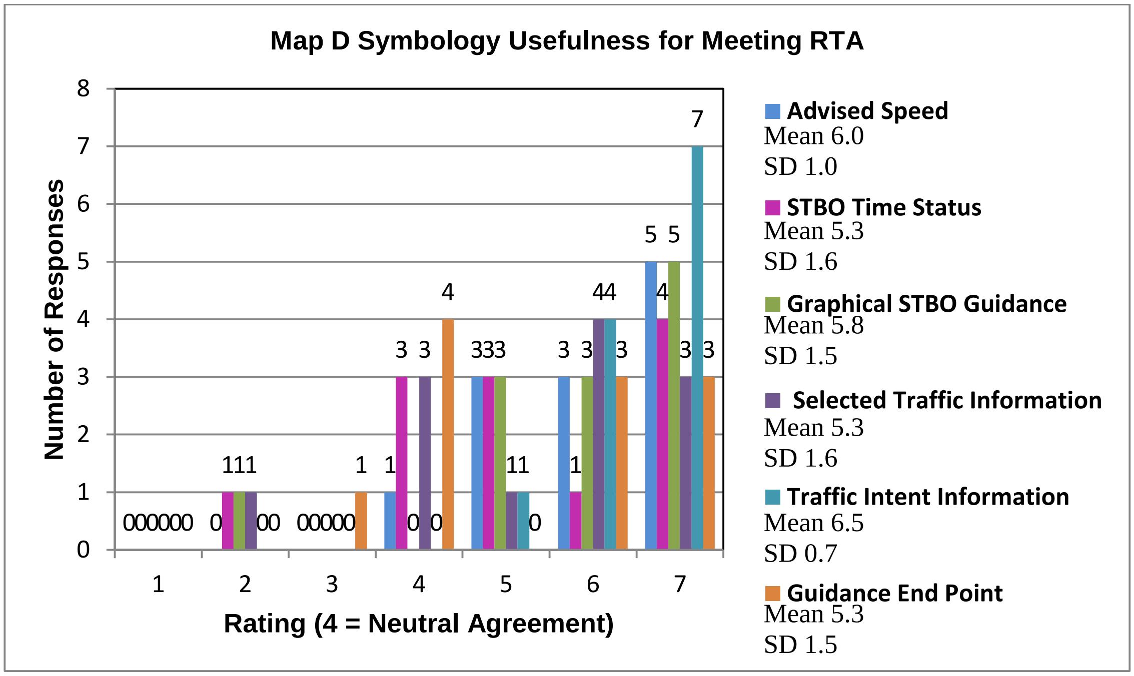


Figure J.29. Map D Symbology Usefulness for Meeting RTA Responses.

Table J.7. ANOVA Statistics for Map D Symbology Usefulness for Meeting RTA.

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
STBO_ELEMENTS	Sphericity Assumed	67745.500	5	13549.100	.988	.434
	Greenhouse-Geisser	67745.500	1.000	67734.644	.988	.342
	Huynh-Feldt	67745.500	1.000	67731.388	.988	.342
	Lower-bound	67745.500	1.000	67745.500	.988	.342
Error(STBO_ELEMENTS)	Sphericity Assumed	754393.833	55	13716.252		
	Greenhouse-Geisser	754393.833	11.002	68570.268		
	Huynh-Feldt	754393.833	11.002	68566.971		
	Lower-bound	754393.833	11.000	68581.258		

Pilots	(A) Advised Speed	(B) STBO Time Status	(C) Graphical STBO Guidance	(D) Selected Traffic Information	(E) Traffic Intent Information	(F) Guidance End Point
Captains	5.8 mean 1.3 SD	4.5 mean 1.6 SD	5.7 mean 2.0 SD	4.3 mean 1.5 SD	6.3 mean 0.8 SD	5.8 mean 1.5 SD
First Officers	6.2 mean 0.8 SD	6.0 mean 1.3 SD	6.0 mean 0.9 SD	6.3 mean 0.8 SD	6.7 mean 0.5 SD	4.6 mean 1.3 SD

What, if anything, could be changed or modified to increase the rating?

Subject	Suggested Changes
3	See #35.
4	(no answer)
7	Increase turn speed to 9 or 10 kts.
8	(no answer)
11	Taxi speed on turns is not realistic and needs to be changed.
12	(no answer)
15	(no answer)
16	Nothing.
19	Use status bar on magenta line to replace forecast position instead of white circle. E.g., Push power and see progress color move to green ball.
20	(no answer)
23	None.
24	I love the routing – for us and other traffic < max useful. Several times I selected moving targets and got no path. Not helpful.

37. Refer to the item labeled (D) on the figure above. Rate the usefulness of the selected traffic information in determining the intent of that aircraft. 1 = Not Useful; 7 = Very Useful

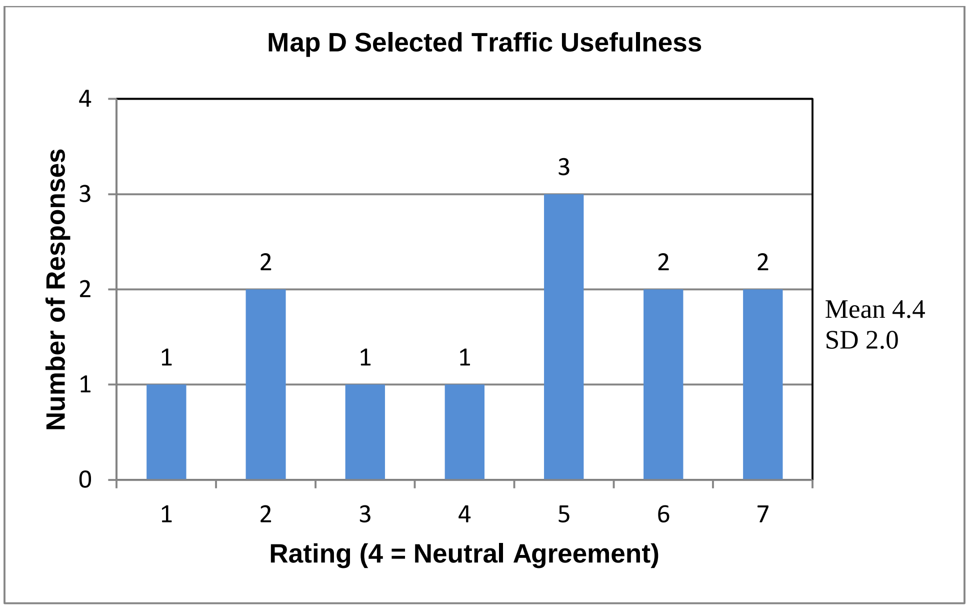


Figure J.30. Map D Selected Traffic Usefulness Responses.

What information could be added or deleted to enhance the quality and value of the selected traffic information (item D)?

Subject	Suggested Changes
3	I preferred the graphical (E) traffic intent.
4	(no answer)
7	Time to cross my track.
8	(no answer)
11	(no answer)
12	(no answer)
15	We are not ATC and not our job to sort sequencing.
16	Nothing.
19	None.
20	(no answer)
23	The route depiction is much more useful.
24	If you have data and he's taxiing give us his path.

38. Refer to the item labeled (E) on the figure above. Rate the usefulness of the traffic graphical intent information (traffic taxi route and guidance circles) in determining the intent of that aircraft.
1 = Not Useful; 7 = Very Useful

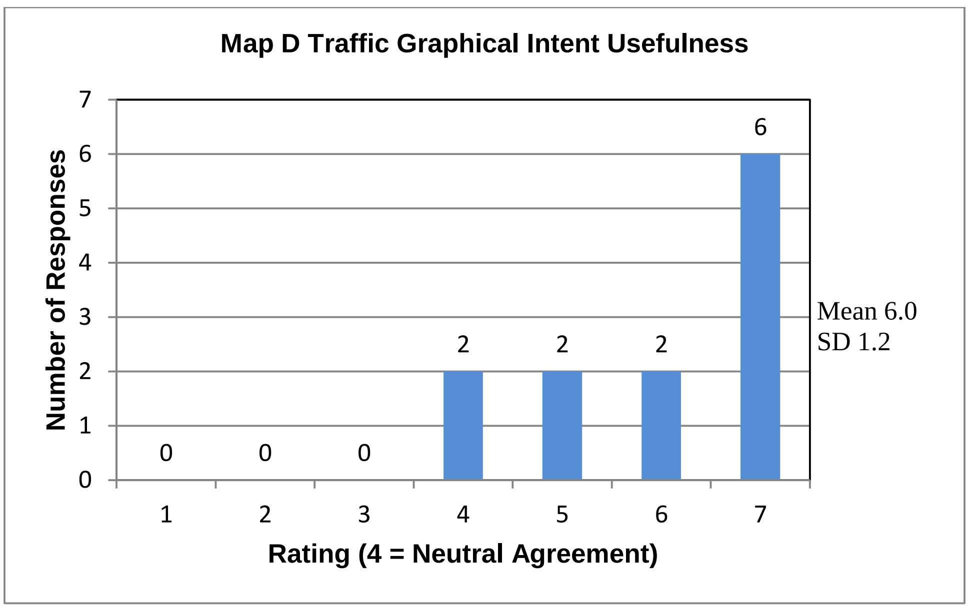


Figure J.31. Map D Traffic Graphical Intent Usefulness Responses.

What information could be added or deleted to enhance the quality and value of the graphical intent information (item E)?

Subject	Suggested Changes
3	N/A – Very useful for deconfliction.
4	(no answer)
7	Speed.
8	Predicted path isn't necessarily actual.
11	Nothing!
12	(no answer)
15	Knowing potential conflict good. Sequencing not useful.
16	Maybe a CPA symbol (CPA = closest point of approach).
19	None.
20	(no answer)
23	None.
24	Route – very helpful. Guidance circles – what is it telling me?

39. The traffic intent information was useful in identifying traffic conflict situations.
    1 = Not Useful; 7 = Very Useful

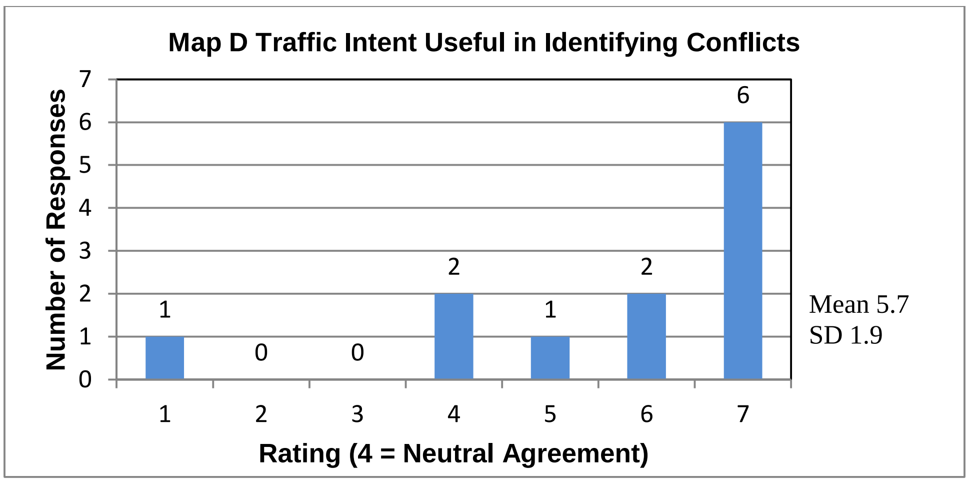
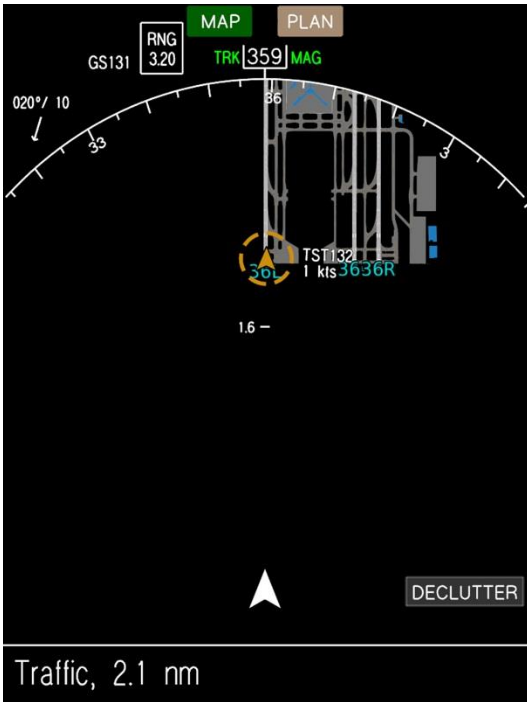


Figure J.32. Map D Traffic Intent Usefulness in Identifying Conflicts Responses.

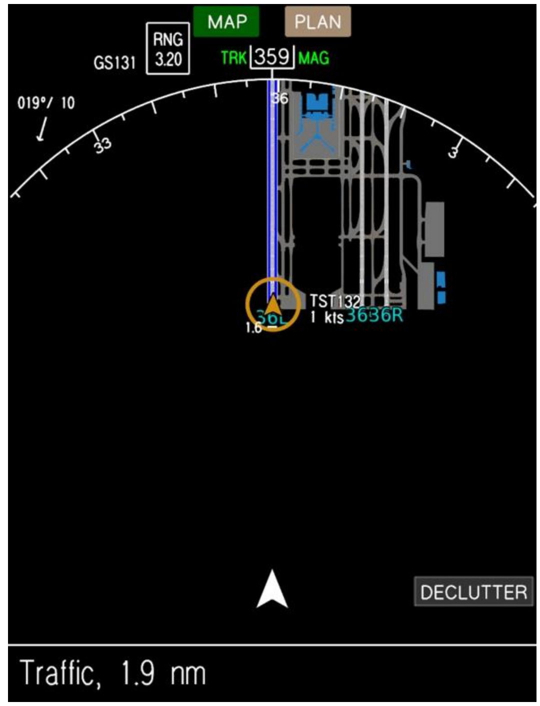
How may the traffic intent information be improved to increase traffic conflict situation identification?

Subject	Suggested Changes
3	N/A
4	(no answer)
7	Warning a little sooner.
8	(no answer)
11	(no answer)
12	Make traffic behind you more prevolent.
15	Same as #38.
16	Change color if aircraft doesn't follow it.
19	N/A not sure.
20	(no answer)
23	Changes color when a "caution". Changes color when a "warning".
24	Maybe with more use we could learn to use it but today it ??enied ineffective.

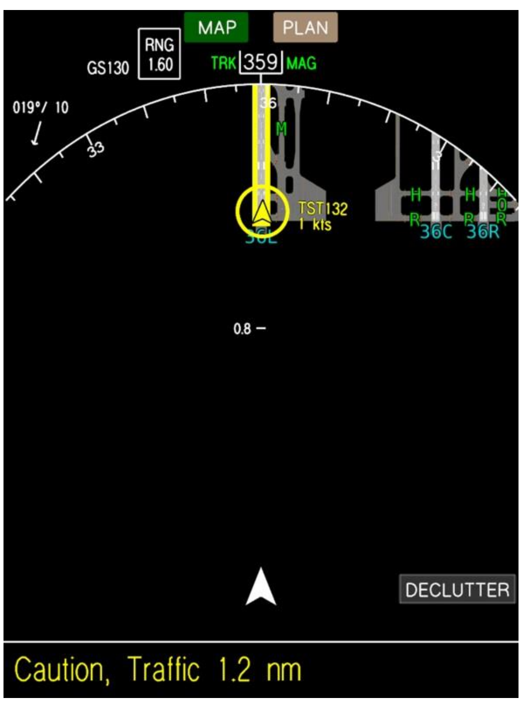
CD&R Symbology



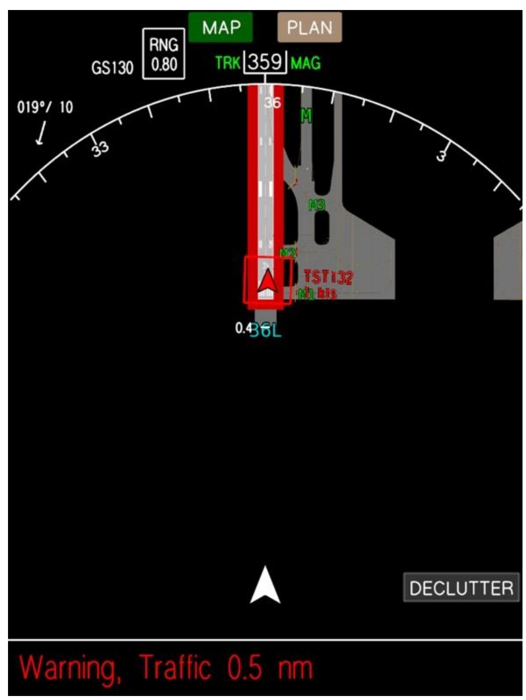
Traffic Indication



Runway Status Indication



Caution Alert



Warning Alert

Figure J.33. Indication and Alerting Symbology.

40. How effective was the CD&R symbology in providing information on the conflict traffic?.
1 = Minimal; 7 = Substantially

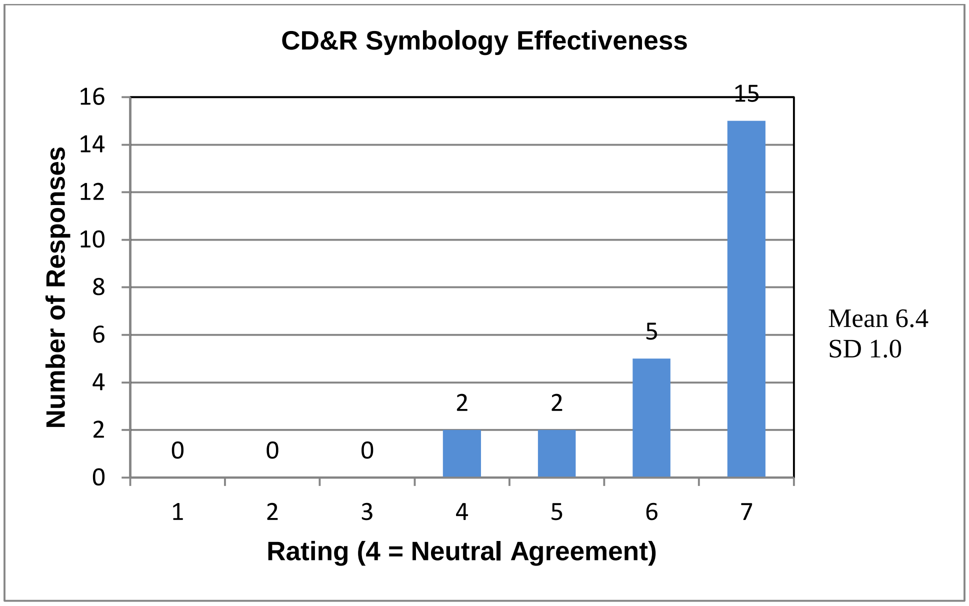


Figure J.34. CD&R Symbology Effectiveness.

41. The CD&R symbology provided a clear indication of the relative location of the conflict traffic.
1 = Strongly Disagree; 7 = Strongly Agree

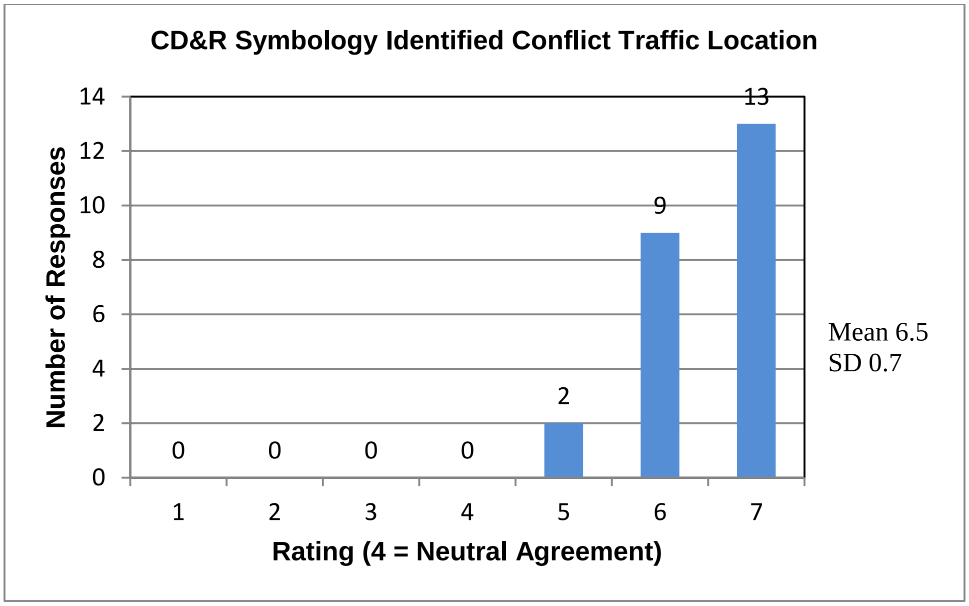


Figure J.35. CD&R Symbology Identified Conflict Traffic Location.

42. I received Indications during the experiment. (Yes, No, Don't Know)

Yes	No	Don't Know
23	1	0

If you did receive indications:

A. I found Indications helpful in determining critical runway safety information.
1 = Strongly Disagree; 7 = Strongly Agree

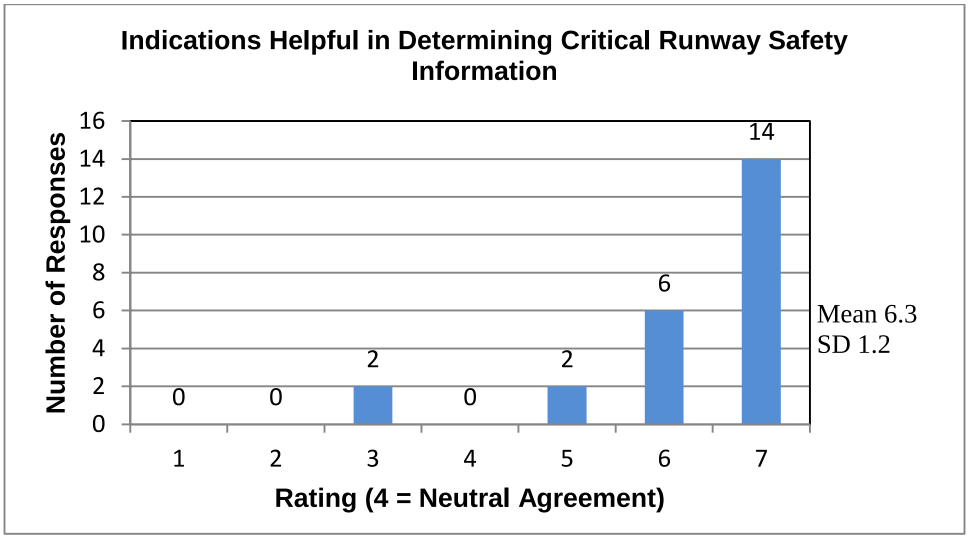


Figure J.36. Indications Helpful in Determining Critical Runway Safety Information.

B. Indications provided additional information over surface map traffic.
1 = Strongly Disagree; 7 = Strongly Agree

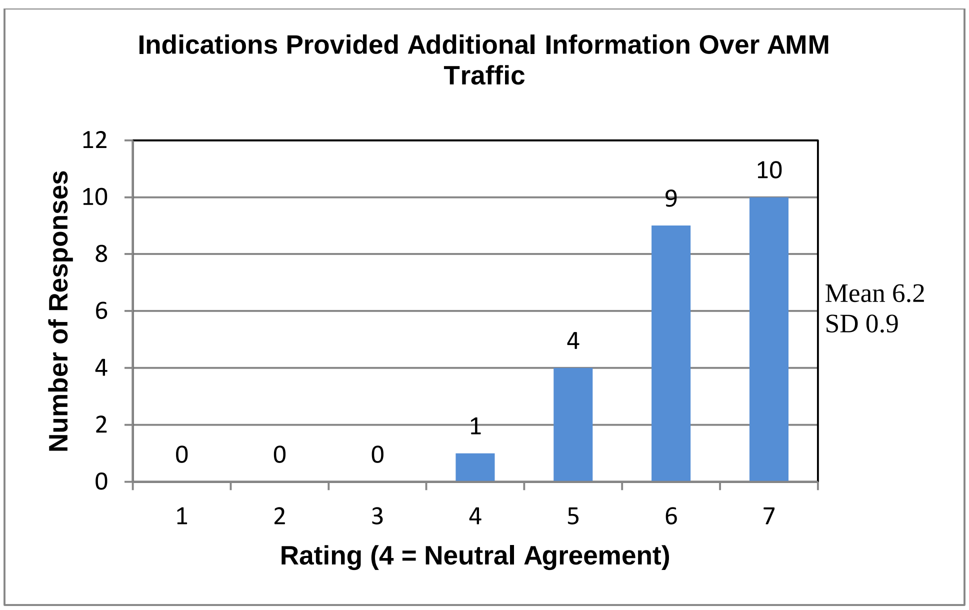


Figure J.37. Indications Provided Additional Information Over AMM Traffic.

C. Indications helped me in determining the location and movement of traffic that was relevant to the safety of my own aircraft. 1 = Strongly Disagree; 7 = Strongly Agree

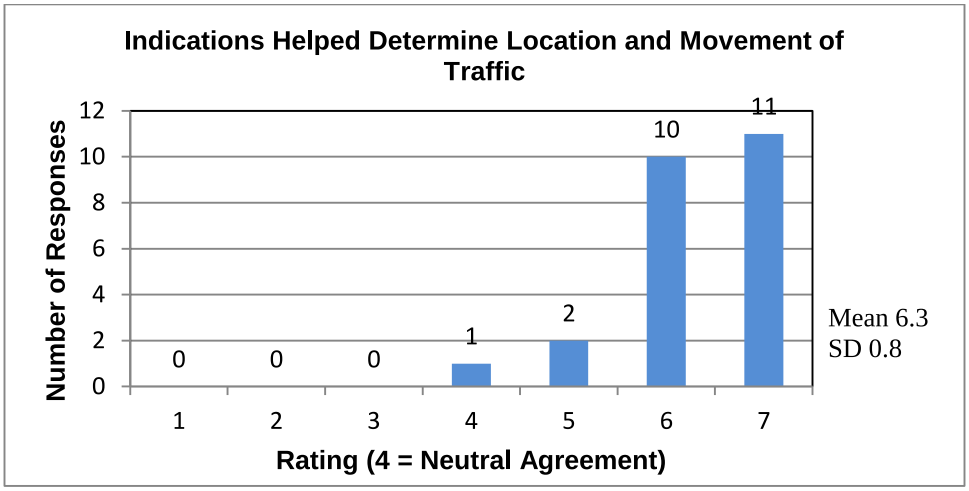


Figure J.38. Indications Helped Determine Location and Movement of Traffic.

Please provide any comments regarding Indications.

Subject	Suggestions
1	Color change of symbology is essential.
2	The one we got was off scale and hard to notice with other duties (confirming taxi route compliance, checklist performance (causing loss of moving map), and other ground taxi duties we didn’t perform in sim (calling F/AS, departure PA, etc.) Have an aural alert for runway status indication.
3	Very helpful.
4	(no answer)
5	(no answer)
6	(no answer)
7	Change color to yellow – pulse.
8	(no answer)
9	(no answer)
10	(no answer)
11	(no answer)
12	Except overtaking from behind.
13	(no answer)
14	(no answer)
15	(no answer)
16	(no answer)
17	(no answer)
18	Solid circle is good, but maybe it could blink a few times!
19	(no answer)
20	(no answer)
21	I really liked this info the most as it was visually easy to make conflict stand out! As a pilot, I want all available information, but want it in a form I can decipher quickly. I think it meets this requirement nicely!
22	A lot more training and experience with the system would be required before I felt comfortable using it.
23	Very clear – easy and quick to understand.
24	(no answer)

43. I received Alerts during the experiment. (Yes, No, Don't Know)

Yes	No	Don't Know
23	1	0

If you did receive alerts:

A. I found Alerts helpful in determining critical runway safety information.
1 = Strongly Disagree; 7 = Strongly Agree

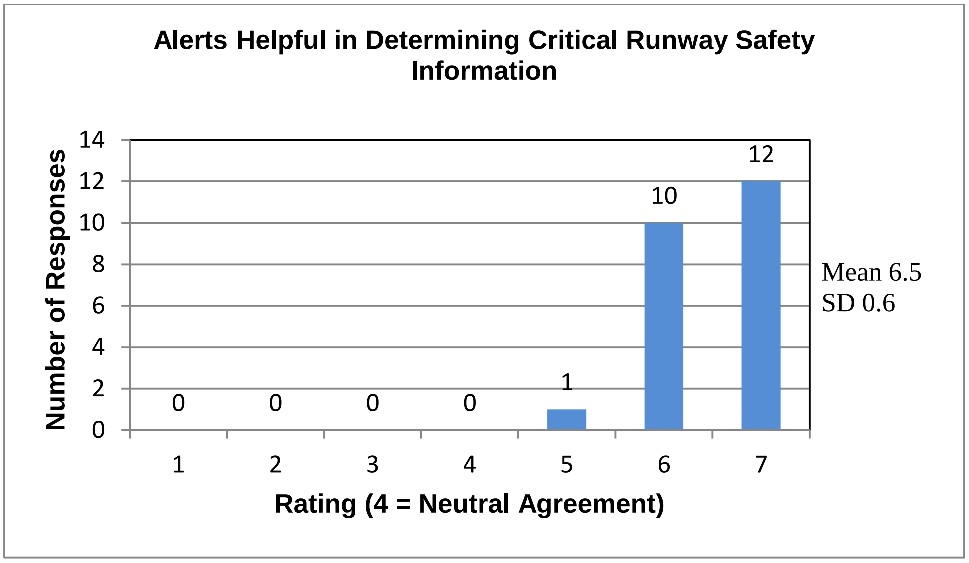


Figure J.39. Alerts Helpful in Determining Critical Runway Safety Information.

B. Alerts provided additional information over surface map traffic.
1 = Strongly Disagree; 7 = Strongly Agree

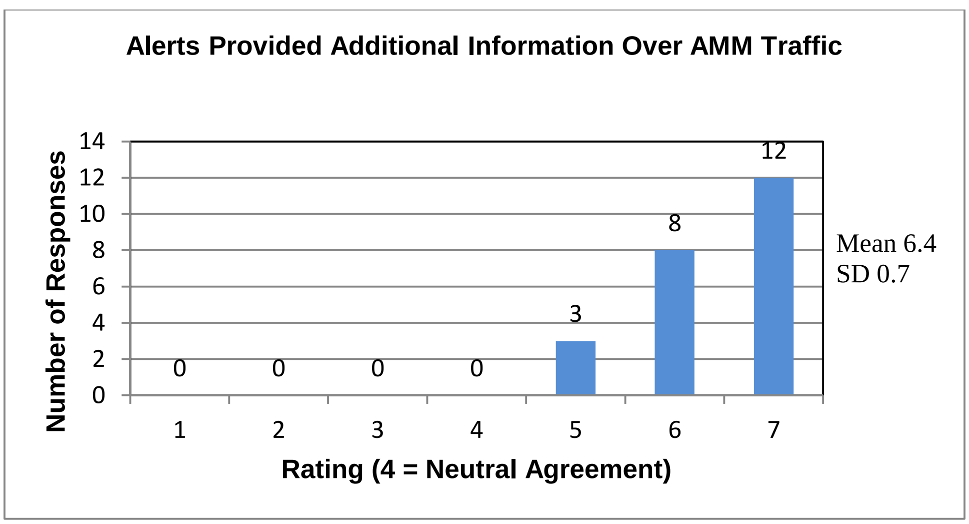


Figure J.40. Alerts Provided Additional Information Over AMM Traffic.

C. Alerts helped me in determining the location and movement of traffic that was relevant to the safety of my own aircraft. 1 = Strongly Disagree; 7 = Strongly Agree

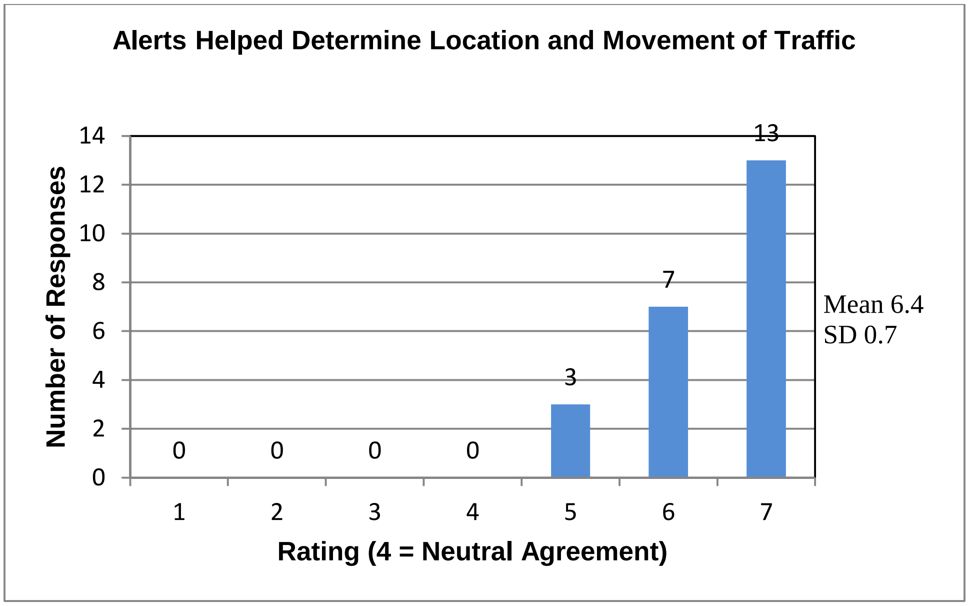


Figure J.41. Alerts Helped Determine Location and Movement of Traffic.

Please provide any comments regarding Alerts.

Subject	Suggestions
1	All good.
2	(no answer)
3	Very helpful in making a go-around/land decision.
4	(no answer)
5	(no answer)
6	They were much more graphic (i.e. caught my attention to possible conflicts).
7	Warning at ¾ mile.
8	(no answer)
9	(no answer)
10	(no answer)
11	Change chevron of conflicting aircraft to red!
12	(no answer)
13	(no answer)
14	(no answer)
15	Aural alerts needs to be unique and unambiguous.
16	(no answer)
17	Alerts could be a distration if intentionally taxiing too close to another.
18	Excellent.
19	(no answer)
20	(no answer)
21	Same as comments on #42 above.
22	Still has areas of ambiguity that needs to be resolved.
23	Excellent!
24	(no answer)

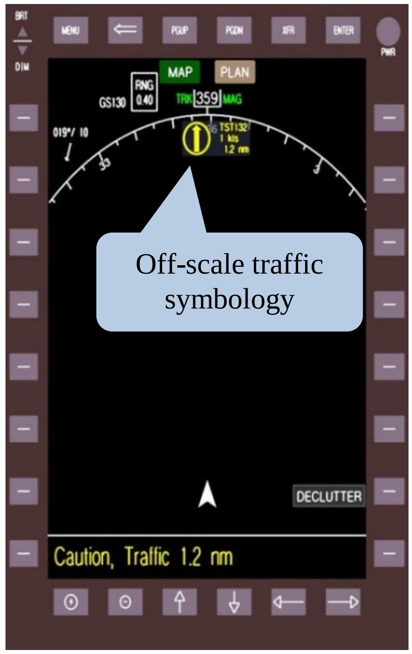


Figure J.42. Off-Scale Traffic Symbology.

When an indication or alert occurred and the potential conflict traffic was not shown on the surface map at the current map scale, an off-scale traffic symbol was displayed.

44. I viewed off-scale indication or alert symbology during the experiment. (Yes, No, Don't Know)

Yes	No	Don't Know
21	2	1

If you did view off-scale symbology:

A. How effective was the off-scale symbology in providing information on the conflict traffic?
1 = Minimal; 7 = Substantially

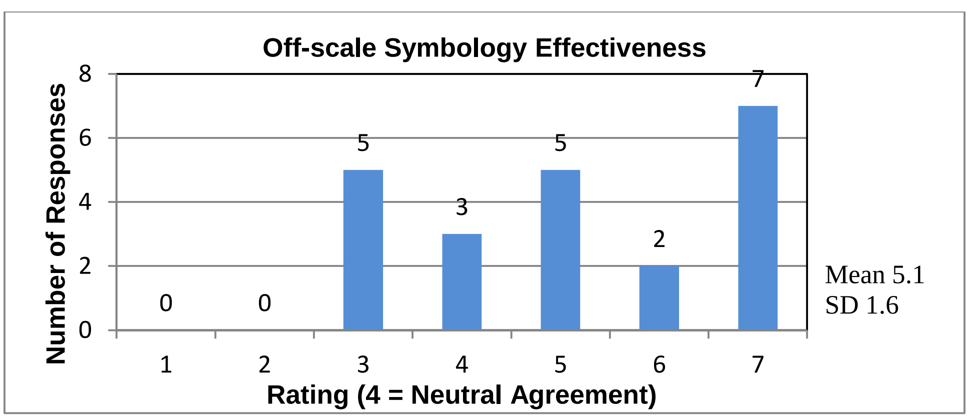


Figure J.43. Off-Scale Symbology Effectiveness.

B. This implementation provided a clear indication of the relative location of the conflict traffic.
1 = Strongly Disagree; 7 = Strongly Agree

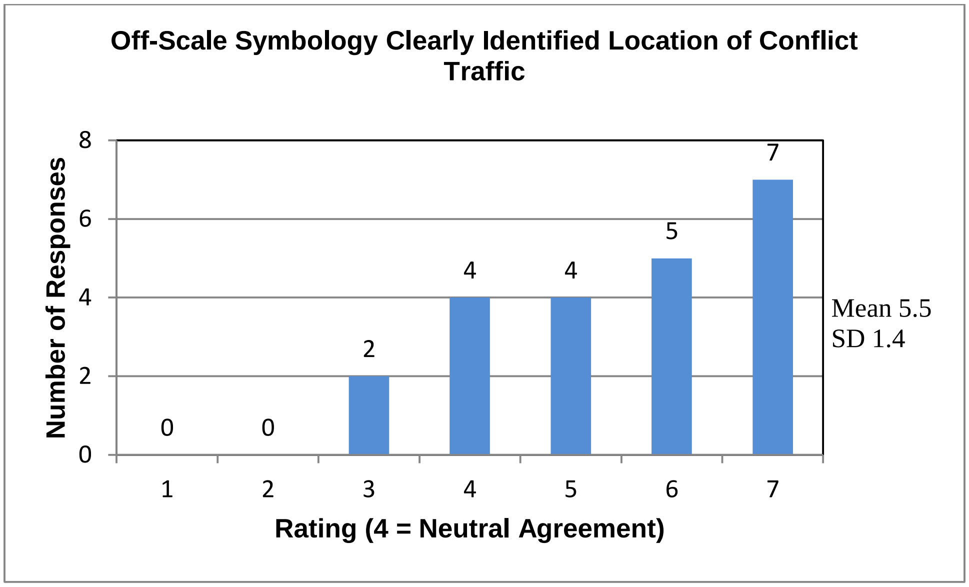


Figure J.44. Off-Scale Symbology Clearly Identified Location of Conflict Traffic.

Recommendations for changes or improvements to display of off-scale traffic on the surface map.

Subject	Suggestions
1	Not enough experience with symbology to quickly decipher what it is trying to tell me.
2	If causes a conflict alert, caution or warning, have moving map scale change.
3	Only saw it once, and didn't really find it useful.
4	(no answer)
5	(no answer)
6	None.
7	Have language say "off-scale".
8	Works – not great – but….
9	(no answer)
10	(no answer)
11	(no answer)
12	(no answer)
13	Depending on workload it is difficult to focus head down to determine if a threat or not.
14	See #7. Your aircraft should be in center of screen.
15	(no answer)
16	None.
17	Automatic AMM range change to include actual position of "off-scale traffic".
18	Works well.
19	(no answer)
20	(no answer)
21	Same as #42 and #43 comments above.
22	This feature is fine.
23	The current display is sufficient.
24	One situation with us cleared traffic cross runway with traffic on t/o roll. I was immediately alerted with a/c vector and speed then got blue runway and even though didn't have a/c symbol the info we got saved us!

45. When an indication or alert occurs and the potential conflict traffic is not shown on the map at the current map scale, would you prefer the map to auto-zoom to a scale that shows the traffic symbol.
(Yes, No, Don't Know)

Yes	No	Don't Know
15	6	3

46. The CD&R system was effectively integrated with the STBO display concepts.
(1 = Strongly Disagree; 7 = Strongly Agree)

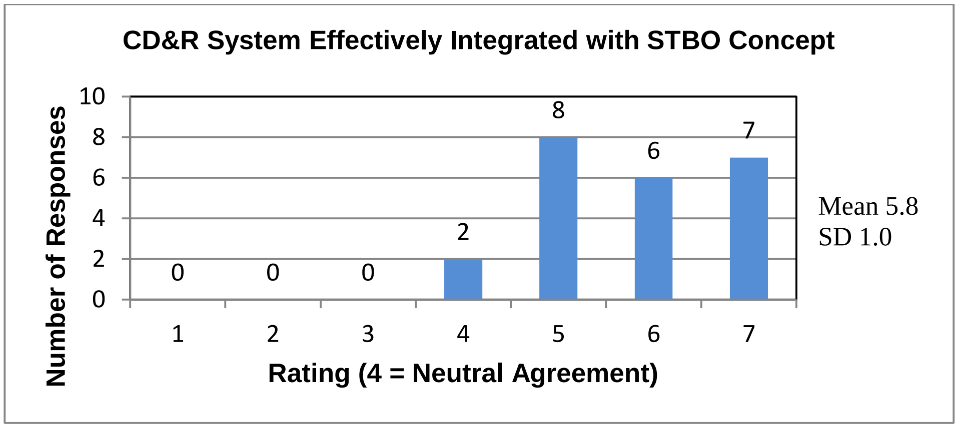


Figure J.45. CD&R System Effectively Integrated with STBO Concept.

47. If you received any CD&R during STBO, please answer the following:
Rate your subjective estimate of the effectiveness of the CD&R during STBO.
(1 = Minimal; 7 = Substantially)

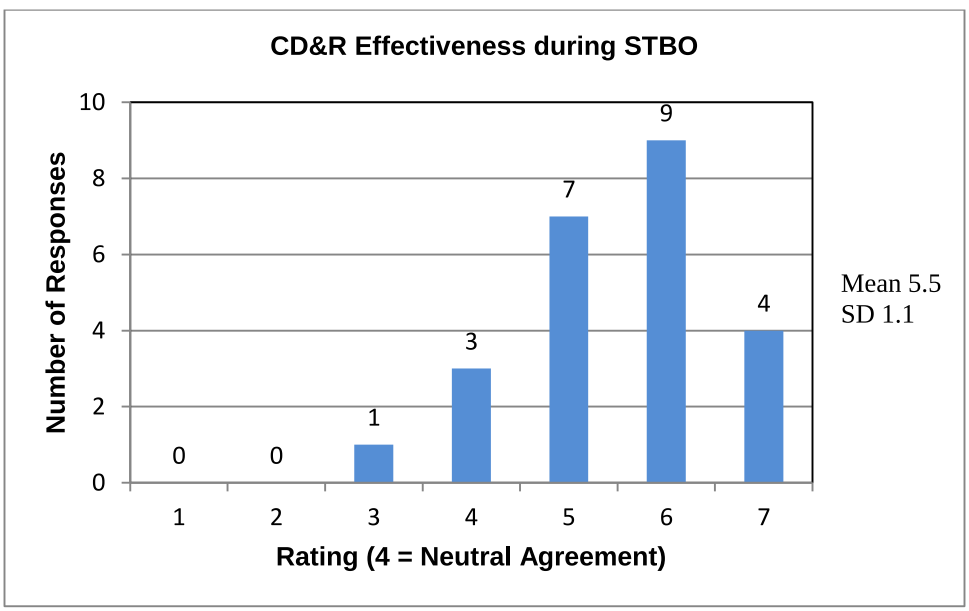


Figure J.46. CD&R Effectiveness During STBO.

48. Please provide any comments that may help improve the quality of the CD&R, or the STBO, or better jointly implement both technologies.

Subject	Suggestions
1	As mentioned previously, bigger bubbles for cautions/alerts and graphic displays of their intended taxi routes.
2	What we saw was not bad but at airports with tons of ground traffic, I can see the display getting very cluttered. Somehow need to declutter. Maybe declutter aircraft heading away from you.
3	Did not see the integration of the two systems during our session.
4	(no answer)
5	See previous runway crossing situation comments
6	The integration worked well. My lack of experience (with the system) may have made it difficult to see how both work together.
7	1) Approach – able to slew so you can see if a/c is conflicting. 2) Aircraft chevron symbol needs to change size as scale. It is huge as you scale down. 3)Taxi a/c, yellow closer to time rings. 4) ADV speed on HUD in center R7 or left. 5) Need time to check airport charts before taxi even if you have taxi magenta laid out.
8	(no answer)
9	As mentioned earlier, I was not confident in the capability of the system to identify all potential taxi conflicts.
10	Not enough warning time during taxi ops.
11	Symbology arrows (chevrons) should be smaller and color coded for threat level, like TCAS. HUD didn't do anything but add a distraction to taxiing.
12	(no answer)
13	Airliners do not turn that slow. Put the + or – time on the HUD. Show a trajectory of other aircraft that may conflict with you. Something like speed trend vector.
14	1) STBO and CD&R – As before, your aircraft should be in the center of the screen. 2) CD&R – Excellent tool. Best part of test today. Good display, good audio. Keep it like TCAS, because we're trained to that already. Must be similar. 3) STBO – Nominally effective unless all aircraft and vehicles have capability to be displayed. 4) Keep task loading to a minimum! Risk management!
15	We saw it before the indication. If the vis is so low as not to see it first, then too many aircraft were moving without ATC intervention.
16	(no answer)
17	(no answer)
18	These systems greatly enhance our safety within the airport area. Would like to see them on the line as soon as possible!
19	(no answer)
20	(no answer)
21	Well, on the one hand, you have this ETA that we are tasked with making, then on the other you had a few conflicts. This needs to be addressed, to ATC, would likely modify your time, since there will be many variables to the new equation, if both a/c stop for example, there has to be a way to resolve this quickly, otherwise, a snowball of enormous proportions will start to build, affecting more and more a/c at very busy times of day. With what we were given, I didn't see resolutions to these potential problems.
22	STBO needs to account for the a/c size and weight. Large a/c such as the 747 must consistantly manage their energy and momentum. Directing a 747 at gross weight to maintain a set speed in a turn may not be possible. In addition, brake and tire overheating can result at gross weight if trying to maintain an STBO directed speed.
23	Integrate with HUD as much as possible. Integrate into wearable glasses to be used for ground operations. Integrate cautions and warnings onto PFD.
24	In one scenario we were pos and hold for a long time. The off scale symbol for a/c behind us actually displayed on the screen to our left. Which just happended to line the syumbol up with a parallel runway. (Note: in reality the aircraft was actually going to the parallel runway) We

	were very nervous because we didn't know if we had an a/c about to land on us or if it was a nuisance warning from the parallel to our left. When our runway turned blue, the excitement really escallated. Too bad we stopped the run because I would love to know what to do when you think you are going to get hit but don't have t/o clearance.

49. Please provide any additional comments that will help us in our evaluation and development of the concepts you saw today.

Subject	Suggestions
1	(no answer)
2	1- Sometimes we were cleared to taxi on a route that crosses a runway (off duty). FARs changed a few years ago that require verbal clearance to cross a runway whether not in use or even closed. Recommend incorporation of this into pre-recorded taxi clearances. 2- The aircraft that took off in front of us never received an audio clearance to take off. This is a problem for 2 reasons. A) You think you are on the wrong frequency and become distracted with checking the proper frequency. B) The verbal T/O clearance the aircraft in front of you receives is a "cue" for us to be ready to take the runway. Recommend you incorporate this audio in your pre-recorded audio messages.
3	I do like the expanding scale idea, as well as more deconfliction info during the STBO guidance phase, up to and including "stop"guidance.
4	(no answer)
5	(no answer)
6	Overall my perceptions of the technology presented was enhancing to the user by improving information given to avoid potential rwy/taxi conflicts. As a first time user, it was not a difficult system to quickly understand for use. The system would be very beneficial at major airports.
7	1) HUD could provide guidance - like google maps in 300 ft 90 degree right turn with distance tracking down to turn. 2) Aural notice "100 ft turn right" or "half right" or "45 degree right" for example with ability to turn arual off when you are 100%.
8	This is certainly an improvement over our current environment. We have pilots that are predominantly extremely experienced. I would be interested to see inexperienced pilots performance
9	You have developed a great system. For it to be most effective: 1) all traffic needs to be displayed in some form, 2) STBO needs to become less labor intensive for the captain, 3) ground conflicts need to be displayed with higher reliability.
10	I like the technology… Only the time taxi is overly intrusive.
11	I like this a lot and hope it gets implemented in the not too far future!
12	I like the equipment but it adds to the workload. I found myself inside the cockpit more than usual.
13	(no answer)
14	Too much orientation time for pilots who have never flown a B757/767 advanced 737 model. I would recommend that be specified in the online application.
15	1) Excellent tools and concepts. Must consider ATC interactions with procedures. These tools must be global applicability not just US centric. 2) The more uncertainty in targets in flight or ground, the increased work load for pilots. 3) Ground taxi performance and fidelity unrealistic. Light weight aircraft need less power/more braking to maintain speeds, heavier ones much more power. End result - more fuel/wear tear, increased hazard to unreliability with traffic deconfliction and heads down time for ATC efficiency??? Not a good trade-off.
16	Auto-zoom for off scale and maybe aural tones to get our attention of conflicts. Great product so far.
17	HUD information is a substantial increase in SA concerning STBO.
18	System is excellent. Training will be paramount. Once up and running, safety will definitely be enhanced. The text feature is needed now. Anything we can do to cut down on radio calls is a plus. Thank you for letting me praticipate in this study. Good luck going forward and I look forward to using these wonderful tools on the line!

19	As PIC, I found taxi guidance to be a distraction and tempted me to follow the line instead of knowing my position on the field. I worry about complacency and not seeing the threat directly out the window. Procedures would require an aural annunciation when deviating from taxi instructions because of workload during normal taxi out. My humble opinion.
20	(no answer)
21	Very good and usable system to enhance safety and SA!! Watching throughout my career things like; flight data recorders, TCAS, CPDLC, GPWS, then EGPWS, Wx avoidance, surface radar, etc… etc… develop and then become a normal piece of everyday equipment, I think that the system presented here today adds an incredibly better dose of situational awareness to the flight deck. As stated earlier, as an operating crew memeber, I want as much information as I can get to make for a SAFER OPERATION. But it of course needs to come in a form thats easily usable to avoid info overload. That said, the use of this system met these goals with some minor changes and would definitely enhance SA and avoid conflicts. But I do use this as back-up to human interaction making final decisions. The concept is great and puts another tool in my box!
22	Airline operations departments should be involved in the testing. Some airlines will likely oppose being assigned a set taxi time and speed. Some carriers are known to taxi very fast, while others taxi much slower. Having a fast moving Southwest jet taxi with STBO, while coordinating with a very slow moving foreign carrier - 747 at ORD would likely create problems with this system. Also some airports like ANC have inclines on the taxiway which would make maintaining a set speed nearly impossible without creating a hazard from the jet blast behind the a/c.
23	Less is better - the less distracting information flow to the pilots - the better. Heads up during T/O, approach, and ground operations is critical. Heads up display/goggles or voice information is excellent!
24	Also we took off over an a/c with a midfield incursion. I saw him hold short with approximately 3-4 other a/c symbols all nosed on our runway. Its unnerving and distracting to watch all these symbols wondering if they are going to poke their nose on. As you watch engine performance and call V speeds I thought I saw him start to move on the screen but he was 3-4 K feet down the runway. I'm wondering about range accuracy, resolution, his position accuracy and if he really is moving. In the mean time, I get him out the window rolling on to our runway with no alert or warning and we early rotate the aircraft to try and clear him. Not many war fuzzies there. Overall its a great idea. Still lots of gotchas in a system that could easily lull an unsuspecting crew into thinking they were safe. I noticed every time I went away from moving map, my SA on our position and that of traffic went to almost zero.

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
01- 03 - 2016

2. REPORT TYPE
Technical Publication

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Conducting Safe and Efficient Airport Surface Operations in a NextGen Environment

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Jones, Denise R.; Prinzel, Lawrence J., III; Bailey, Randall E.; Arthur, Jarvis J., III; Barnes, James R.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
284848.02.50.07

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-20536

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)
NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
NASA/TP-2016-219172

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified
Subject Category 03
Availability: STI Program (757) 864-9658

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Next Generation Air Transportation System (NextGen) vision proposes many revolutionary operational concepts, such as surface trajectory-based operations (STBO) and technologies, including display of traffic information and movements, airport moving maps (AMM), and proactive alerts of runway incursions and surface traffic conflicts, to deliver an overall increase in system capacity and safety. A piloted simulation study was conducted at the National Aeronautics and Space Administration (NASA) Langley Research Center to evaluate the ability of a flight crew to conduct safe and efficient airport surface operations while utilizing an AMM. Position accuracy of traffic was varied, and the effect of traffic position accuracy on airport conflict detection and resolution (CD&R) capability was measured. Another goal was to evaluate the crew's ability to safely conduct STBO by assessing the impact of providing traffic intent information, CD&R system capability, and the display of STBO guidance to the flight crew on both head-down and head-up displays (HUD). Nominal scenarios and off-nominal conflict scenarios were conducted using 12 airline crews operating in a simulated Memphis International Airport terminal environment. The data suggest that all traffic should be shown on the airport moving map, whether qualified or unqualified, and conflict detection and resolution technologies provide significant safety benefits. During the STBO testing, the flight crews met their required time-of-arrival at route end within 10 seconds on 98 percent of the trials, well within the acceptable performance bounds of 15 seconds.

15. SUBJECT TERMS
Air transportation; Airport; Flight crews; Runway incursions; Safety; Surface trajectory-based operations; Traffic

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					STI Help Desk (email: help@sti.nasa.gov)
					19b. TELEPHONE NUMBER ***(Include area code)***
U	U	U	UU	179	(757) 864-9658