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Simulator Evaluation of Runway Incursion Prevention Technology for General Aviation Operations

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Space Administration

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Acronyms and Symbols

α	Alpha, probability of Type 1 error
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above Ground Level
AMASS	Airport Movement Area Safety System
ANOVA	Analysis of Variance
ASDE-3	Airport Surface Detection Equipment Model 3
ASDE-X	Airport Surface Detection Equipment Model X
ATC	Air Traffic Control
B	Baseline
BA	Baseline with Audible Incursion Alerts
BAMO	Baseline with Surface Map and Ownship and Audible Incursion Alerts
BAMOT	Baseline with Surface Map and Ownship, Traffic, and Incursion Alerts
BMO	Baseline with Surface Map and Ownship
BMOT	Baseline with Surface Map and Ownship and Traffic
BRIPS	Baseline with Perspective Surface Map
C-206	Cessna 206
EFB	Electronic Flight Bag
EP	Evaluation Pilot
FAA	Federal Aviation Administration
FBO	Fixed Based Operator
F	F-ratio, variance ratio
FY	Fiscal Year
GA	General Aviation
GS	Ground Speed
IFD	Integration Flight Deck
IMC	Instrument Meteorological Conditions
KRNO	Reno/Tahoe International Airport
LaRC	Langley Research Center
MANOVA	Multivariate Analysis of Variance
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NTSB	National Transportation Safety Board
OVR	Overview
$\underline{p}$	Probability of occurrence of an event
RD	Research Display
RIPS	Runway Incursion Prevention System
RSM	Runway Safety Monitor
RWSL	Runway Status Lights
SA	Situation Awareness
SART	Situation Awareness Rating Technique
TA	Terrain Awareness
TCAS	Traffic Alert and Collision Avoidance System
TLX	Task Load Index
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

Abstract

A Runway Incursion Prevention System (RIPS) has been designed under previous research to enhance airport surface operations situation awareness and provide cockpit alerts of potential runway conflict, during transport aircraft category operations, in order to prevent runway incidents while also improving operations capability. This study investigated an adaptation of RIPS for low-end general aviation operations using a fixed-based simulator at the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC). The purpose of the study was to evaluate modified RIPS aircraft-based incursion detection algorithms and associated alerting and airport surface display concepts for low-end general aviation operations. This paper gives an overview of the system, simulation study, and test results.

Introduction

Runway incursions are a serious aviation safety hazard, particularly for general aviation (GA) operations. According to the Federal Aviation Administration (FAA) (FAA, 2007), during the four year period from fiscal year (FY) 2003 through FY 2006, there were approximately 250 million aircraft operations and 1,306 runway incursions reported at United States towered airports – approximately 5.2 runway incursions for every one million operations. General aviation was involved in 72 percent of these incursions but only 55 percent of the operations. Eighty-two percent of the most severe incursions (98 of 120 incursions) involved at least one GA aircraft. Four incursions resulted in collisions, with one of these collisions involving GA aircraft. These statistics do not consider incidents that occur at non-towered airports.

Current FAA initiatives are targeting reductions in the severity and rate of runway incursions by implementing a combination of technology, infrastructure, procedural, and training interventions (FAA, 2007). These solutions include Airport Surface Detection Equipment Model 3 (ASDE-3) and ASDE Model X (ASDE-X) radar; Airport Movement Area Safety System (AMASS); multilateration systems; in-pavement loops; Runway Status Lights (RWSL); enhanced controller training; airport surface operations advisory circulars; improved airport markings; improved pilot education, training, and awareness; and revised pilot/controller communications phraseology. These efforts target improved awareness and enhanced surveillance, but do not include on-board technology solutions for the flight deck.

The National Transportation Safety Board (NTSB) considers runway incursions to be a serious aviation safety hazard, listing runway incursion prevention as one of their "most wanted" transportation safety improvements (NTSB, 2007). The NTSB specifically recommends that the FAA implement technology that "give immediate warnings of probable collisions/incursions directly to flight crews in the cockpit" (NTSB, 2000). In response to this recommendation, the FAA has begun to research the concept of transmitting ground-generated incursion alerts to aircraft and vehicles.

NASA developed a Runway Incursion Prevention System (RIPS) for commercial and business transport aircraft operations to improve airport safety by providing surface situation awareness (SA) information and guidance cues, and alerts of runway conflicts and route deviations directly to the flight crew. The system was evaluated in several flight tests and simulation studies (Jones, Quach, and Young, 2001; Jones, 2002; Jones, 2005).

In the present work, RIPS was adapted for small-aircraft, GA operations. A piloted simulation study was conducted at NASA LaRC to evaluate RIPS for low-end GA operations that focused on evaluation of incursion detection algorithms and cockpit display concepts. This paper presents an overview of the system, description of the simulation study, and test results.

System Description

Simulation Facility

Flight Deck Simulator

NASA LaRC's Integration Flight Deck (IFD), normally used as a transport-category, fixed-based, high-fidelity, flight simulator, was adapted for this study because its visual, tactile, and audio capabilities provided the highest level of fidelity at LaRC toward meeting the research objectives (e.g., visual traffic acquisition). The IFD was configured to emulate a Cessna 206 (C-206) GA aircraft (herein referred to as the ownship). A six-degree-of-freedom, non-linear, simulation model of the C-206 and representative control-force and braking models were used. The left throttle was utilized to control the aircraft power while the right throttle was utilized to control the fuel mixture. In order to avoid distractions, extraneous displays and gauges were covered or turned off during data collection.

As shown in Figure 1, an electronic research display (RD) was installed on the instrument panel directly in front of the left seat and control yoke. The RD was composed of two 10.4.inch liquid crystal displays and was capable of displaying two separate digital displays, side-by-side. An electronic flight bag (EFB) display, located to the left of the RD, was used to present the airport surface map display concepts described below. This display measured 10.4 inches diagonally with a resolution of 1280 x 1024 pixels. The collimated out-the-window scene provided a 200 degree horizontal by 40 degree vertical field of view at 26 pixels per degree resolution.

This configuration was used in a previous simulation, and feedback from the subjects of that study indicated that the simulation fidelity and cockpit environment were sufficiently representative of a C-206 aircraft (Bartolone et al, 2005).

Traffic position data were "broadcast" at a 1 Hz rate. No additional latency or surveillance data inaccuracies were applied. Ownship position data were updated at 20 Hz.

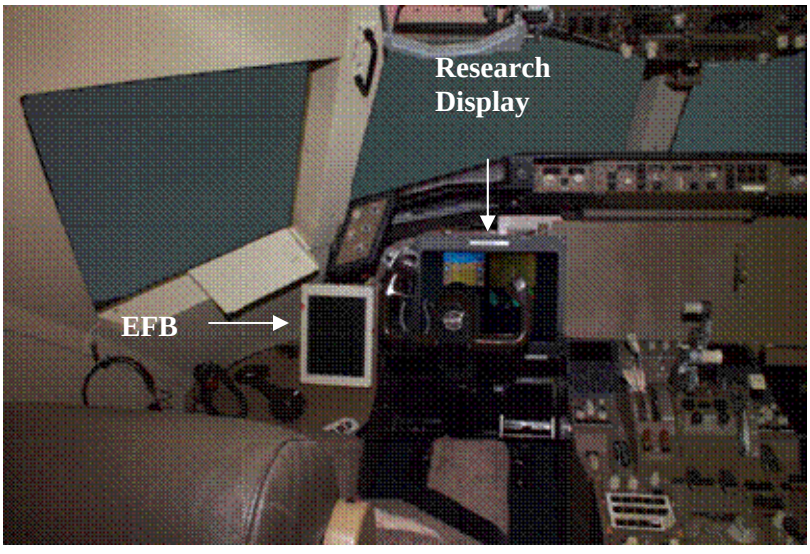

Figure 1. IFD simulator cockpit configuration and displays.

Air Traffic Control Simulation

Approach and tower air traffic control (ATC) instructions and pilot requests and replies were used in the simulation to increase the simulation fidelity of the terminal area environment and provide normal pilot workload demands during the study. All ATC and other aircraft radio messages were pre-recorded using different voices. The messages were then played through the flight deck speaker system when the ownship and simulated traffic reached specified locations. The subject pilots were asked to provide radio replies, when requested by the pre-recorded ATC messages, as per normal operating procedures.

Research Displays

This simulation study was designed for low-end, GA aircraft; therefore, standard round dial instrumentation was used as the "baseline" display concept around which various airport surface map formats and alerting concepts were experimentally evaluated. The genesis and background for the RIPS concepts are described in detail from previous research (Jones, et al, 2001; Jones, 2002; and Jones, 2005). The map format and alerting concepts were intended to identify which RIPS elements from previous research, as well as new elements, are most applicable and necessary to prevent runway incursion accidents and incidents for low-end, GA aircraft operations.

The round-dial displays were shown on the RD located in front of the evaluation pilot (EP) (see Flight Deck Simulator section).

When dictated by experimental condition, an airport surface map was displayed on the EFB located to the left of the round dial display. The surface map was generated using a Reno/Tahoe International (KRNO) airport geographic database developed to RTCA standards (RTCA, 2001). The map scale was set to 2.5 nm for the airborne scenarios and 1.5 nm for the ground based scenarios and was not pilot-selectable. Audible alerts sounded through the flight deck speaker system.

Seven display conditions were evaluated during the course of the study as described below.

Baseline (B)

The Baseline (B) display condition consisted of a set of six instruments (airspeed indicator, attitude indicator, altimeter, vertical speed indicator, directional gyro, and turn coordinator) plus manifold pressure and instrument landing system data. All instruments were three inches in diameter and configured on the RD as shown in Figure 2.

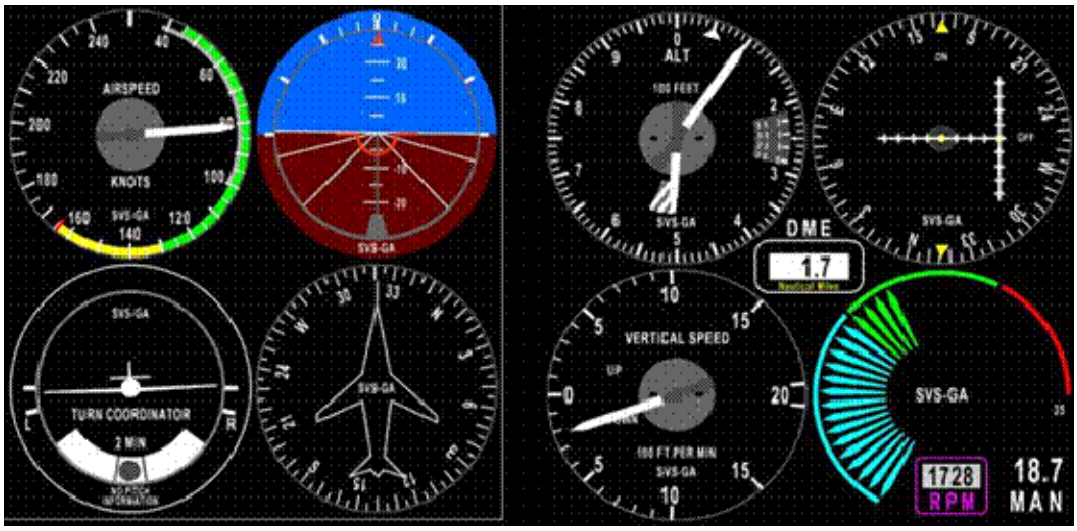

Figure 2. Baseline display condition.

Baseline with Surface Map and Ownship (BMO)

The BMO display condition consisted of the baseline round dials displayed on the RD with the addition of a plan view surface map displayed on the EFB (Figure 3). This version of the surface map displayed an airport layout along with ownship position. Neither traffic nor ATC instructions (such as assigned taxi route) were shown. Incursion alerting was not part of this condition.

Baseline with Surface Map and Ownship and Traffic (BMOT)

The BMOT display condition was equivalent to the BMO condition but with the addition of traffic on the surface map (Figure 4). It was assumed that traffic was reported by an Automatic Dependent Surveillance-Broadcast (ADS-B) system. All traffic positions were reported without any positional inaccuracy (albeit at only a 1 Hz update rate). No data drop-outs, false reporting, or un-equipped traffic were simulated.

Traffic was displayed as dark blue chevrons when on the ground and cyan chevrons when airborne. The direction of travel was indicated by the pointed end of the chevron. A circular symbol was used when traffic was traveling less than six knots, since the direction of travel could not be reliably estimated from just the simulated broadcast of position. Incursion alerting was not part of this condition.

Figure 3. BMO display condition.

Figure 4. BMOT display condition.

Baseline with Audible Incursion Alerts (BA)

The BA display condition consisted of the baseline round dials displayed on the RD and audible runway incursion alerts that sounded over the flight deck speaker when a potential conflict was detected. The detection method used to generate the alert is described in detail in the Runway Incursion Alerting section.

Baseline with Audible Incursion Alerts, Surface Map and Ownship (BAMO)

The BAMO display condition was equivalent to the BMO condition with the addition of audible runway incursion alerts.

Baseline with Incursion Alerts, Surface Map and Ownship, and Traffic (BAMOT)

The BAMOT display condition was equivalent to the BMOT condition with the addition of both audible and visual runway incursion alerts (Figure 5). The alerting displays and detection method are described in detail in the Runway Incursion Alerting section.

Baseline with Perspective Surface Map (BRIPS)

The BRIPS display condition consisted of the baseline round dials displayed on the RD with a perspective surface map displayed on the EFB (Figure 6). The map graphically depicted a perspective, track-up airport layout with current ownship and traffic locations and incursion alerts, which are the same information presented with the plan view BAMOT condition. ATC instructions, including the approved taxi route and hold short locations, were sent via a simulated data-link and automatically loaded and depicted as a magenta route on the surface map and shown as an alpha-numeric string. Audible incursion alerts were also sounded.

Audible route deviation and crossing hold alerts were also generated. Route deviation alerts were generated if ownship left its assigned path during taxi. Crossing hold alerts were generated if ownship crossed a hold line without clearance.

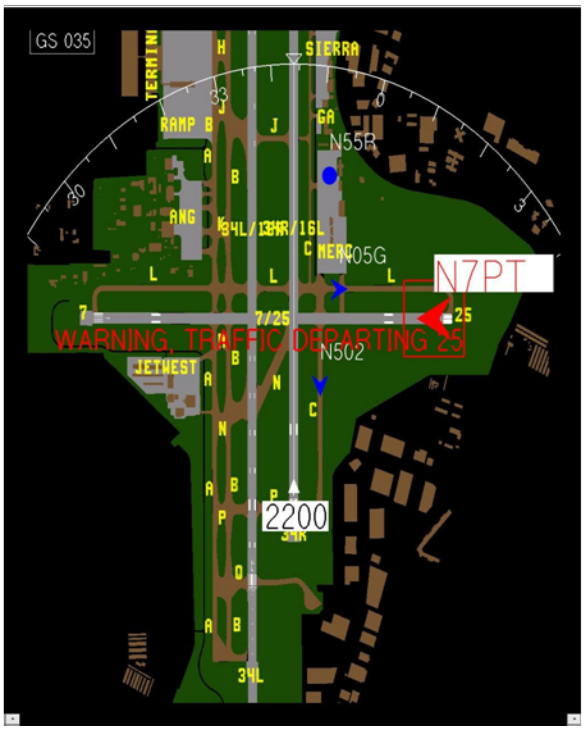

Figure 5. BAMOT display condition with warning alert.

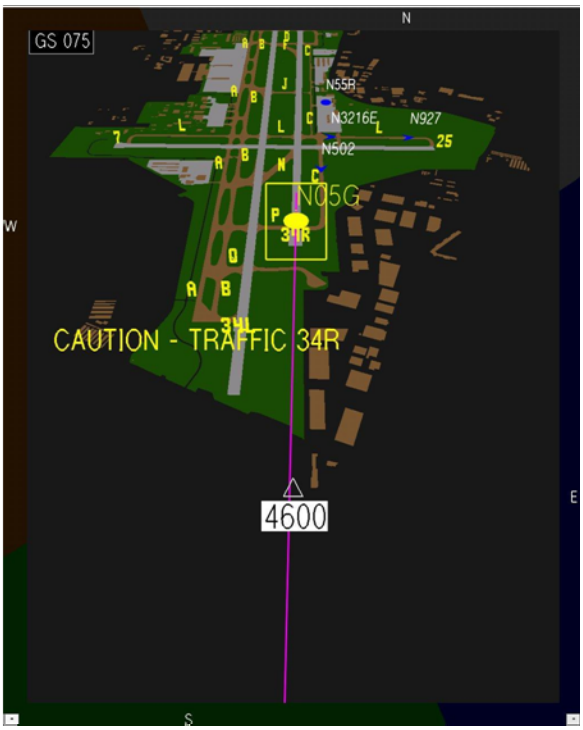

Figure 6. BRIPS display condition with caution alert.

Runway Incursion Alerting

Two different incursion detection algorithms, Runway Safety Monitor and PathProx™, were evaluated during the simulation study. Both algorithms were originally developed for large commercial and business transport aircraft operations and were modified for the low-end GA application reported herein.

Runway Safety Monitor

The Runway Safety Monitor (RSM) incursion detection algorithm (Green, 2006) uses a generic approach for detecting and generating incursion alerts. The RSM monitors traffic that enters a three-dimensional virtual protection zone around the runway that is being used by ownship. Incursion detection is based on the operational state of ownship and traffic, as well as other criteria, including separation and closure rate, to avoid false alerts. Identification, position, and altitude data are used to track the traffic in the protection zone. Traffic data projections are calculated within RSM since, from flight test experience, reliable position updates are not received at consistent intervals. RSM generates a Warning alert, which occurs when a runway incursion is detected and evasive action is required to avoid a potential collision. Information provided with each alert includes identification of the incurring traffic and separation distance to potential conflict.

Modifications were made to RSM for this study to enable incursion detection and alerting for low-end GA operations. Ownship parameters were defined for the specifications and dimensions of the C-206 aircraft. Improvements and refinements were made to the RSM alerting criteria that consider the availability of data, aircraft characteristics, and specific separation requirements for GA. For example, different minimum separation distances and aircraft land/rollout distances typically apply for GA aircraft, representative of a C-206. Since C-206 aircraft may travel slower than larger commercial aircraft, the minimum alerting distance can be less. See Green, et al. 2009 for detailed specifications for RSM alerting criteria for both low-end GA and non-GA aircraft.

PathProx™

The PathProx™ detection algorithm (Cassell et al, 2003) is designed to handle over 40 specific runway incursion scenarios. Alerts are issued based on the states of the ownship and traffic and on conditions including position, speed, and track angle. PathProx™ generates two types of alerts analogous to the Traffic Alert and Collision Avoidance System (TCAS) approach. A Caution alert informs the flight crew of a potential incursion or an incursion where the conflict does not yet require evasive action. The crew can take evasive action, however, at their discretion. PathProx™ also generates Warning alerts when immediate evasive action is required. Information provided with each alert includes identification of the incurring traffic, the associated runway, and separation distance between the traffic and ownship.

Alerting Displays

Incursion alerts could be presented to the flight crew visually on the surface map and/or audibly. The visual and audible alert phraseology were identical. The alert phrases were designed to provide descriptive information regarding the location of the conflicting traffic. It was postulated that providing more details about the location of the incurring traffic would provide additional situation awareness, particularly during the condition when only audible alerts were provided. The incursion alert phrases developed for this study are listed in Table 1. As shown in Figures 5 and 6, the textual forms of these alerts were presented on the surface map. Also, the traffic symbol representing the conflicting traffic was enlarged, changed color (yellow for Caution and red for Warning), and was highlighted by a target designator box. The identification tag was also highlighted. In the event that the incurring traffic symbol was not shown because of the display scale, a symbol was pegged on the edge of the display in the direction of the traffic on the perspective surface map only. The estimated distance to conflict (in feet)

was shown beneath the ownship symbol. An example of a Warning alert for a scenario where both ownship and traffic are departing on intersecting runways is shown in Figure 5. An example of a Caution alert for a scenario where ownship is on approach to a runway with traffic in position and hold for departure is shown in Figure 6.

Table 1. Incursion Alert Phrases

Warning, Traffic 34R
Caution, Traffic 34R
Warning, Traffic 25
Caution, Traffic 25
Warning, Traffic Departing 34R
Caution, Traffic Departing 34R
Warning, Traffic Departing 25
Caution, Traffic Departing 25
Warning, Traffic Approaching 34R
Caution, Traffic Approaching 34R
Warning, Traffic Approaching 25
Caution, Traffic Approaching 25

Test Method

The testing was conducted in two phases, rare event and usability.

The rare event phase was designed to evaluate pilot reaction to a runway incursion event with a given display condition and incursion detection algorithm without expectation on the part of the subject (Newman and Foyle, 2003; Foyle and Hooey, 2003). This effect was created by flying 18 runs under "nominal" (i.e., no incursions) followed by the last run in this phase being a runway incursion event. The evaluation pilot (EP) was not told that this last run concluded the experiment phase or that a runway incursion was planned.

Following the "rare event" phase, a usability phase was conducted.

Test Matrix

The test matrix conditions are identified in Table 2. A full-factorial evaluation across 3 alerting conditions (no alerts, audible alerts, and audible plus visual alerts) and 4 display conditions (Baseline, plan view map, plan view map with traffic, and perspective map with traffic) was considered but rejected for practical and expediency reasons as follows:

- Evaluating visual alerts in the baseline and baseline with plan view map (ownship only) conditions was rejected as not applicable (N/A) because the map did not contain any traffic information; therefore, the value of adding and testing visual alerting for these cases was considered to be small.
- It was assumed that if traffic was provided on a surface map, both audible and visual alerts would be displayed; therefore, the conditions with audible-only alerts were not evaluated.
- The experiment matrix then contains a 2x2 evaluation of the influence of a plan view map (on and off, with ownship position only) and audible alert (on and off).

- The effect of a surface map displaying traffic in addition to ownship was evaluated with no incursion alerts and with combined audible and visual alerts.
- Finally, the perspective surface map displaying ownship and traffic along with ATC instructions (such as the approved taxi route and hold short locations) was considered an advanced condition; therefore, only the most advanced display alerting condition (audible and visual alerts) was evaluated with this condition.

Table 2. Display Test Conditions

	No Alert	*Audible Alert*	*Audible & Visual Alert*
Baseline (B)	B	BA	N/A
B + plan view map with ownship	BMO	BAMO	N/A
B + plan view map with ownship & traffic	BMOT	Did not evaluate	BAMOT
B + perspective map with ownship & traffic	Did not evaluate	Did not evaluate	BRIPS

Rare Event Testing Phase

Four display conditions (BMO, BMOT, BAMO, BAMOT) were evaluated across subjects. The EP flew only one display condition for 19 runs during the rare event testing phase.

These four display conditions were chosen to evaluate the effects of (a) displaying traffic without alerting (BMO and BMOT) and (b) with alerting (BAMO and BAMOT). The evaluation of these four display conditions allowed for direct comparison of the efficacy of alerting without the display of traffic. The rare event testing matrix further enabled direct evaluation of the contribution of display of traffic, both with and without alerting, to determine whether just showing traffic is sufficient for situation awareness and runway incursion avoidance or whether alerting is required.

Eighteen trials were randomly flown that consisted of six different approaches in varying day time visual meteorological conditions (VMC) and instrument meteorological conditions (IMC) visibility conditions (see Appendix A). The intent of these trials was to provide sufficient variety and task demands to hide the rare event, a runway incursion. Pilots were unaware of the total number of trials to be conducted. The final trial in the block was the runway incursion event (Scenario 1 as described below) conducted in marginal VMC conditions (3 nm visibility and 1000 ft ceiling). Scenario 1 – the arrival/takeoff hold incursion – was selected because of its prevalence in runway incursion incident and accident statistics. The RSM incursion detection algorithm was used as the alert source. A wind profile was introduced to add workload to the tasks (see Appendix A).

Usability Testing Phase

Following the rare event phase, a usability study phase evaluated the effectiveness of the display conditions for runway incursion prevention. Each EP evaluated all five incursion scenarios with the seven display conditions (see Appendix B). The first trial for each scenario group used the baseline display condition. All of the trials that provided alerting used the RSM incursion detection algorithm as the alert source. In this study phase, the subjects had an expectation for the study intent (i.e., runway incursions), but they did not know the scenario before the initial trial. Another purpose of the usability study was to evaluate the RSM and PathProx™ incursion detection algorithms for GA operations. Each EP evaluated both algorithms using all five incursion scenarios and the BRIPS display condition. All trials in the usability study were conducted in marginal VMC conditions (3 nm visibility and 1000 ft ceiling) without winds.

Runway Incursion Scenarios

Five incursion scenarios were developed. Within each scenario, an incursion was staged by a blunder from one of the participating other aircraft.

A traffic pattern was established to create reasonable traffic flow at KRNO (Figure 7). Alternating arrivals and departures were simulated using Runway 34R with interleaving departures on Runway 25. Traffic traveled through the intersection of Runways 25 and 34R every minute. The incurring traffic was interleaved into this traffic flow.

Every effort was made to produce similar timing for the scenarios; however, a certain amount of variability in the timing was naturally introduced due to the maneuvering conducted by the EP (i.e., approach speed, taxi speed, etc.).

Scenario 1 – arrival/takeoff hold

This scenario began with ownship approaching Runway 34R for landing, 3 nm from the threshold at 1010 ft above ground level (AGL), and at an indicated airspeed of 90 kt. The EP was cleared to land by tower. Another aircraft was stopped and holding at the 34R hold line nearest to the runway threshold.

Scenario 1 tested the incursion situation where an aircraft moves into position and holds for takeoff even though another aircraft was approaching the same runway for a landing (Figure 8). The traffic for this scenario, instead of holding short of the active runway, taxied into position without clearance when the ownship was 2 nm from the threshold and held in that location awaiting takeoff clearance.

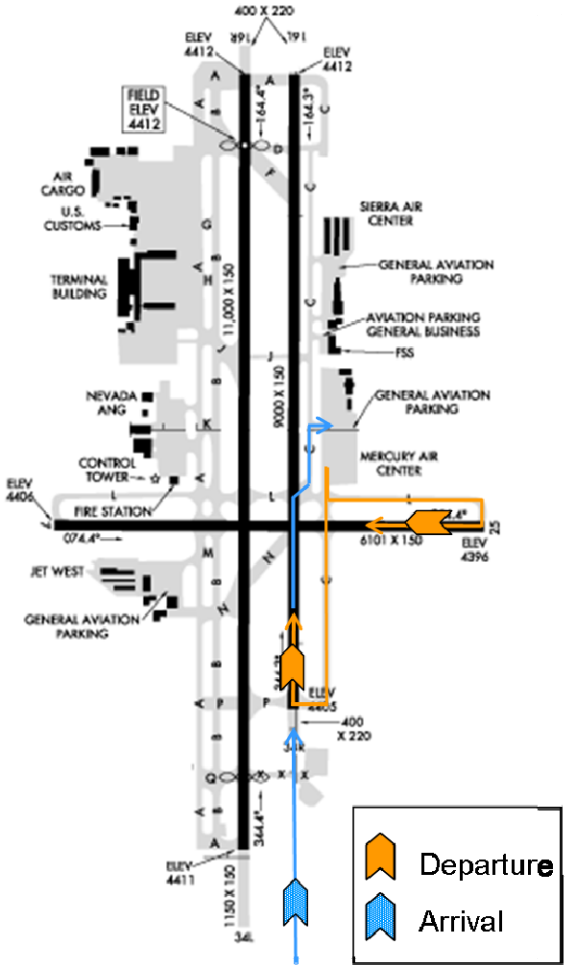

Figure 7. Traffic pattern.

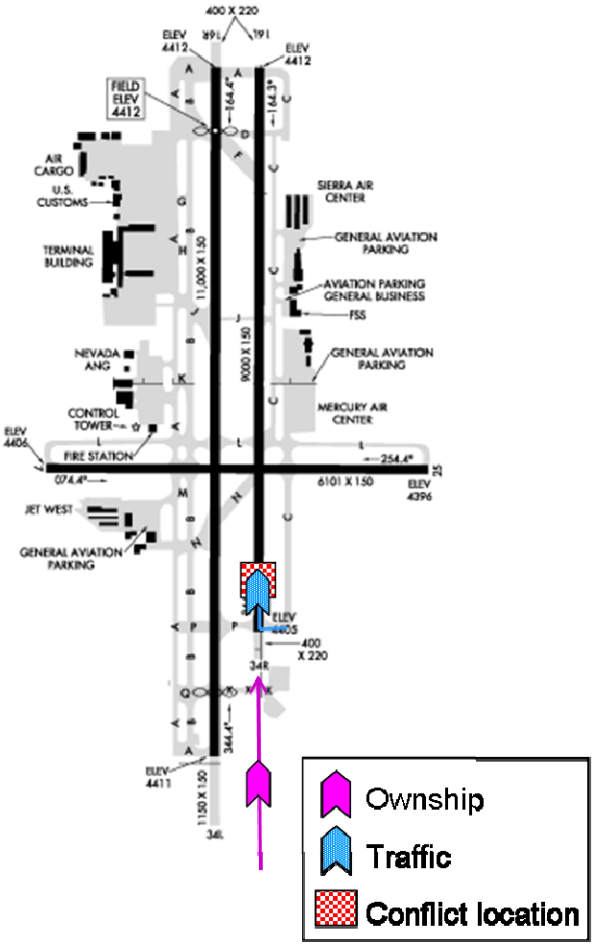

Figure 8. Scenario 1 configuration.

Scenario 2 – departure/intersection departure

This scenario began with ownship taxiing on Taxiway C at 8 kt toward Runway 34R threshold, approximately 500 ft from the threshold. The EP was cleared to taxi to Runway 34R via Taxiway C and hold short of Runway 34R. The traffic was cleared to taxi to Runway 34R via Taxiway L, holding short of Runway 34R for an intersection take-off. (Taxiway L is approximately 3000 ft from Runway 34R threshold.) Ownship was then cleared for takeoff.

Scenario 2 tested the incursion situation where one aircraft is departing as another aircraft enters the runway for an intersection departure (Figure 9). The traffic for this scenario, instead of holding short of the active runway, taxied across the hold line and entered the runway without clearance once the ownship began its takeoff (i.e., on runway heading and traveling greater than 10 kt ground speed).

Scenario 3 – arrival/departure

This scenario began with ownship approaching Runway 34R for landing, 3nm from the threshold at 1010 ft AGL, and at an indicated airspeed of 90 kt. Another aircraft was taxiing on Taxiway L near the Runway 25 hold line at the threshold. The other aircraft was cleared into position for departure on Runway 25. The ownship EP was then cleared to land on Runway 34R by tower.

Scenario 3 tested the incursion situation where an aircraft was departing even though another aircraft was landing on an intersecting runway (Figure 10). The traffic for this scenario, instead of holding in position, began its takeoff on Runway 25 without clearance as the ownship crossed the threshold of Runway 34R.

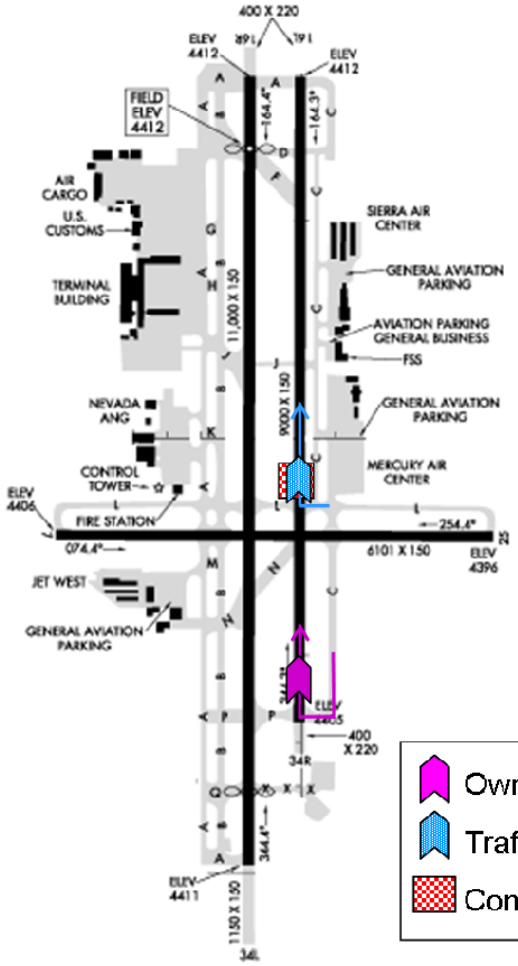

Figure 9. Scenario 2 configuration.

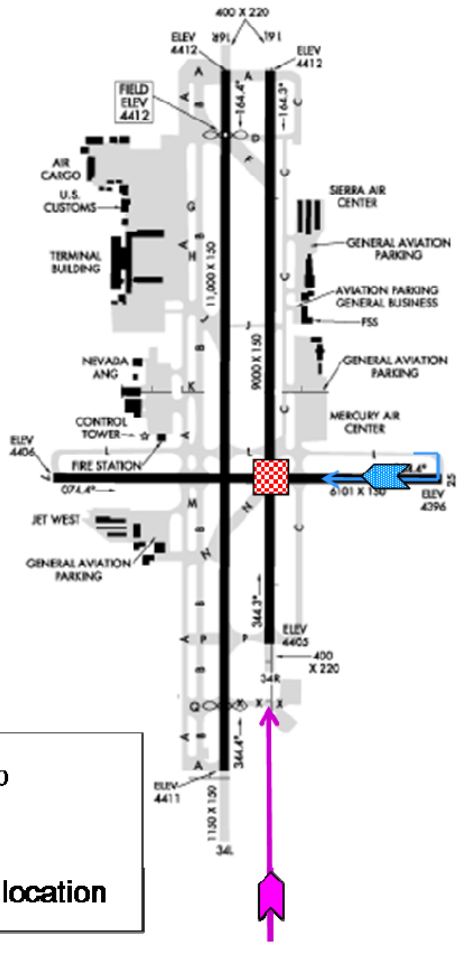

Figure 10. Scenario 3 configuration.

Scenario 4 – departure/departure

This scenario began with ownship taxiing on Taxiway C at 8 kt toward Runway 34R threshold, approximately 500 ft from the threshold. The EP was cleared to taxi to Runway 34R via Taxiway C and hold short of Runway 34R. Another aircraft was taxiing on Taxiway L near the Runway 25 hold line at the threshold. The other aircraft was cleared into position for departure on Runway 25. The ownship EP was then cleared for takeoff on Runway 34R.

Scenario 4 tested the incursion situation where an aircraft was departing even though another aircraft was departing on an intersection runway (Figure 11). The traffic for this scenario, instead of holding in position, began its takeoff on Runway 25 without clearance as the ownship began its takeoff (i.e., on runway heading and traveling greater than 10 kt ground speed).

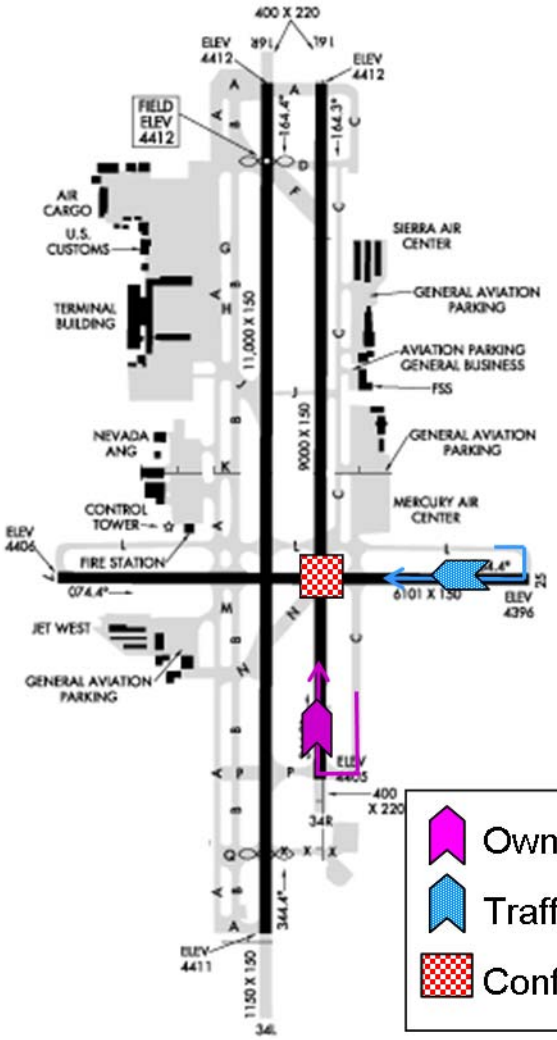

Figure 11. Scenario 4 configuration.

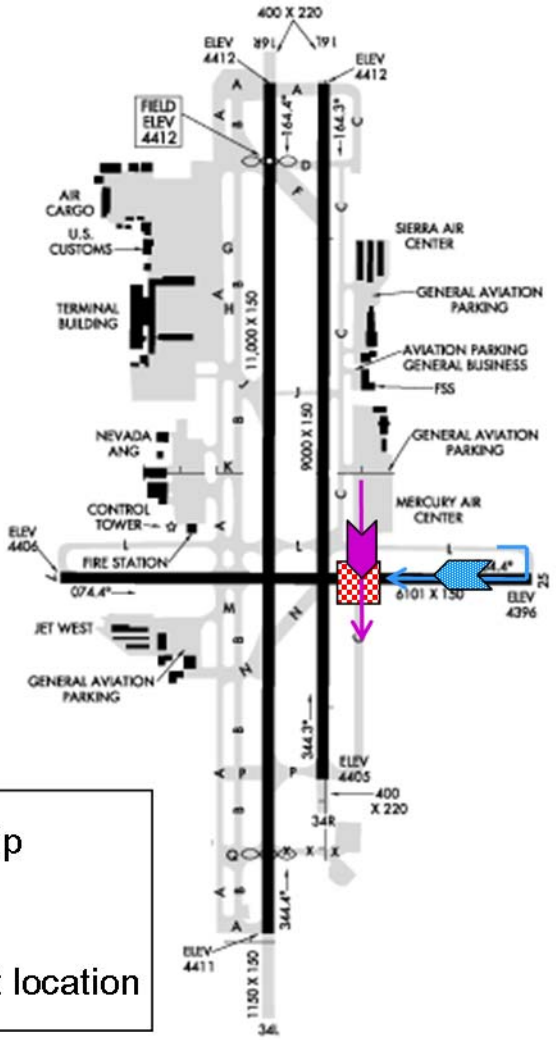

Figure 12. Scenario 5 configuration.

Scenario 5 – taxi crossing/departure

This scenario began with ownship parked on the ramp at the Mercury Air Center (Fixed-Base Operator (FBO)) facing Taxiway L. Another aircraft was stopped on Taxiway L behind the Runway 25 hold line at the runway threshold. The EP was cleared to taxi to Runway 34R via Taxiway C, cleared to

cross Runway 25, and hold short of Runway 34R. The other aircraft was cleared into position for departure on Runway 25 while the ownship taxied out of the ramp.

Scenario 5 tested the incursion situation where an aircraft taxis across a runway even though another aircraft is taking-off from the same runway (Figure 12). The traffic for this scenario, instead of holding in position, began its takeoff on Runway 25 without clearance as the ownship crossed the centerline of Taxiway L.

Procedure

Prior to the rare event testing phase, each EP participated in a briefing and training session. The training did not reveal the focus of the experiment (runway incursion prevention).

The EP received training on the incursion alerting system prior to the rare event testing *only if* the display condition evaluated included alerting. The EP was trained to abort if a warning alert was given during departure, go-around if a warning alert was given on approach, and stop if a warning alert was given during taxi. The EP was not required to take evasive action when a caution alert was issued.

Before each trial, the EP was briefed on the run conditions, e.g. approach or departure, visibility, and displays available. The case order list is shown in Appendix C.

For the usability study phase, the EP received training on the incursion alerting system prior to data collection. Before each trial, the EP was briefed on the run conditions, e.g. approach or departure, visibility, alerting system selected, and displays available. The EP was asked to continue the maneuver until a warning alert was received for evaluation purposes. The case order list is shown in Appendix D.

The test runs were documented via audio, video, and digital data recordings, and post-run, post-block, and post-test questionnaires (Appendices E through J).

Evaluation Pilots

Sixteen GA pilots served as EPs. The EPs were selected to create four cross-sections of flying experience representative of the Part 91 pilot population: low-time (≤400 hours) visual flight rules (VFR), high-time (>400 hours) VFR, low-time (≤1000 hours) instrument-rated, and high-time (>1000 hours) instrument-rated (see Table 3).

Table 3. EP Experience

Low Time VFR (≤ 400 Hours)		High Time VFR (> 400 Hours)		Low Time Instrument-Rated (≤ 1000 Hours)		High Time Instrument-Rated (> 1000 Hours)	
EP	Flight Hours	EP	Flight Hours	EP	Flight Hours	EP	Flight Hours
1	80	5	415	9	590	13	4170
2	300	6	765	10	393	14	15000
3	175	7	450	11	1000	15	5365
4	160	8	401	12	510	16	3500
Mean	*178.8*	*Mean*	*507.8*	*Mean*	*623.3*	*Mean*	*7008.8*
St. Dev.	*91.0*	*St. Dev.*	*172.7*	*St. Dev.*	*263.9*	*St. Dev.*	*5383.1*

Results

A summary of quantitative and qualitative results is presented for the rare event testing and usability study phases. All data are referenced from the center of gravity of the aircraft. All statistically significant results are presented at the $p < 0.05$ level unless stated otherwise.

Rare Event Testing Phase

Each EP flew 18 various approach tasks before being presented with the runway incursion event (Scenario 1).

The FAA runway incursion severity rating (FAA, 2007), described below, was used to categorize the runway incursion incident results. The data were independently evaluated by a subject matter expert for classification.

Category A – Separation decreases, extreme action taken to narrowly avoid collision, or collision occurs;
Category B – Separation decreases, significant potential for collision;
Category C – Separation decreases, ample time and distance to avoid collision;
Category D – Little or no chance of collision but meets definition of runway incursion.

Fourteen of the 16 runway incursions resulted in the less hazardous Category C and D incursions, one resulted in a Category A incursion, and one resulted in a Category B incursion. (All trials generated at least a Category D rating because the scenario was designed to elicit a runway incursion situation.)

The 14 less hazardous Category C and D incursions were mitigated by the EPs by conducting a go-around and gaining separation from the traffic.

The Category A runway incursion occurred with the EP flying the BMOT display concept. Despite the traffic indications on the surface map and out-the-window visuals, the EP demonstrated no awareness of the runway traffic and over-flew the traffic and landed.

The Category B incident occurred when the EP over-flew the runway traffic (at 146 ft AGL) before conducting a go-around. The EP was aware of the incursion after having received an audible alert (BAMO display concept) but continued to descend to visually acquire the traffic to confirm the alert. This incident would have been classified as a Category D incursion if the EP had initiated the go-around at first awareness of the alert. Post-experimental briefings confirmed that the pilot was aware of the traffic but, because of the information provided by the display concept, felt safe proceeding lower in altitude to visually confirm the hazard.

No statistically significant differences were found between the display conditions for both the distance from ownship to the incurring traffic or for the difference in time (i.e.reaction time) from the incursion event to when a go around was initiated by the pilots, based on a Multivariate Analysis of Variance (MANOVA) ($p > 0.05$); therefore, separate ANOVAs were not conducted on these dependent variables.

Table 4. Algorithm Performance for Rare Event Scenario.

	Distance to Traffic		*Time to Traffic*	
	Mean (ft)	Std. Dev. (ft)	Mean (sec)	Std. Dev. (sec.)
PathProx™ Caution	5836	348.5	35	2.0
PathProx™ Warning	4234	268.0	25	2.0
RSM Warning	4060	135.7	24	2.6

Data on both incursion detection algorithms were collected during the incursion events; however, only the alerts generated by the RSM algorithm were displayed to the EP, when the display condition included alerting. The alerting algorithm performance for the rare event incursion scenarios trials are presented in Table 4. Data from two EPs were omitted as outliers from these means because the pilots were initially heading to the wrong runway and turned toward Runway 34R within 1.1 nm. Even though alerts were generated the results were skewed. The "Time to Traffic" in Table 4 is estimated based on the relative distance from the traffic and the relative ground speed of the ownship at the time of the alert. A MANOVA showed a significant effect between the incursion detection algorithms tested ($F(4,42) = 190.163$). Subsequent Analysis of Variances (ANOVAs) on the dependent variables revealed that the PathProx™ Caution alert was generated significantly earlier ($F(2,42) = 6.839$) and at a greater distance from the incursion aircraft ($F(2,42) = 7.302$) than either the PathProx™ Warning alert or the RSM Warning alert. There were no significant differences between the PathProx™ Warning alert and RSM Warning alert.

Of the 16 trials,

- 8 EPs initially became aware of the incursion traffic by viewing out the window, before the alert would have occurred;
- 5 visually acquired the traffic out the window after an incursion alert would have occurred if it were active;
- 1 saw the traffic on the surface map well before the alert occurred; and
- 2 EPs did not see the traffic at all (i.e., the Category A and B incursions described above).

The number of EP's for each initial traffic awareness location, categorized by display condition, are shown in Table 5.

Table 5. Initial Traffic Awareness Location during Rare Event Scenarios (16 pilots).

Display Condition	*Out the Window, Before Alert Threshold*	*Out the Window, After Alert Threshold*	*Surface Map, Before Alert Threshold*	*Did Not See Traffic*
BMO	1	3	0	0
BMOT	2	1	0	1
BAMO	3	0	0	1
BAMOT	2	1	1	0
Total	8	5	1	2

As shown in Table 6, the EP's initial awareness of the traffic was not affected by display concept (i.e., differences were not statistically significant at the $\alpha = 0.05$ level); however, the data indicates a trend ($p = 0.09$) where the incursion traffic was acquired sooner when the EP was provided with traffic on the surface map and/or incursion alerts. The data for the two EPs that did not acquire the traffic (BMOT and BAMO display conditions) and the two EPs that headed to the incorrect runway (BMO and BAMOT display conditions) were omitted from Table 6.

Table 6. Initial Traffic Awareness Measurements during Rare Event Scenarios (12 pilots).

	Distance to Traffic		*Time to Traffic*	
Display Condition	Mean (ft)	Std. Dev. (ft)	Mean (sec)	Std. Dev. (sec.)
BMO	3927	575.6	24	1.7
BMOT	4910	1171.3	29	7.6
BAMO	5261	622.3	28	7.1
BAMOT	4745	1598.1	28	9.5

For those displays that had alerting (BAMO, BAMOT), there were no significant differences in qualitative measures of timeliness of the alerting in terms of being able to take evasive action. However, when pilots were asked to rate all four display concepts on the perceived efficacy of the alerts ($F(3,16) = 10.948$) and the additional safety value added ($F(3,16) = 8.814$), an ANOVA revealed a significant effect between the displays ($p < 0.05$). Subsequent post-hoc Student Newman Kuels tests showed that pilots reported that the BMO display condition was significantly lower in perceived efficacy and safety value added than the other three display conditions. Comparisons between the remaining three display conditions did not yield any significant statistical differences in qualitative ratings for these dependent variables

Usability Study Phase

All test trials conducted during the usability study phase included incursion events. Although the EPs were aware that each trial would contain an incursion event, they were not told the type of incursion before the initial trial for each scenario. During each test trial, data were simultaneously collected on the performance of both incursion detection algorithms; however, only one method, when dictated by the experimental configuration, was chosen for flight deck alerting.

The EPs evaluated each incursion scenario with the seven display conditions to determine the effectiveness of the display for runway incursion prevention. The initial trial evaluated the baseline (B) display condition. This was done to determine if the EP would visually acquire the incursion traffic out the window since the surface map and alerting were not available. The RSM algorithm was used as the alert source for display in these trials. The EPs then evaluated both the RSM and PathProx™ incursion detection algorithms using the five incursion scenarios and the BRIPS display condition.

During the course of usability data collection, it became apparent that the BMO and BAMO display conditions provided nearly identical traffic awareness for the EPs as the B (no alerts) and BA (audible alerts only) display conditions, respectively; therefore, a limited number of BMO and BAMO test trials were conducted in the interest of time.

Quantitative Results

The alerting algorithm performance is summarized in Table 7. A total of 602 test trials were completed. Data were not analyzed for 14 trials due to missing data files and one test trial was omitted due to unorthodox maneuvering by the EP, yielding a total of 587 trials.

Alerts were required for display on 415 test trials. During these 415 trials, the RSM was the alert source 81 percent of the time (336 trials).

RSM generated alerts on 524 of the 587 total trials. RSM did not alert on 60 trials due to the maneuver taken by the EP. For example, the EP may have acquired the traffic out the window and conducted a go-around before the alerting criteria were met. RSM did not alert on three trials due to the scenario timing (the EP maneuvered such that no incursion event occurred).

Of the possible 587 test trials, PathProx™ generated warning alerts on 345 trials. The 242 trials in which PathProx™ did not alert were generally due to the maneuvering performed by the EP. For instance, when RSM alerting was provided, the pilot executed an avoidance maneuver and this generally occurred before the PathProx™ alerts were generated. Caution alerts were only possible on 232 trials (scenarios 1 and 5) and of these, alerts were generated on 154 trials. Detailed PathProx™ analysis was not possible because specific alerting criteria are proprietary.

Table 7. Summary of Alerts Generated.

Scenario	Number of Trials	RSM		PathProx Caution		PathProx Warning		Missing File
		Alerts	No Alert	Alerts	No Alert	Alerts	No Alert	
1	117	97	20	116	1	98	19	4
2	117	113	4	N/A	N/A	84	33	5
3	121	116	5	N/A	N/A	61	60	1
4	117	109	8	N/A	N/A	64	53	2
5	115	89	26	38	77	38	77	3
Total	587	524	63	154	78	345	242	15

Scenario 1 arrival/takeoff hold results – For the Baseline display (B) condition, all 16 EPs acquired the incursion traffic out the window for Scenario 1 when approximately 1 nm from the runway threshold. As a result, the average go-around initiation point was 443 ft AGL and 5240 ft (approximately 28 seconds) from the traffic. During the Baseline condition cases, data were still being collected on the conflict detection algorithms. On average, the EP initiated a go-around after the PathProx™ caution alert would have occurred (475 ft AGL and 5641 ft – approximately 34 seconds – from the traffic for the baseline condition), but before either the RSM (409 ft AGL and 4272 ft – approximately 24 seconds – from the traffic for the baseline condition) or PathProx™ warning alert (392 ft AGL and 4117 ft - approximately 24 seconds – from the traffic for the baseline condition) would have occurred.

Algorithm performance analyses for all Scenario 1 test trials are shown in Table 8. The PathProx™ caution alert was generated much earlier than the warning alerts. Both the RSM and PathProx™ warning alerts were generated at essentially the same moment. It should be noted that during the test trials in which alerts were provided, the EP was asked to continue the maneuver until the alert was received for evaluation purposes.

Table 8. Algorithm Performance for Scenario 1.

	AGL		*Distance to Traffic*		*Time to Traffic*	
	Mean (ft)	Std. Dev.(ft)	Mean (ft)	Std. Dev. (ft)	Mean (sec)	Std. Dev. (sec)
PathProx™ Caution	613	98.0	5757	325.7	36	1.2
PathProx™ Warning	496	88.7	4175	278.7	25	1.0
RSM Warning	492	92.6	4115	114.7	25	2.1

Scenario 2 departure/intersection departure results - Six of 16 EPs (37.5 percent) did not acquire the incursion traffic visually for Scenario 2, or saw the traffic too late to abort the departure and actually over-flew the runway traffic when using the Baseline (B) display condition.

Data on the abort initiation location (identified when the throttles and\or ground speed were reduced) are shown in Table 9. The EPs aborted at a further distance from Taxiway L when provided with those display configurations having alerting (BA, BAMO, BAMOT, and BRIPS). The EPs also aborted the departure for all of the trials with alerting provided. Based on measured data, the departure was aborted later when alerting was not provided (B, BMO, and BMOT), although still with enough time to stop prior to reaching the traffic. Also, as noted above, the EP actually took off on six trials and over-flew the traffic, using the Baseline display.

For this departure scenario, the RSM warning alert was generated before and at a lower ground speed than the PathProx™ warning alert (Table 10); however, both provided ample time to abort and stop before reaching the incurring traffic. PathProx™ caution alerts are not generated on departure.

Table 9. Abort Initiation during Scenario 2 for Display Conditions.

	Nunber of Abort Occurrences	*Distance to Taxiway L*		*Time to Taxiway L*	
		Mean (ft)	Std. Dev. (ft)	Mean (sec)	Std. Dev. (sec.)
B	8	2177	485.6	18	1.9
BMO	3	2004	595.3	15	5.7
BMOT	12	1849	408.6	13	3.4
BA	14	2493	108.1	19	1.1
BAMO	5	2530	56.5	19	1.1
BAMOT	15	2498	160.0	19	1.3
BRIPS	16	2542	86.0	19	0.9

Table 10. Algorithm Performance for Scenario 2.

	Ground Speed		*Distance from Twy L*		*Time from Twy L*	
	Mean (kt)	Std. Dev. (kt)	Mean (ft)	Std. Dev. (ft)	Mean (sec)	Std. Dev. (sec)
PathProx™ Warning	41	4.4	2452	75.2	19	1.5
RSM Warning	28	4.7	2637	102.9	21	1.4

Scenario 3 arrival/departure results – For the Baseline (B) condition, 13 of 16 EPs (81 percent) did not acquire the incursion traffic visually for Scenario 3. Due to the scenario design; however, 14 EPs landed and stopped before reaching the crossing runway. One EP landed but taxied through the intersection as the traffic was departing from crossing Runway 25. One EP conducted a go-around.

The algorithm performance for Scenario 3 is presented in Table 11. On average, the RSM Warning alert was generated slightly before the PathProx™ Warning alert. Both algorithms alerted at or slightly before touchdown. PathProx™ Caution alerts were not generated for this scenario.

For all Scenario 3 trials (122 total), a go-around was conducted just before touchdown (7 ft AGL) on 11 percent (14) of the trials.

Table 11. Algorithm Performance for Scenario 3.

	Distance to Runway 34R/25 Intersection		*Time to Runway 34R/25 Intersection*	
	Mean (ft)	Std. Dev. (ft)	Mean (sec)	Std. Dev. (sec)
PathProx™ Warning	1190	306.4	9	2.8
RSM Warning	1301	944.2	11	1.4

Scenario 4 departure/departure results – Five of 16 EPs (31.3 percent) saw the incursion traffic visually and aborted the departure when using the Baseline (B) display condition. Nine of 16 EPs (62.5 percent) did not see the incursion traffic visually, or saw the traffic too late to abort the departure. For these trials, the ownship came within an average distance of 458 ft (range from 179 ft to 795 ft) from the incursion traffic. Two of the trials resulted in no incursion event due to the scenario timing; therefore, these data are not included in the analysis.

Generally, when alerts were provided (BA, BAMO, BAMOT, and BRIPS), the EPs were aware of the traffic conflict and initiated aborts earlier than without the alerts as shown in Table 12. For trials in which

the EP visually acquired traffic - either out-the-window or using a map with traffic display - the departure was still aborted with enough time to stop before the crossing runway.

The RSM warning alerts were generated before the PathProx™ warning alerts for this departure scenario. When RSM alerts were presented, the EP typically reacted based on those alerts; therefore, PathProx™ alerts were sometimes not generated or generated after initiation of the abort maneuver. For an accurate assessment of PathProx™ performance, only the results from the trials in which the PathProx™ alerts were shown to the EP are presented (Table 13). Again, the RSM warning alert was generated before and at a lower ground speed than the PathProx™ warning alert; however, both still provided ample time to abort and stop before reaching the incurring traffic. PathProx™ caution alerts are not generated on departure.

Table 12 . Abort Initiation during Scenario 4 for Display Conditions.

	Distance to Runway 25		*Time to Runway 25*	
	Mean (ft)	Std. Dev. (ft)	Mean (sec)	Std. Dev. (sec.)
B	1194	799.7	9	6.2
BMO	1928	293.4	15	2.7
BMOT	1743	531.6	13	4.6
BA	2091	65.8	17	0.6
BAMO	2056	151.6	16	2.1
BAMOT	2107	69.4	17	0.9
BRIPS	2096	79.6	17	1.2

Table 13. Algorithm Performance for Scenario 4.

	Ground Speed		*Distance from Rwy 25*		*Time from Rwy 25*	
	Mean (kt)	Std. Dev. (kt)	Mean (ft)	Std. Dev. (ft)	Mean (sec)	Std. Dev. (sec)
PathProx™ Warning	48	8.5	1891	115.2	15	1.8
RSM Warning	29	4.8	2216	35.3	18	0.9

Scenario 5 taxi crossing/departure results - Fourteen of 16 EPs (87.5 percent) acquired the incursion traffic out the window when using the Baseline (B) condition and stopped before reaching Runway 25. One EP did not see the traffic and actually crossed Runway 25 in front of the departing traffic. One EP saw the departing traffic out the window but chose to cross Runway 25 anyway.

The RSM algorithm uses predictive alerting, triggered on the aircraft ground speed, in an attempt to keep the aircraft clear of a runway, behind the hold line. If the ownship is traveling 8 kt or greater and is not slowing down, the alert will be generated before the aircraft reaches the hold line, providing sufficient distance to stop before crossing the hold line. As the taxi speed increases, the alert is generated when the ownship is a farther distance from the hold line. However, the alert is not generated until after the ownship crosses the hold line when the ownship is traveling less than 8 kt. The 8 kt threshold was used to minimize false or nuisance alerts as the ownship taxis toward a hold line. Details on the PathProx™ implementation are proprietary.

The effect of predictive alerting with the RSM alert using an 8 kt ground speed trigger is shown in Table 14. If the ground speed was above 8 kt approaching the hold line, the RSM alert was generated before reaching the hold line (positive value). A negative value indicates the aircraft crossed over the hold line before the alert was generated. Note that the hold line was 170 ft from the edge of the runway

for this scenario so in all cases the alert was still generated well before the aircraft entered the runway. The proactive RSM alerting trigger speed may need to be reassessed to keep a higher percentage of taxi blunders from crossing hold lines. These data indicate that almost 40% of the time ownship crossed the hold line (i.e., technically, a runway incursion).

As with Scenario 4, the RSM alerts were generated before the PathProx™ alerts. Therefore, for an accurate assessment of PathProx™, only the results from trials in which the PathProx™ alerts were given to the EP are presented (Table 15). The data shows that PathProx does not use predictive alerting. All warning and cautions occurred after the ownship crossed the hold line, but were still triggered 153 and 130 ft, respectively, prior to the runway. Assuming a reasonable taxi speed, ownship should have been able to react and stop prior to the runway.

Table 14. Scenario 5 RSM Alert Generation

EP	Ground Speed (kt)	Distance to hold line (feet)
1	9.7	59
2	9.7	48
3	9.2	59
4	7.9	-12
5	7.0	-6
6	8.4	56
7	6.0	-7
8	13.4	17
9	10.3	70
10	8.4	48
11	8.3	48
12	7.5	-17
13	7.4	-14
15	6.5	-7
16	10.6	8

Table 15. Algorithm Performance for Scenario 5.

	Distance Before/Past Hold Line		*Distance from Runway 25 Edge*	
	Mean (ft)	Std. Dev. (ft)	Mean (ft)	Std. Dev. (ft)
PathProx™ Caution	17 past	3.8	153	3.8
PathProx™ Warning	41 past	19.5	130	19.5
RSM Warning	23 before	32.6	193	32.6

Qualitative Results

Post-run (Appendices E and F), post-block (Appendices G and H), and post-test (Appendices I and J) questionnaires were administered. These data are discussed in the following. Ratings for most of the questions were generally based on a scale of 1 (low) to 10 (high). The result values shown in this section are the mean values based on the 1 to 10 scale, unless stated otherwise.

Moving Map Display – Statistical analyses were not conducted on the qualitative data on pilot ratings of the moving map display because of limited power, due to the low number of observations, for the non-parametric test; therefore, descriptive data are reported below. When the EPs rated the effectiveness of the perspective surface map relative to the plan view map for prevention of runway incursions, the perspective map was rated slightly more effective (2.88 on a 10-point scale). However, the location of the surface map was deemed suboptimal and should be positioned closer to the pilot's head-up field of view. The traffic presentation on the surface map was considered easily discernable (8.38). Most EPs (14 of 16) considered traffic presentation necessary to prevent runway incursions. The addition of traffic was rated to provide increased (8.56) SA over a surface map with only ownship location. Over half of the EPs (10 of 16) indicated visual presentation of alerts on the surface map was necessary to prevent runway incursions. The addition of visual alerts was rated to provide increased (6.27) SA. The EPs considered the terms used for the incursion alerts (e.g. "Warning, Traffic Departing 25") to be very effective (8.88).

For display conditions with alerting available, the EPs indicated that the incursion event would most likely be brought to their attention first through audible alerting, then on the surface map, and lastly out the window. Nine of 16 EPs indicated that an audible alert alone would be the minimum necessary for an effective incursion prevention display, while five of 16 indicated a surface map with ownship and traffic but without alerting would be the minimum to be effective. However, all 16 EPs indicated a surface map with ownship and traffic in conjunction with an audible alert would be an optimal incursion prevention display. According to averaged EP ratings, for all alerting display conditions, the caution and warning alerting system was perceived to provide the greatest amount of runway incursion awareness (see Table 16). Based on the descriptive results, there was no consistency across the EPs in terms of alerting preference for incursion awareness and perceived SA improvement. For each of the four display conditions (BA, BAMO, BAMOT, BRIPS), the majority of EPs rated the "caution and warning" alerting higher for incursion awareness. However, for each display condition, at least 6 of 16 EPs rated the "warning only" alerting as preferable for incursion awareness and, for these EPs, the average SA rating was 6.5 to 7.7 in perceived SA improvement.

Table 16. Alerting Preference for Incursion Awareness and Perceived SA Improvement

Alerting Type	*Warning Only*		*Caution & Warning*	
	Number of EPs	SA Rating	Number of EPs	SA Rating
BA	6	6.5	10	4.2
BAMO	6	6.7	10	4.3
BAMOT	7	7.7	9	5
BRIPS	7	7.6	9	5.2

Note: "Number of EPs" column represents the number of EPs that indicated preference for alerting condition. "SA Rating" column represents the amount of SA improvement (0 – 10 scale) for the alerting condition indicated by that EP.

Algorithm Alerting - All EPs indicated that both the RSM and PathProx™ alerting provided sufficient time to avoid a potential conflict. Only six of 16 EPs (37.5 percent) thought providing both

caution and warning alerts was more effective in preventing runway incidents than a single warning alert. However, nine of 16 EPs indicated that the caution and warning system provided greater (4.39) SA and provided more reaction time. Eleven of 16 EPs (68.8 percent) liked the idea of having a caution alert in conjunction with a warning to provide more evaluation and reaction time, i.e. a greater comfort level. For the scenarios evaluated, the EPs generally felt that providing caution and warning alerts on approach was most effective, while a warning alert alone was sufficient when on the airport surface (during departure and taxi).

The EPs were asked if resolutions or maneuver guidance should be provided in addition to runway incursion alerts for various operations. The majority of EPs would like to be provided with maneuver guidance for conflict resolution on final approach (12 of 16) and when taxiing across a runway (nine of 16). Half of the EPs would like maneuver guidance on departure.

Surface Operations Safety - In general, the EPs felt safer during runway incursion encounters when alerting was provided (B=2.06, BMO=2.75, BMOT= 5.38, BA=7.19, BAMO=7.44, BAMOT=9.31, and BRIPS=9.19). Analysis of pilot responses to their perceived safety and runway incursion prevention effectiveness support this conclusion with significant main effects found (i.e., for perceived safety ($F(6,90) = 857.390$) and runway incursion prevention effectiveness ($F(6, 90) = 188.793$)). The addition of traffic was marginally beneficial when presented on a moving map display and was only effective when alerting was provided. A possible cause may be that pilots ARE out-the-window and CANNOT BE focused on a head-down display during this critical phase of flight, especially in VMC flight conditions. When alerted, the pilot is provided a cue that it might be beneficial for them to direct focus and attention to the head-down display to locate the incurring traffic. In fact, pilots rated having audible alerts (BA) and having alerts with a map with ownship but no traffic (BAMO) similarly for runway incursion prevention on almost all dependent variables measured. For the experimental scenarios tested, the moving map display appeared beneficial in preventing incursions only when both traffic AND alerting were included. Ideally, a system should have the ability to alert the pilot to incurring events and cue them where to look without having to go head-down, into the cockpit. Head-up and head-worn displays provide this type of capability but are to date, not generally installed in low-end GA aircraft.

Conclusions

A Runway Incursion Prevention System (RIPS), developed for commercial transport flight decks and adapted for general aviation operations, was evaluated in a piloted simulation study. The purpose of the study was to evaluate the aircraft-based incursion detection algorithms and associated alerting and airport surface display concepts for general aviation operations using a rare event study followed by a usability study.

The results indicate that, during the rare event testing, for the scenario evaluated, most pilots were able to acquire the incurring traffic by looking out the cockpit windows (in VMC conditions), even before incursion alerting was activated. In the usability study, for some scenarios, pilots were generally unable to detect the incurring traffic out-the-window. This emphasized the importance of providing alerts of potential runway conflicts to the pilot.

The surface map showing ownship (without other traffic) was rated as being significantly inferior to a surface map showing traffic and/or incursion alerting for perceived safety value added. However, one pilot experienced a severe runway incursion and risk for collision despite having traffic displayed on a surface map. The addition of traffic was marginally beneficial when presented on a surface map display and was only effective when alerting was provided. A possible cause may be that pilots had transitioned heads-up out the window and were not focused on the head-down display to locate the incurring traffic. Pilots reported that the utility of the surface map would be significantly more effective if located higher on the instrument panel closer to the pilot's head-up field of view.

The results generally match past research on commercial operations in that the incursion alerts provided sufficient time to avoid a potential incursion conflict. Departures were generally aborted sooner

when alerts were provided, resulting in greater safety margins. A surface map showing ownship and traffic along with audible alerts was considered an optimal incursion prevention display, while an audible alert alone was considered a minimally effective display. Over half of the pilots would like maneuver guidance for conflict resolution in conjunction with incursion alerting. In general, the pilots felt substantially safer during potential runway incursion incidents with alerting onboard.

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Appendix A: Rare Event Test Matrix

Evaluation Pilot EPn (n=1 to 16)

RIPS Scenario Scenario 1 – arrival / takeoff hold (see Figure 8)

Meteorological VMC1 = 3 nm, day, 1000 ft ceiling
VMC2 = 3 nm, day, 2000 ft ceiling
IMC1 = 1 nm, day, 1000 ft ceiling
IMC2 = 1 nm, day, 400 ft ceiling
IMC3 = 2 nm, day, 1000 ft ceiling

Altitude (ft)	*4412 (0 AGL)*	*4420 (8 AGL)*	*5420 (1008 AGL)*	*7100+ (2688 AGL)*
Wind Speed (kt)	10	10	20	30
Wind Direction (deg)	260	260	260	360

Note: gradual shift of wind speed and direction

Display Concept BMO = Baseline + surface map and ownship
BMOT = Baseline + surface map and ownship and traffic
BAMO = BMO + audible incursion alerts
BAMOT = BMOT + incursion alerts (audible & visual)

Note: IC = Initial Condition

Approach S34RL = Straight-in approach to 34R and land. IC is 3nm out, 1010 ft AGL, 90 kt
S34RW = Straight-in approach to 34R then waveoff at 200 ft AGL. IC is 3 nm out, 1010 ft AGL, 90 kt
S34LSS= Straight-in approach, lined up with 34L, sidestep to 34R and land. IC is 3nm out, 1010 ft AGL, 90 kt
S25L = Straight-in approach to 25 and land. IC is 3 nm out, 1800 ft AGL
C-long = Non-precision approach – initial approach to 34R from base leg ending in Circling approach to 25 and land. IC is 9.56 nm out from 34R on left base (85 degree heading & 1.6 nm left offset), 2737.5 ft AGL
S-long = ILS approach – approach to 34R from base leg, follow approach path and go around at 200 ft. IC is 9.56 nm from 34R on left base (85 degree heading & 1.6 nm left offset), 2737.5 ft AGL

Rare Event Test Matrix

EP	*Case No.*	*RIPS Scenario*	*Meteoro-logical*	*Alert Source*	*Display Concept*	*Approach*
1,5,9,13	1	None	VMC1	N/A	BMO	S34RL
	2	Scenario 1	VMC1	N/A	BMO	S34RL
	3	None	IMC2	N/A	BMO	S34RL
	4	None	IMC2	N/A	BMO	S34RL
	5	None	VMC1	N/A	BMO	S34RW
	6	None	VMC1	N/A	BMO	S34RW
	7	None	IMC2	N/A	BMO	S34RW
	8	None	IMC2	N/A	BMO	S34RW
	9	None	VMC1	N/A	BMO	S34LSS
	10	None	VMC1	N/A	BMO	S34LSS
	11	None	VMC1	N/A	BMO	S34LSS
	12	None	VMC1	N/A	BMO	S34LSS
	13	None	VMC2	N/A	BMO	S25L
	14	None	VMC2	N/A	BMO	S25L
	15	None	VMC2	N/A	BMO	S25L
	16	None	VMC2	N/A	BMO	S25L
	17	None	IMC3	N/A	BMO	C-long
	18	None	IMC3	N/A	BMO	C-long
	19	None	IMC2	N/A	BMO	S-long
2,6,10,14	20	None	VMC1	N/A	BMOT	S34RL
	21	Scenario 1	VMC1	N/A	BMOT	S34RL
	22	None	IMC2	N/A	BMOT	S34RL
	23	None	IMC2	N/A	BMOT	S34RL
	24	None	VMC1	N/A	BMOT	S34RW
	25	None	VMC1	N/A	BMOT	S34RW
	26	None	IMC2	N/A	BMOT	S34RW
	27	None	IMC2	N/A	BMOT	S34RW
	28	None	VMC1	N/A	BMOT	S34LSS
	29	None	VMC1	N/A	BMOT	S34LSS
	30	None	VMC1	N/A	BMOT	S34LSS
	31	None	VMC1	N/A	BMOT	S34LSS
	32	None	VMC2	N/A	BMOT	S25L
	33	None	VMC2	N/A	BMOT	S25L
	34	None	VMC2	N/A	BMOT	S25L
	35	None	VMC2	N/A	BMOT	S25L
	36	None	IMC3	N/A	BMOT	C-long
	37	None	IMC3	N/A	BMOT	C-long

	38	None	IMC2	N/A	BMOT	S-long
3,7,11,15	39	None	VMC1	N/A	BAMO	S34RL
	40	Scenario 1	VMC1	RSM	BAMO	S34RL
	41	None	IMC2	N/A	BAMO	S34RL
	42	None	IMC2	N/A	BAMO	S34RL
	43	None	VMC1	N/A	BAMO	S34RW
	44	None	VMC1	N/A	BAMO	S34RW
	45	None	IMC2	N/A	BAMO	S34RW
	46	None	IMC2	N/A	BAMO	S34RW
	47	None	VMC1	N/A	BAMO	S34LSS
	48	None	VMC1	N/A	BAMO	S34LSS
	49	None	VMC1	N/A	BAMO	S34LSS
	50	None	VMC1	N/A	BAMO	S34LSS
	51	None	VMC2	N/A	BAMO	S25L
	52	None	VMC2	N/A	BAMO	S25L
	53	None	VMC2	N/A	BAMO	S25L
	54	None	VMC2	N/A	BAMO	S25L
	55	None	IMC3	N/A	BAMO	C-long
	56	None	IMC3	N/A	BAMO	C-long
	57	None	IMC2	N/A	BAMO	S-long
4,8,12,16	58	None	VMC1	N/A	BAMOT	S34RL
	59	Scenario 1	VMC1	RSM	BAMOT	S34RL
	60	None	IMC2	N/A	BAMOT	S34RL
	61	None	IMC2	N/A	BAMOT	S34RL
	62	None	VMC1	N/A	BAMOT	S34RW
	63	None	VMC1	N/A	BAMOT	S34RW
	64	None	IMC2	N/A	BAMOT	S34RW
	65	None	IMC2	N/A	BAMOT	S34RW
	66	None	VMC1	N/A	BAMOT	S34LSS
	67	None	VMC1	N/A	BAMOT	S34LSS
	68	None	VMC1	N/A	BAMOT	S34LSS
	69	None	VMC1	N/A	BAMOT	S34LSS
	70	None	VMC2	N/A	BAMOT	S25L
	71	None	VMC2	N/A	BAMOT	S25L
	72	None	VMC2	N/A	BAMOT	S25L
	73	None	VMC2	N/A	BAMOT	S25L
	74	None	IMC3	N/A	BAMOT	C-long
	75	None	IMC3	N/A	BAMOT	C-long
	76	None	IMC2	N/A	BAMOT	S-long

Appendix B: Usability Study Test Matrix

RIPS Scenario
1 = Arrival / takeoff hold
2 = Departure / intersection departure
3 = Arrival / departure
4 = Departure / departure
5 = Taxi crossing / departure

Display Concept
B = Baseline round dials
BMO = B + surface map and ownship
BMOT = B + surface map and ownship and traffic
BA = B + audible incursion alerts
BAMO = BMO + audible incursion alerts
BAMOT = BMOT + incursion alerts (audible & visual)
BRIPS = B + perspective surface map

All runs conducted under VMC1 (3nm, day, 1000 ft ceiling, no wind)

Table B.1: Display Concept Evaluation for Runway Incursion Prevention

Case No.	RIPS Scenario	Alert Source	Display Concept
77	1	N/A	B
78	1	N/A	BMO
79	1	N/A	BMOT
80	1	RSM	BA
81	1	RSM	BAMO
82	1	RSM	BAMOT
83	1	RSM	BRIPS
84	2	N/A	B
85	2	N/A	BMO
86	2	N/A	BMOT
87	2	RSM	BA
88	2	RSM	BAMO
89	2	RSM	BAMOT
90	2	RSM	BRIPS
91	3	N/A	B
92	3	N/A	BMO
93	3	N/A	BMOT
94	3	RSM	BA
95	3	RSM	BAMO
96	3	RSM	BAMOT
97	3	RSM	BRIPS
98	4	N/A	B
99	4	N/A	BMO

100	4	N/A	BMOT
101	4	RSM	BA
102	4	RSM	BAMO
103	4	RSM	BAMOT
104	4	RSM	BRIPS
105	5	N/A	B
106	5	N/A	BMO
107	5	N/A	BMOT
108	5	RSM	BA
109	5	RSM	BAMO
110	5	RSM	BAMOT
111	5	RSM	BRIPS

Table B.2: RSM and PathProx™ Incursion Detection Algorithm Evaluation

Case No.	RIPS Scenario	Alert Source	Display Concept
148	1	RSM	BRIPS
150	1	PathProx™	BRIPS
152	2	RSM	BRIPS
154	2	PathProx™	BRIPS
156	3	RSM	BRIPS
158	3	PathProx™	BRIPS
160	4	RSM	BRIPS
162	4	PathProx™	BRIPS
164	5	RSM	BRIPS
166	5	PathProx™	BRIPS

Appendix C: Rare Event Case Lists

Tables C.1 and C.2 lists the experimental case order for each evaluation pilot for the rare event portion of the testing. Refer to Appendix A for a detailed description of each case.

Table C.1. Rare Event Case Order for Evaluation Pilots 1 through 8

	EP1	EP2	EP3	EP4	EP5	EP6	EP7	EP8
Run 1	17	36	55	74	17	36	55	74
Run 2	16	33	49	65	15	31	49	60
Run 3	10	25	47	62	11	24	51	64
Run 4	6	30	48	61	7	33	44	68
Run 5	11	23	54	73	4	28	48	71
Run 6	13	35	46	71	14	23	41	62
Run 7	7	34	43	64	13	32	50	66
Run 8	8	27	45	69	1	22	39	58
Run 9	12	26	42	67	10	35	47	61
Run 10	15	29	52	60	5	25	45	70
Run 11	19	38	57	76	19	38	57	76
Run 12	3	31	44	66	16	26	46	73
Run 13	1	22	51	70	12	20	54	65
Run 14	9	24	53	72	6	29	43	72
Run 15	14	28	39	68	8	34	52	69
Run 16	4	20	41	58	3	27	42	63
Run 17	5	32	50	63	9	30	53	67
Run 18	18	37	56	75	18	37	56	75
Run 19	2	21	40	59	2	21	40	59

Table C.2. Rare Event Case List for Evaluation Pilots 9 through 16

	EP9	EP10	EP11	EP12	EP13	EP14	EP15	EP16
Run 1	17	36	55	74	17	36	55	74
Run 2	3	28	44	68	12	34	54	67
Run 3	11	32	53	71	8	27	47	60
Run 4	1	35	39	69	3	23	41	63
Run 5	13	23	42	72	1	25	46	64
Run 6	16	31	47	58	14	33	52	70
Run 7	8	33	49	62	5	32	43	68
Run 8	12	30	50	63	4	22	42	69
Run 9	14	29	51	65	6	35	39	61
Run 10	9	34	48	73	13	29	50	65
Run 11	19	38	41	76	19	38	57	76
Run 12	6	20	57	66	15	31	49	58
Run 13	10	26	54	61	7	28	44	71
Run 14	15	24	43	60	9	24	51	73
Run 15	5	27	45	64	16	20	45	66
Run 16	7	22	52	67	10	26	48	62
Run 17	4	25	46	70	11	30	53	72
Run 18	18	37	56	75	18	37	56	75
Run 19	2	21	40	59	2	21	40	59

Appendix D: Usability Study Case Lists

Tables D.1 through D.4 lists the experimental case order for each evaluation pilot for the usability study portion of the testing. Refer to Appendix B for a detailed description of each case. In Tables D1 and D2, the cases shown with 'skip' were not conducted.

Part 1: Display Concept Evaluation

Table D.1. Case List for Display Concept Evaluation for Pilots 1 through 8

EP1	EP2	EP3	EP4	EP5	EP6	EP7	EP8
77	77	84	84	91	91	98	98
78	83	90	85	92	97	104	99
79	82	89	86	93	96	103	100
80	81	88	87	94	95	102	101
81	80	87	88	95	94	101	102
82	79	86	89	96	93	100	103
83	78	85	90	97	92	99	105
84	84	91	91	98	98	105	105
90	85-skip	92-skip	97	104	99-skip	106-skip	111
89	86	93	96	103	100	107	110
88	87	94	95-skip	102	101	108	109-skip
87	88-skip	95-skip	94	101	102-skip	109-skip	108
86	89	96	93	100	103	110	107
85	90	97	92-skip	99-skip	104	111	106-skip
91	91	98	98	105	105	77	77
92	97	104	99-skip	106-skip	111	83	78-skip
93	96	103	100	107	110	82	79
94	95-skip	102-skip	101	108	109-skip	81-skip	80
95	94	101	102-skip	109-skip	108	80	81-skip
96	93	100	103	110	107	79	82
97	92-skip	99-skip	104	111	106-skip	78-skip	83
98	98	105	105	77	77	84	84
104	99-skip	106-skip	111	83	78-skip	85-skip	90
103	100	107	110	82	79	86	89
102	101	108	109-skip	81-skip	80	87	88-skip
101	102-skip	109-skip	108	80	81-skip	88-skip	87
100	103	110	107	79	82	89	86
99	104	111	106-skip	78-skip	83	90	85-skip
105	105	77	77	84	84	91	91
106	111	83	78-skip	85-skip	90	97	92-skip
107	110	82	79	86	89	96	93
108	109-skip	81-skip	80	87	88-skip	95-skip	94
109	108	80	81-skip	88-skip	87	94	95-skip
110	107	79	82	89	86	93	96
111	106-skip	78-skip	83	90	85-skip	92-skip	97

Table D.2. Case List for Display Concept Evaluation for Pilots 9 through 16

EP9	EP10	EP11	EP12	EP13	EP14	EP15	EP16
105	105	77	77	84	84	91	91
106	111	78	83	85	90	92	97
107	110	79	82	86	89	93	96
108	109	80	81	87	88	94	95
109	108	81	80	88	87	95	94
110	107	82	79	89	86	96	93
111	106	83	78	90	85	97	92
77	77	91	91	98	98	105	105
83	78-skip	97	92-skip	104	99-skip	111	106-skip
82	79	96	93	103	100	110	107
81	80	95-skip	94	102-skip	101	109-skip	108
80	81-skip	94	95-skip	101	102-skip	108	109-skip
79	82	93	96	100	103	107	110
78-skip	83	92-skip	97	99-skip	104	106-skip	111
84	84	105	105	77	77	84	84
85-skip	90	106-skip	111	78-skip	83	85-skip	90
86	89	107	110	79	82	86	89
87	88-skip	108	109-skip	80	81-skip	87	88-skip
88-skip	87	109-skip	108	81-skip	80	88-skip	87
89	86	110	107	82	79	89	86
90	85-skip	111	106-skip	83	78-skip	90	85-skip
91	91	84	84	91	91	98	98
97	92-skip	90	85-skip	97	92-skip	104	99-skip
96	93	89	86	96	93	103	100
95-skip	94	88-skip	87	95-skip	94	102-skip	101
94	95-skip	87	88-skip	94	95-skip	101	102-skip
93	96	86	89	93	96	100	103
92-skip	97	85-skip	90	92-skip	97	99-skip	104
99	98	98	98	105	105	77	77
99-skip	104	99-skip	104	106-skip	111	78-skip	83
100	103	100	103	107	110	79	82
101	102-skip	101	102-skip	108	109-skip	80	81-skip
102-skip	101	102-skip	101	109-skip	108	81-skip	80
103	100	103	100	110	107	82	79
104	99-skip	104	99-skip	111	106-skip	83	78-skip

Part 2: Incursion Detection Algorithm Evaluation

Table D.3. Case List for Incursion Detection Algorithm Evaluation for Pilots 1 through 8

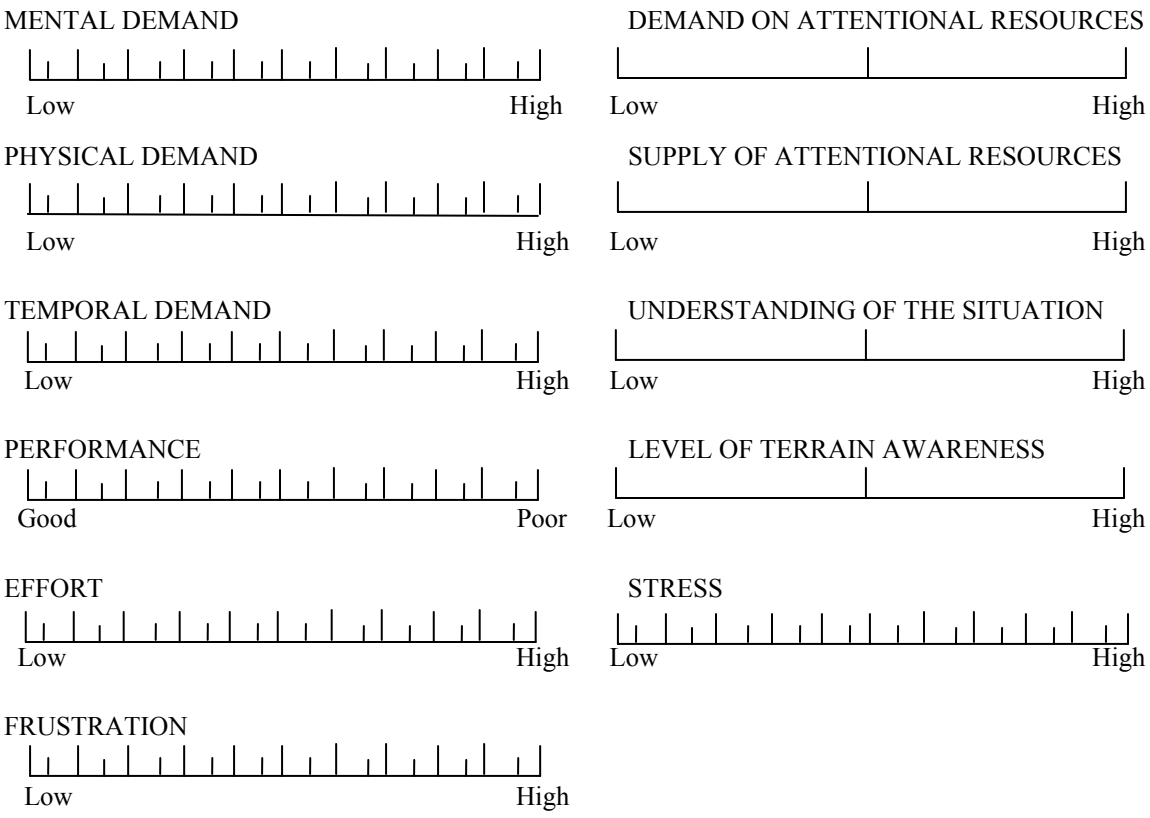
EP1	EP2	EP3	EP4	EP5	EP6	EP7	EP8
148	150	148	150	152	154	152	154
150	148	150	148	154	152	154	152
154	152	154	152	162	160	162	160
152	154	152	154	160	162	160	162
156	158	156	158	148	150	148	150
158	156	158	156	150	148	150	148
162	160	162	160	158	156	158	156
160	162	160	162	156	158	156	158
164	166	164	166	164	166	164	166
166	164	166	164	166	164	166	164

Table D.4. Case List for Incursion Detection Algorithm Evaluation for Pilots 9 through 16

EP9	EP10	EP11	EP12	EP13	EP14	EP15	EP16
164	166	164	166	148	150	148	150
166	164	166	164	150	148	150	148
162	160	162	160	158	156	158	156
160	162	160	162	156	158	156	158
156	158	156	158	164	166	164	166
158	156	158	156	166	164	166	164
154	152	154	152	154	152	154	152
152	154	152	154	152	154	152	154
148	150	148	150	160	162	160	162
150	148	150	148	162	160	162	160

Appendix E: Post Run Questionnaires

The evaluation pilot completed a questionnaire (see below) at the end of each evaluation run. Mental Demand, Physical Demand, Temporal Demand, Performance (Pilot), Effort, and Frustration were all Task Load Index (TLX) measures that evaluated workload. Demand on and Supply of Attentional Resources and Understanding of Situation values were combined to derive the Situation Awareness Rating Technique (SART) rating. Level of Terrain Awareness and Stress were two other independent measures that were collected.



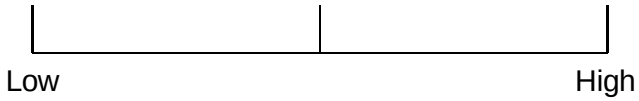
Workload:	Situational Awareness:
TLX - Mental Demand	SART - Demand on Attentional Resources
Physical Demand	Supply of Attentional Resources
Temporal Demand	Understanding of the Situation
Performance	
Effort	
Frustration	

Run Questionnaire Key:

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?

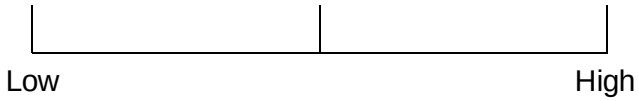
Please rate your overall impression of the scenario in terms of how much attention and effort was required to perform the scenario successfully. Things to consider are the degree of instability, complexity, and variability that you perceived while flying the scenario.

DEMAND ON ATTENTIONAL RESOURCES



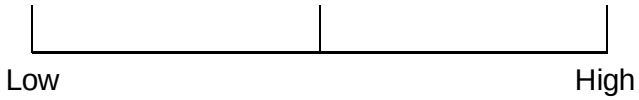
Please rate your overall impression of the scenario in terms of the amount of "spare" attention to give to other tasks. Was 100% of your attention directed towards successfully completing the scenario? Or, could you have completed other sub-tasks while flying the scenario? Things to consider include your level of arousal, level of concentration, and if you attention was divided across many sub-tasks.

SUPPLY OF ATTENTIONAL RESOURCES



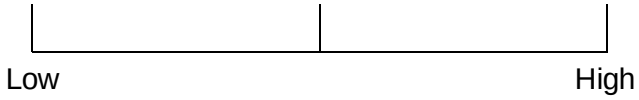
Please rate your overall understanding of what was happening with the aircraft. Mark on the line below the degree to which you felt confident that you were aware of the elements in your environment. Things to consider include the level of information quantity and quality as well as familiarity that you felt you had with what was taking place during the scenario.

UNDERSTANDING OF THE SITUATION



Please rate you overall understanding of the terrain environment you were operating within. Things to consider for this response are how comfortable were you with your terrain awareness.

LEVEL OF TERRAIN AWARNESS



Please rate your overall level of stress that you experienced while completing the experimental test run.

STRESS

1. *Please rate your level of traffic awareness experienced with the display concept during the approach. 1 = Low; 10 = High*

2. *Please rate your level of awareness of where you were (ownship position awareness) using the display concept during the approach. 1 = Low; 10 = High*

3. *Please rate your ability to stay on path (flight path awareness) using the display concept during the approach. 1 = Low; 10 = High*

Appendix F. Rare Event Run Questionnaire Results

The following questionnaire was administered to the EP at the conclusion of the rare event runway incursion run. Four different display conditions were used for the rare event testing as follows:

EP #	Display Condition
1, 5, 9, 13	BMO
2, 6, 10, 14	BMOT
3, 7, 11, 15	BAMO
4, 8, 12, 16	BAMOT

Only half of the EPs received incursion alerts for the rare event test run.

1. ***If applicable (BAMO and BAMOT only), please rate the timeliness of the alert (did the alert happen in a timely manner) in terms of providing enough time to take evasive action.***
1 = Poor; 10 = Excellent

EP	BAMO
3	8
7	5
11	9
15	9
Mean	7.75
Std. Dev.	1.89

EP	BAMOT
4	7
8	8
12	10
16	9
Mean	8.5
Std. Dev.	1.29

2. ***Upon receiving an incursion alert, was your immediate reaction to :***
Confirm the hazard; Take evasive action; Other: Explain Reason

EP #	Confirm Hazard	Take Evasive Action	Other	Reason
1	N/A			
2	N/A			
3	√			Would have queried ATC with warning
4		√		Already confirmed traffic prior to alert
5	N/A			
6	N/A			
7	√	√		Need radio response. Initiate each, can continue if valid or realign if not.
8	√			
9	N/A			
10	N/A			
11		√		

12	√			Unfamiliar with warning
13	N/A			
14	N/A			
15		√		Saw first – alert confirmed visual
16	√			
Total	5	4		

3. ***Please indicate where you first perceived the location of the incursion aircraft. Window; Surface Map (if applicable); Audible Alert (if applicable)***

If applicable, upon seeing the incursion aircraft, where did you then focus your attention? Window; Surface Map (if applicable); Audible Alert (if applicable)

If applicable, please estimate how useful each of the following were in helping you to detect and avoid the runway incursion situation (total 100%) Window; Surface Map (if applicable); Audible Alert (if applicable)

	First Perceived Location			Focus Attention			Detection Usefulness (%)		
EP #	Window	Map	Audible	Window	Map	Audible	Window	Map	Audible
1	√	N/A	N/A	√		N/A	100	0	N/A
2	√		N/A	√		N/A	100	0	N/A
3		N/A	√	√			10	0	90
4		√		√			40	60	0
5	√	N/A	N/A	√		N/A	100	0	N/A
6	√		N/A	√		N/A	80	20	N/A
7	√	N/A		√			95	0	5
8	√				√		50	50	0
9	√	N/A	N/A	√		N/A	100	0	N/A
10	-	-	N/A	-	-	N/A	-	-	N/A
11	√	N/A		√			100	0	0
12			√		√		0	40	60
13	√	N/A	N/A	√		N/A	100	0	N/A
14	√		N/A	-	-	N/A	-	-	N/A
15	√	N/A				√	80	0	20
16	√				√		33	33	34
Total	12	1	2	10	3	1	70.6	14.5	26.1

4. ***If applicable, how did you use the surface map to detect and locate the incursion aircraft?***

EP 1 – N/A
EP 2 – N/A
EP 3 – N/A
EP 4 – Saw traffic location on the map and then confirmed the traffic by looking out the window. Looked at map afterwards for additional confirmation.
EP 5 – N/A
EP 6 – N/A
EP 7 – N/A
EP 8 – I was looking at the display to confirm my visual out-the-window look when it lit up red.
EP 9 – N/A
EP 10 – N/A
EP 11 – N/A
EP 12 – Upon audible, I confirmed on map then visually.
EP 13 – None
EP 14 – No response
EP 15 – Out of field of view.
EP 16 – Confirm visual.

If applicable, please indicate whether the surface map alone was sufficient to help you detect and locate the intrusion aircraft? Yes; No; Likelihood of detection (%)

EP #	Yes	No	Likelihood of Detection (%)
1		√	
2		√	0
3	N/A		
4		√	75
5	N/A		
6	N/A		
7	N/A		
8	√		100
9		√	
10		√	
11		√	
12		√	
13	N/A		
14		√	
15		√	
16		√	
Total	1	10	

What enhancements could be made to the surface map to raise the likelihood?

EP 2 – More attention getting symbol, location of display is too far from site picture
EP 4 – Highlight traffic before alert generated. A longer warning on map with audible warning meaning imminent danger.
EP 6 – Location
EP 7 – Traffic of hazard to this aircraft, should have bright/flash indication of hazard with warning
EP 11 – Adding traffic
EP 12 – Positioning
EP 14 – Placement
EP 15 – Place within field of view.
EP 16 – Too cluttered.

5. ***If applicable, please indicate whether the audible alert alone was sufficient to help you detect and locate the intrusion aircraft? Yes; No; Likelihood (%)***

EP #	Yes	No	Likelihood of Detection (%)
1	N/A		
2	N/A		
3	√		90
4			No answer
5	N/A		
6	N/A		
7	√		25
8		√	
9	N/A		
10	N/A		
11	√		100
12	√		
13	N/A		
14	N/A		
15	√		
16		√	
Total	5	2	

What enhancements could be made to the audible alert (e.g. 3-D Audio) to raise the likelihood?
EP 3 – Position
EP 7 – Need clear beep/squawk to alert about the alert. Plus voice distinct from ATC.
EP 11 – Audio is OK
EP 12 – None
EP 15 – Tone
EP 16 – Female with British accent.

6. ***Please indicate your rating of how much aid the display concept provided in detection of the incursion aircraft. 1 = None; 10 = Exceptional***

EP	BMO
1	1
5	1
9	1
13	1
Mean	1
Std. Dev.	0

EP	BMOT
2	1
6	4
10	1
14	2
Mean	2
Std. Dev.	1.41

EP	BAMO
3	8
7	2
11	8
15	7
Mean	6.25
Std. Dev.	2.87

EP	BAMOT
4	8
8	10
12	9
16	8
Mean	8.75
Std. Dev.	0.96

Collective

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

Mean	4.5
Std. Dev.	3.58

7. ***Please indicate the likelihood that the display concept would prevent similar runway incursions in the real world (based on your experiences). 1 = Low; 10 = High***

EP	BMO
1	1
5	1
9	5
13	1
Mean	2
Std. Dev.	2

EP	BMOT
2	10
6	9
10	8
14	5
Mean	8
Std. Dev.	2.16

EP	BAMO
3	9
7	4
11	8
15	10
Mean	7.75
Std. Dev.	2.63

EP	BAMOT
4	9
8	10
12	10
16	10
Mean	9.75
Std. Dev.	0.5

Collective

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

Mean	6.88
Std. Dev.	3.5

8. ***Please rate your level of perceived safety you believe you would experience if you had this system onboard your aircraft during a similar runway incursion event. 1 = Low; 10 = High***

EP	BMO
1	1
5	1
9	5
13	5
Mean	3
Std. Dev.	2.31

EP	BMOT
2	10
6	9
10	7
14	5
Mean	7.75
Std. Dev.	2.22

EP	BAMO
3	7
7	7
11	6
15	10
Mean	7.5
Std. Dev.	1.73

EP	BAMOT
4	8
8	10
12	10
16	9
Mean	9.25
Std. Dev.	0.96

Collective

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

Mean	6.88
Std. Dev.	2.94

9. ***Please rate (if applicable) the effectiveness of the display concept <u>compared to what is currently available onboard Part 23 aircraft</u> for prevention of runway incursions. 1 = None; 10 = Exceptional***

EP	BMO
1	1
5	1
9	1
13	5
Mean	2
Std. Dev.	2

EP	BMOT
2	10
6	10
10	7
14	5
Mean	8
Std. Dev.	2.5

EP	BAMO
3	9
7	4
11	8
15	8
Mean	7.25
Std. Dev.	2.22

EP	BAMOT
4	10
8	10
12	10
16	9
Mean	9.75
Std. Dev.	0.5

Collective

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

Mean	6.75
Std. Dev.	3.45

Please indicate the reason for your rating.

EP 1 – The display concept did not show aircraft on it.
EP 2 – No airport display / map in current aircraft.
EP 3 – One more piece of information.
EP 4 – No current indications of traffic available. This display concept gives exceptional traffic information.
EP 5 – System is not indicating traffic.
EP 6 – Like having co-pilot and second pair of eyes.
EP 7 – Definite potential for improvement.
EP 10 – Enhances traffic awareness if used the technology & knew how to use it & part of scan
EP 11 – Less subjective type of information
EP 12 – Only visual on Part 23 in low visibility conditions. Audible and surface map make a big difference.
EP 13 – No display of traffic.
EP 15 – Focus attention where many tasks may be involved
EP 16 – Gives more information than just visual – gets pilot's attention.

10. ***Please provide any other comments or suggestions for improvement of the efficacy of the display concept for prevention of runway incursions.***

EP 1 – Needs to show aircraft on it.
EP 2 – Ability to use software to make numbers, dials, letters, symbols bigger/smaller, brighter/dimmer.
EP 6 – Automatic range scaling.
EP 8 – Because of current vs prior experience.
EP 10 – On instrument approaches would rely more on ATC.

Appendix G: Usability Study Display Evaluation Questionnaire Results

The EPs evaluated the seven display conditions after each test scenario. The acronyms for the display conditions are defined as follows:

B	Baseline
BMO	Baseline with Surface Map and Ownship
BMOT	Baseline with Surface Map and Ownship and Traffic
BA	Baseline with Audible Incursion Alerts
BAMO	Baseline with Surface Map and Ownship and Audible Incursion Alerts
BAMOT	Baseline with Surface Map and Ownship, Traffic, and Incursion Alerts
BRIPS	Baseline with Perspective Surface Map

1. ***Please rate the likelihood that the display configuration would prevent the runway incursion scenario evaluated. 1 = low; 10 = high***

Scenario 1: arrival / takeoff hold

EP #	B	BMO	BMOT	BA	BAMO	BAMOT	BRIPS
1	6	6	8	7	7	10	9
2	1	1	5	5	5	8	8
3	1	1	4	6	6	7	8
4	3	3	4	7	7	10	10
5	1	1	8	10	10	10	10
6	0	0	3	8	8	10	8
7	1	4	5	4	5	8	9
8	1	1	4	10	10	10	10
9	1	1	6	7	7	9	9
10	1	1	5	7	7	8	8
11	1	1	5	8	8	10	10
12	1	1	5	8	8	10	10
13	1	2	5	4	6	8	9
14	1	1	2	7	7	9	8
15	1	1	3	7	7	8	9
16	1	1	3	7	7	9	9
Mean	1.38	1.63	4.69	7	7.19	9	9
Std. Dev.	1.36	1.5	1.66	1.71	1.42	1.03	0.82

Scenario 2: departure / intersection departure

EP #	B	BMO	BMOT	BA	BAMO	BAMOT	BRIPS
1	6	6	8	7	7	10	10
2	1	2	6	6	6	8	9
3	1	1	3	6	6	8	8
4	2	2	7	7	7	10	10
5	1	1	3	9	9	9	10
6	0	0	3	8	8	10	8
7	1	3	4	4	5	9	8
8	1	1	4	10	10	10	10
9	1	3	6	7	8	9	9
10	1	1	5	6	6	9	9
11	1	1	6	8	8	10	10
12	1	1	5	10	10	10	10
13	1	2	5	4	7	9	8
14	1	2	2	7	7	9	8
15	1	1	2	7	7	7	8
16	1	2	3	7	7	9	9
Mean	1.31	1.81	4.5	7.06	7.38	9.13	9
Std. Dev.	1.3	1.38	1.79	1.73	1.41	0.89	0.89

Scenario 3: arrival / departure

EP #	B	BMO	BMOT	BA	BAMO	BAMOT	BRIPS
1	4	4	5	6	6	10	9
2	1	2	5	7	8	9	10
3	1	1	4	7	7	8	8
4	2	2	4	7	7	10	10
5	1	1	3	8	9	10	10
6	1	3	6	8	8	10	10
7	1	3	5	2	5	8	9
8	1	1	1	10	10	10	10
9	1	1	4	8	8	8	8
10	1	1	5	7	7	8	8
11	1	1	5	8	8	10	10
12	1	1	4	8	8	10	10
13	1	1	5	5	5	8	8
14	1	1	1	2	2	3	3
15	1	1	2	8	8	9	10
16	1	1	3	7	8	9	9
Mean	1.25	1.56	3.88	6.75	7.13	8.75	8.88
Std. Dev.	0.77	0.96	1.5	2.14	1.89	1.77	1.78

Scenario 4: departure / departure

EP #	B	BMO	BMOT	BA	BAMO	BAMOT	BRIPS
1	4	4	6	6	6	10	10
2	1	2	6	8	8	9	10
3	1	1	4	7	7	8	8
4	1	2	5	6	6	9	9
5	0	1	3	10	10	10	10
6	0	2	6	8	8	10	8
7	1	4	5	5	6	9	9
8	1	1	3	10	10	10	10
9	1	1	4	8	8	8	8
10	1	1	6	7	8	8	8
11	1	1	7	8	8	10	10
12	1	1	4	10	10	10	10
13	1	3	5	5	7	9	8
14	1	1	3	7	7	9	8
15	1	1	3	7	7	8	8
16	1	1	3	7	7	9	9
Mean	1.06	1.69	4.56	7.44	7.69	9.13	8.94
Std. Dev.	0.85	1.08	1.36	1.59	1.35	0.81	0.93

Scenario 5: taxi crossing / departure

EP #	B	BMO	BMOT	BA	BAMO	BAMOT	BRIPS
1	4	4	6	7	7	10	10
2	1	3	6	7	8	9	10
3	1	1	4	6	7	7	8
4	2	2	7	5	5	9	9
5	1	1	8	10	10	10	10
6	0	3	6	8	8	10	8
7	1	2	6	4	5	9	8
8	1	1	10	10	10	10	10
9	1	1	6	7	7	9	8
10	1	1	5	7	7	10	10
11	1	1	8	8	8	10	10
12	1	1	6	8	8	10	10
13	1	3	5	6	7	9	8
14	1	1	5	7	7	9	8
15	1	1	2	8	8	9	9
16	1	2	2	5	7	9	9
Mean	1.19	1.75	5.75	7.06	7.44	9.31	9.06
Std. Dev.	0.83	1.0	2.05	1.65	1.36	0.79	0.93

2. ***Please rate the efficacy of the display concept for runway incursion prevention with and without alerting for the following display concepts. 1 = low; 10 = high***

Scenario 1 – arrival / takeoff hold

EP #	B + no alert	B + audible alert	BMO + no alert	BMO + audible alert	BMO + visual alert	BMO + audible & visual alert	BMOT + no alert	BMOT + audible alert	BMOT + visual alert	BMOT + audible & visual alert	BRIPS + no alert	BRIPS + audible alert	BRIPS + visual alert	BRIPS + audible & visual alert
1	5	5	5	6	6	6	6	8	9	10	7	7	8	9
2	1	6	1	5	4	6	5	6	5	8	5	5	5	8
3	1	5	1	6	4	4	4	7	6	7	4	8	7	8
4	3	7	3	7	4	8	8	9	8	10	8	9	8	10
5	1	10	1	10	8	10	8	10	8	10	8	10	8	10
6	0	8	0	8	3	8	3	8	8	10	3	8	8	8
7	1	4	4	5	5	7	5	7	6	8	6	8	7	9
8	1	10	1	10	4	10	4	10	4	10	4	10	4	10
9	1	7	1	7	6	7	6	9	6	9	6	9	7	9
10	1	7	1	7	6	7	5	7	6	8	5	7	6	8
11	1	8	1	8	6	8	5	8	6	10	5	8	6	10
12	1	8	1	8	8	10	5	10	8	10	5	10	8	10
13	1	4	2	6	3	7	5	7	6	8	5	6	6	9
14	1	7	1	7	1	7	2	7	2	9	2	7	2	8
15	1	7	1	7	4	7	3	8	6	8	4	9	7	9
16	1	7	1	7	5	7	3	9	7	9	3	9	7	9
Mean	1.31	6.94	1.56	7.13	4.81	7.44	4.81	8.13	6.31	9.0	5.0	8.13	6.5	9.0
Std. Dev.	1.14	1.73	1.31	1.45	1.83	1.59	1.68	1.26	1.74	1.03	1.71	1.45	1.67	0.82

Scenario 2 – departure / intersection departure

EP #	B + no alert	B + audible alert	BMO + no alert	BMO + audible alert	BMO + visual alert	BMO + audible & visual alert	BMOT + no alert	BMOT + audible alert	BMOT + visual alert	BMOT + audible & visual alert	BRIPS + no alert	BRIPS + audible alert	BRIPS + visual alert	BRIPS + audible & visual alert
1	6	7	6	7	7	7	8	9	9	10	8	9	9	10
2	1	6	2	6	5	5	6	6	5	8	6	8	7	9
3	1	6	1	6	4	7	3	6	4	8	4	6	4	8
4	2	7	2	7	4	8	7	9	8	10	7	9	8	10
5	1	10	1	10	8	10	7	10	8	10	8	10	9	10
6	0	8	0	8	3	8	3	8	6	10	3	8	6	8
7	1	4	3	5	4	6	4	8	7	9	5	7	6	8
8	1	10	1	10	1	10	4	10	4	10	4	10	4	10
9	1	7	3	8	4	8	6	8	6	9	5	9	6	9
10	1	6	1	6	5	6	5	6	5	9	5	6	5	9
11	1	8	1	8	7	9	6	10	9	10	7	10	9	10
12	1	10	1	10	8	10	1	10	8	10	1	10	8	10
13	1	4	2	7	5	7	5	7	7	9	4	7	7	8
14	1	7	2	7	2	7	2	7	2	9	2	7	2	8
15	1	7	1	7	2	6	2	7	3	7	3	7	3	8
16	1	7	2	7	5	8	3	9	7	9	3	9	7	9
Mean	1.31	7.13	1.81	7.44	4.63	7.63	4.5	8.13	6.13	9.19	4.69	8.25	6.25	9.0
Std. Dev.	1.3	1.82	1.38	1.5	2.09	1.54	2.07	1.5	2.13	0.91	2.09	1.44	2.18	0.89

Scenario 3 – arrival / departure

EP #	B + no alert	B + audible alert	BMO + no alert	BMO + audible alert	BMO + visual alert	BMO + audible & visual alert	BMOT + no alert	BMOT + audible alert	BMOT + visual alert	BMOT + audible & visual alert	BRIPS + no alert	BRIPS + audible alert	BRIPS + visual alert	BRIPS + audible & visual alert
1	5	6	5	6	6	6	8	9	9	10	8	9	9	10
2	1	7	2	8	7	8	5	8	7	9	6	7	7	10
3	1	7	1	7	4	7	4	7	6	8	3	7	4	8
4	2	7	2	7	3	8	4	10	4	10	4	10	4	10
5	1	8	1	9	2	9	3	10	2	10	3	10	3	10
6	1	8	3	8	6	10	6	8	6	10	6	8	6	10
7	1	2	3	5	4	6	5	6	7	8	5	8	7	9
8	1	10	1	10	1	10	1	10	1	10	1	10	1	10
9	1	8	1	8	4	8	4	8	4	8	4	8	4	8
10	1	7	1	7	6	8	5	7	7	8	5	7	7	8
11	1	8	1	8	6	9	5	9	7	10	6	9	7	10
12	1	8	1	8	4	10	4	8	8	10	8	10	8	10
13	1	5	1	5	4	7	5	7	6	8	5	7	7	8
14	1	2	1	2	2	2	1	3	2	3	1	3	2	3
15	1	8	1	8	3	8	2	9	4	9	2	9	4	10
16	1	7	1	8	4	9	3	7	4	9	3	7	4	9
Mean	1.31	6.75	1.63	7.13	4.13	7.81	4.06	7.88	5.25	8.75	4.38	8.06	5.25	8.94
Std. Dev.	1.01	2.14	1.15	1.89	1.71	2.01	1.81	1.78	2.32	1.77	2.16	1.81	2.29	1.81

Scenario 4 – departure / departure

EP #	B + no alert	B + audible alert	BMO + no alert	BMO + audible alert	BMO + visual alert	BMO + audible & visual alert	BMOT + no alert	BMOT + audible alert	BMOT + visual alert	BMOT + audible & visual alert	BRIPS + no alert	BRIPS + audible alert	BRIPS + visual alert	BRIPS + audible & visual alert
1	5	6	5	6	6	6	8	9	9	10	8	9	9	10
2	1	8	2	8	7	8	6	8	8	9	7	8	7	10
3	1	7	1	7	6	8	4	7	6	8	4	8	5	8
4	1	6	2	6	5	7	5	7	5	9	5	7	5	9
5	1	10	1	10	3	10	3	10	3	10	3	10	3	10
6	0	8	2	8	2	8	6	8	6	10	2	8	6	10
7	1	5	4	6	5	7	5	7	6	9	5	7	6	9
8	1	10	1	10	5	10	3	10	5	10	2	10	2	10
9	1	8	1	8	4	8	4	8	4	8	4	8	4	8
10	1	7	1	8	6	8	6	8	6	8	6	8	6	8
11	1	8	1	8	8	10	7	10	10	10	7	10	10	10
12	1	10	1	10	4	10	4	10	4	10	4	10	4	10
13	1	5	3	7	5	7	5	7	6	9	3	6	5	8
14	1	7	1	7	2	7	3	7	3	9	2	7	2	8
15	1	7	1	7	3	7	3	7	4	8	3	7	4	8
16	1	7	1	7	5	7	3	7	5	9	5	9	7	9
Mean	1.19	7.44	1.75	7.69	4.75	8	4.69	8.13	5.63	9.13	4.38	8.25	5.31	9.06
Std. Dev.	1.05	1.59	1.24	1.35	1.69	1.32	1.58	1.26	2.00	0.81	1.89	1.29	2.24	0.93

Scenario 5 – taxi crossing / departure

EP #	B + no alert	B + audible alert	BMO + no alert	BMO + audible alert	BMO + visual alert	BMO + audible & visual alert	BMOT + no alert	BMOT + audible alert	BMOT + visual alert	BMOT + audible & visual alert	BRIPS + no alert	BRIPS + audible alert	BRIPS + visual alert	BRIPS + audible & visual alert
1	4	6	4	6	5	6	6	8	7	10	6	8	7	10
2	1	7	3	8	7	8	6	8	7	9	6	8	8	10
3	1	6	1	5	4	7	4	7	6	7	5	7	6	8
4	2	5	2	5	5	6	7	9	7	9	6	9	6	9
5	1	10	1	10	9	10	8	10	9	10	8	10	9	10
6	0	8	3	8	6	8	6	8	6	10	8	8	6	8
7	1	4	2	5	4	6	6	8	7	9	5	7	6	8
8	1	10	1	10	5	10	10	10	10	10	10	10	10	10
9	1	7	1	7	5	7	6	9	6	9	6	8	6	8
10	1	7	1	7	4	8	5	7	6	10	5	7	6	10
11	1	8	1	8	9	9	8	10	9	10	8	10	9	10
12	1	8	1	8	6	8	6	10	9	10	6	10	9	10
13	1	6	3	7	6	8	5	8	8	9	6	7	7	8
14	1	7	1	7	2	7	5	8	5	9	5	8	4	8
15	1	8	1	8	7	8	2	8	7	9	2	8	7	9
16	1	5	2	7	5	9	2	9	5	9	9	9	9	9
Mean	1.19	7.00	1.75	7.25	5.56	7.81	5.75	8.56	7.13	9.31	6.31	8.38	7.19	9.06
Std. Dev.	0.83	1.67	1.00	1.53	1.82	1.28	2.05	1.03	1.5	0.79	1.92	1.15	1.64	0.93

3. ***Please rate surface traffic awareness for the following display concepts. 1 = low; 10 = high***

Scenario 1 – arrival / takeoff hold

EP #	B	BMO	BMOT	BRIPS
1	4	4	8	10
2	1	2	8	8
3	1	1	6	7
4	1	1	10	10
5	1	1	10	10
6	0	0	8	6
7	1	5	8	9
8	1	1	10	10
9	1	1	6	6
10	1	1	9	9
11	1	1	8	8
12	1	1	8	8
13	1	1	6	5
14	1	1	9	8
15	1	1	3	4
16	1	2	7	7
Mean	1.13	1.5	7.75	7.81
Std. Dev	0.81	1.26	1.84	1.87

Scenario 2 – departure / intersection departure

EP #	B	BMO	BMOT	BRIPS
1	4	4	9	10
2	1	2	8	9
3	1	1	6	6
4	1	1	9	9
5	1	1	8	10
6	0	0	8	6
7	1	5	9	8
8	1	1	10	10
9	1	3	6	8
10	1	1	9	9
11	1	1	8	8
12	1	1	6	6
13	1	3	7	6
14	1	1	6	5
15	1	1	4	5
16	1	2	5	5
Mean	1.13	1.75	7.38	7.5
Std. Dev.	0.81	1.34	1.71	1.90

Scenario 3 – arrival / departure

EP #	B	BMO	BMOT	BRIPS
1	4	4	10	10
2	1	2	9	10
3	1	1	6	6
4	1	1	8	8
5	0	0	8	8
6	0	3	8	6
7	1	6	8	9
8	10	10	10	10
9	1	1	4	4
10	1	1	9	9
11	1	1	8	8
12	1	1	5	6
13	1	1	5	5
14	1	1	3	3
15	1	1	4	4
16	1	1	5	5
Mean	1.63	2.19	6.88	6.94
Std. Dev.	2.39	2.56	2.28	2.35

Scenario 4 – departure / departure

EP #	B	BMO	BMOT	BRIPS
1	5	5	9	10
2	1	2	8	10
3	1	1	6	6
4	1	1	7	7
5	1	1	3	3
6	0	0	6	6
7	1	2	9	9
8	1	1	10	10
9	1	3	4	4
10	1	1	9	9
11	1	1	10	10
12	1	1	4	4
13	1	3	8	7
14	1	1	3	2
15	1	1	3	4
16	1	1	7	7
Mean	1.19	1.56	6.63	6.75
Std. Dev.	1.05	1.21	2.55	2.74

Scenario 5 – taxi crossing / departure

EP #	B	BMO	BMOT	BRIPS
1	5	5	10	10
2	1	3	9	10
3	1	1	6	7
4	1	1	8	7
5	1	1	10	10
6	0	0	10	8
7	1	4	9	8
8	1	1	10	10
9	1	1	8	8
10	1	1	9	9
11	1	1	8	8
12	1	1	6	6
13	1	3	6	5
14	1	1	8	7
15	1	1	2	2
16	1	1	9	9
Mean	1.19	1.63	8	7.75
Std. Dev.	1.0 5	1.36	2.13	2.14

Appendix H: Usability Study Detection Algorithm Evaluation Questionnaire Results

The EPs evaluated the two incursion detection algorithms after each test scenario. The scenarios are defined as follows:

Scenario 1 **arrival / takeoff hold**
Scenario 2 **departure / intersection departure**
Scenario 3 **arrival / departure**
Scenario 4 **departure / departure**
Scenario 5 **taxi crossing / departure**

1. ***Please rate the effectiveness of the alerting for preventing runway incursions for each display concept (based on the runway incursion scenario experienced). 1 = low; 10 = high***
Note: All evaluations were made using the BRIPS display concept (Baseline with perspective map).

	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
EP #	Single Stage	Two Stage	Single Stage	Two Stage	Single Stage	Two Stage	Single Stage	Two Stage	Single Stage	Two Stage
1	10	10	10	9	10	6	10	7	10	5
2	9	10	10	10	10	10	10	10	9	10
3	7	8	7	7	7		8	7	8	7
4	8	9	9	9	7	7	8	7	7	4
5	10	10	10	10	3	10	10	10	10	3
6	7	10	10	10	10	10	10	9	10	9
7	8	9	9	9	8	9	9	8	9	8
8	10	6	10	8	10	10	10	10	10	10
9	8	9	8	8	8		8	8	8	8
10	8	9	8	8	8	8	8	8	8	9
11	9	10	10	10	10	10	10	10	10	10
12	9	10	10	9	9		10	10	10	10
13	8	9	9	8	9		9	9	9	8
14	8	9	8	8	8	8	8	7	8	8
15	10	9	10	10	9		10	4	10	8
16	9	9	9	9	9		9	9	9	9
Mean	8.63	9.13	9.19	8.88	8.44	8.8	9.19	8.31	9.06	7.88
Std. Dev.	1.02	1.02	0.98	0.96	1.79	1.48	0.91	1.66	1.00	2.16

Comments:

EP1	Scenario 2	two stage – alerted later
EP4	Scenario 1	two stage – more time, chance to evaluate
EP7	Scenario 1	two stage faster
	Scenario 3	based on how landed, thought two stage alerted sooner

	Scenario 4	single stage faster
	Scenario 5	single stage faster
EP9	Scenario 5	caution didn't buy anything
EP13	Scenario 5	caution not beneficial – too close to warning
EP14	Scenario 5	single stage – did not perceive difference in alerting two stage – not useful as implemented
EP15	Scenario 5	two stage – no need for two alerts in this case

2. ***In general, which type of alerting is better for single pilot general aviation operations? Single stage alerting or two stage alerting***

For the choice selected, how much more effective is that alerting type for runway incursion prevention?
1 = low; 10 = high

Please provide a reason for your answer.

EP #	Single Stage	Effectiveness	Two Stage	Effectiveness	Reason
1	1				It gave more time to react with single stage in sim. I'd rather have two stage alerting with the alerting time of single stage.
2			1	2	Both are excellent, two stage provides a higher comfort level.
3			1	4	It is better to have the caution which seems to give you more time to evaluate the situation and react accordingly.
4	1	4	1	6	Two stage for approaches only. Single stage alerting allowed more time for response during ground ops. The two stage, however, allows the pilot to know when to start looking on approach for other aircraft when concentrating on other tasks.
5			1	3	Seems redundant but a second warning may help if the first is not heard.
6	1	8			With one you first react. With two your mind makes you analyze what is happening.
7			1	8	Two stage seems to provide earlier alerting of hazards, enabling pilot attention and decision making – proactive responses. Like selective on stage in certain cases (takeoff …)
8	1	8			(no comment)
9			1	2	Earlier notification
10			1	1	The two stage gave me a chance to look at the display prior to the warning. Better SA.
11			1	3	Single is very good, but two stage offers a little more cushion.
12	1	3			Caution can be confusing
13			1	4	More time to prepare before acting

14			1	3	Early alert for more reaction time
15	1	9			Late alert for two stage
16			1	4	Couldn't tell a big difference
Total	6	6.4	11	3.64	

3. ***With respect to latency, were the incursion alerts provided in a timely manner allowing sufficient time to react to the potential conflict?***

All 16 EPs answered YES

Did either single stage or two stage alerting provide more time for response to the RI?

Please estimate how much more time the alert provided.

If not, when should the alert have occurred?

EP #	Single Stage	Two Stage	Seconds	Comment
1	√		2	
2		√	5 to 10	
3	√	√	3 to 4	Single stage for taxi and departure, two stage for approach
4	√		5 to 10	Two stage taxi (scenario 5) not enough time. Two stage more time on approach.
5			Same	If any thing, alert should have occurred when the other plane begins takeoff roll. Two stage for scenario 3 & 5 was late.
6	√		1 to 1.5	Except for departure, alerts should be sooner.
7		√	1 to 4	Potentially a lifetime.
8			Equal	
9		√	2	Most times single stage is all that is needed. Two stage beneficial on approach only.
10			Neither	
11		√	2 to 3	
12	√		1	
13	√		3	
14	√	√	2	Single stage for takeoff, two stage for landing
15	√		3	
16		√	10 to 15	Two stage on approach
Total	8	7		

Appendix I: Final Semi-Structured Interview Questionnaire Results

A post-test questionnaire was administered to each EP. The acronyms for the display conditions are defined as follows:

B	**Baseline**
BMO	**Baseline with Surface Map and Ownship**
BMOT	**Baseline with Surface Map and Ownship and Traffic**
BA	**Baseline with Audible Incursion Alerts**
BAMO	**Baseline with Audible Incursion Alerts, Surface Map and Ownship**
BAMOT	**Baseline with Incursion Alerts, Surface Map and Ownship, Traffic**
BRIPS	**Baseline with Perspective Surface Map**

I. RIPS General Safety

1. ***In general, please rate the level of safety felt during runway incursion incidents using the following equipage. 1 = Not Safe; 10 = Completely Safe***

EP #	B	BMO	BMOT	BA	BAMO	BAMOT	BRIPS
1	4	4	5	6	6	10	10
2	5	6	7	8	9	10	10
3	1	2	6	6	6	7	8
4	2	2	5	5	5	10	10
5	1	1	7	8	8	9	10
6	0	0	3	8	8	10	8
7	1	5	6	6	7	9	8
8	5	5	8	10	10	10	10
9	1	3	4	7	7	9	9
10	6	6	9	10	10	10	10
11	1	1	8	8	8	10	10
12	1	1	5	10	10	10	10
13	1	3	4	5	6	9	8
14	2	3	3	5	5	9	8
15	1	1	3	7	7	8	9
16	1	1	3	6	7	9	9
Mean	2.06	2.75	5.38	7.19	7.44	9.31	9.19
Std. Dev.	1.84	1.95	2.00	1.76	1.67	0.87	0.9.1

II. RIPS General Advantages and Disadvantages

2a. ***What do you consider the best feature of the RIPS displays/technology you evaluated today?***

Can the feature be improved? If so, how?

EP #	Best Feature	Improvement
1	Showed movement of other aircraft on airport	Liked perspective map better; however, the traffic icons were harder to see
2	Provides enhanced situational awareness, ownship location, airport environment & traffic position & direction moving	Capability to vary font size
3	Audible alert	"Warning, traffic 34R" not descriptive enough
4	Airport layout system for increased situational awareness	Text clutter adjustments (ID labels)
5	Audio alerts	Little sooner to match the graphic takeoff roll
6	Top down view, audible & traffic	N# no help
7	Dynamic and real-time situational awareness and hazard warning	(no comment)
8	N/A	N/A
9	Audible alert	(no comment)
10	Traffic	Warning late sometimes / latency
11	Traffic + audible altering	(no comment)
12	Audible	(no comment)
13	Combination visual & audible alerts	Alert a little sooner
14	Taxi clearance	(no comment)
15	Large red warning symbol with audio alert	Show ownship with larger symbol, use larger traffic symbols at threshold
16	Give warning of incursions when traffic was difficult to see	(no comment)

2b. ***What do you consider to be the worst feature of the RIPS displays/technology you evaluated today?***

Can the feature be improved? If so, how?

EP #	Worst Feature	Improvement
1	Text warning didn't get my attention as well as audible and text	Maybe use a short flashing box that highlights the warning
2	Location of display in cockpit - too much eye movement for cross check	Ability to declutter ID tags readily
3	Top down map looked busy	Less clutter
4	(no comment)	(no comment)
5	Did not like to watch the rotation of the top down view	Not really - leave it in as a choice
6	Perspective view	(no comment)
7	No "worst" feature	Minor tune ups
8	N/A	N/A
9	None	(no comment)
10	(no comment)	(no comment)
11	Location	(no comment)
12	Caution chevron (yellow) hard to see; placement of display	Flashing chevron - reposition panel
13	Position of screen	Move it
14	Clutter, color of symbology	During warning, change display to show only conflict, traffic, speed, distance, time to conflict
15	Small symbol for ownship & traffic & delayed warning on 2 stage alert	With 2 stage alert - make warning earlier - increase size of symbols of a/c moving on surface (traffic and ownship)
16	Display a little cluttered in top down display	(no comment)

2c. ***What are the advantages and disadvantages of the RIPS displays/technology you evaluated compared to the baseline condition (baseline round dials only)?***

EP #	Advantages	Disadvantages
1	Pin points your location in relation to the other a/c on airport and warnings (audible and text)	No disadvantage
2	Situation awareness	Possible sunlight washout of screen
3	Better situational awareness	Training, more to look at
4	Traffic advisories allow for a much higher sense of awareness	The chance a pilot may focus on guidance line during approach
5	The pilot can see traffic and know their direction and location even in poor visibilities and distance locations obscured by airport facilities	Pilots can be too dependent on the technology and less on looking out the window. What if some plane is not compatible with the technology and is not displayed?
6	Situational awareness greatly enhanced	none
7	Great improvement in SA and for intuitive and information	Essentially zero
8	N/A	N/A
9	Audible + perspective + graphic alert	None
10	Situation awareness	Would take training to ensure attention distribution optimally and how to interpret the warnings
11	More aware of traffic and surrounding	Left placement of screen
12	Audible alerts + SA	Audible caution was confusing
13	Gives information you need - my position relative to traffic & airport features	(no comment)
14	(no comment)	(no comment)
15	Audio alert + red (large) warning lettering & symbols on display	None
16	Gave excellent traffic warning especially when audio alert used	None

III. RIPS Surface Ops Evaluation

3. ***Please indicate your level of agreement with each of the following statements for all display concepts. 1 = Low; 10 = High***

3a. ***<u>Where am I?</u> The display concept provides sufficient awareness of my ownship position with respect to runways, taxiways, and stationary objects.***

If unequal rating, please indicate reason.

If not "completely agree" for Surface Map conditions, what can be done to improve the concept to increase awareness?

EP #	B	BMO	BMOT	BA	BAMO	BAMOT	BRIPS	Reasons	Improvement
1	2	10	10	2	10	10	10	Baseline doesn't show my orientation on airport	(no comment)
2	1	10	10	1	10	10	10	(no comment)	(no comment)
3	1	6	6	1	6	6	7	(no comment)	(no comment)
4	2	8	8	2	8	8	8	(no comment)	No vertical indications
5	1	10	10	1	10	10	10	(no comment)	(no comment)
6	1	8	8	1	8	10	8	Easier to interpret top down	(no comment)
7	1	10	10	2	10	10	9	Perspective slightly poor due to relative visibility of certain areas	Same comment
8	6	8	8	6	8	10	10	(no comment)	(no comment)
9	1	9	9	1	9	9	9	Audible provides no info for my position awareness	Nothing
10	4	4	7	6	8	10	10	Airport environment + traffic + alerting	N/A
11	1	8	8	2	8	8	10	Perspective view	(no comment)
12	1	10	10	1	10	10	10	Surface map provides all the information you need	(no comment)
13	1	8	9	1	9	9	8	Prefer top down view on airport surface; traffic alert without map position not as helpful	Move display; adjust scale
14	1	8	8	1	8	8	8	(no comment)	(no comment)
15	1	10	10	2	10	10	10	(no comment)	(no comment)
16	1	9	9	1	9	9	9	(no comment)	Draw picture of clearance
Mean	1.63	8.5	8.75	1.94	8.81	9.19	9.125		
Std. Dev.	1.41	1.67	1.24	1.65	1.17	1.17	1.02		

3b. ***<u>Where am I relative to other moving objects?</u>*** ***The display concept provides sufficient awareness of my ownship position with respect to moving traffic, such as vehicles and other aircraft.***

If unequal rating, please indicate reason.

If not "completely agree" for surface map with traffic conditions, what can be done to improve the concept to increase awareness?

EP #	B	BMO	BMOT	BA	BAMO	BAMOT	BRIPS	Reasons	Improvement
1	1	1	9	1	1	9	10	No traffic info without map (baseline rounds dials only)	Perspective view gave a broader view of airport traffic
2	1	1	8	5	5	10	10	(no comment)	Audible/ visual alerting enhances SA to moving traffic
3	2	2	6	2	2	6	7	(no comment)	(no comment)
4	1	1	8	3	3	9	9	Alert brings any incursions to the users notice	(no comment)
5	1	1	10	2	2	10	10	Audible alerting provides info for one a/c not all	(no comment)
6	0	0	8	6	6	10	8	Like top down	(no comment)
7	1	2	8	2	2	10	9	Need to see traffic + self on map	(no comment)
8	4	4	8	6	6	10	10	(no comment)	(no comment)
9	1	1	6	1	1	8	8	Msg & audible alerts adds value on other traffic position and need to respond	(no comment)
10	4	4	7	6	6	10	10	Elements are shown on map + relevant features, identifiable landmarks, etc.	(no comment)
11	5	5	8	7	7	10	10	(no comment)	(no comment)
12	1	1	10	5	5	10	10	(no comment)	(no comment)
13	1	3	8	6	6	9	8	Prefer top down	Position of display; change scale
14	1	1	8	5	5	9	9	(no comment)	(no comment)
15	1	1	10	1	1	10	10	The 1's don't show traffic	(no comment)
16	1	1	9	7	9	9	9	(no comment)	If unit could show a potential conflict in a different color
Mean	1.63	1.81	8.19	4.06	4.25	9.31	9.19		
Std. Dev.	1.41	1.42	1.22	2.26	2.54	1.08	0.98		

IV. RIPS Display and Alerts

4. ***Please indicate the effectiveness of the perspective map display compared to the top-down views for prevention of runway incursion. 1 = Low; 10 = High***

Reason for rating.

EP #	Rating	Reason
1	9	The perspective gave a broader view of airport traffic
2	2	Preference
3	4	Easier to pick out ownship in less time
4	0	No difference
5	5	Top down showed more, perspective was easier to look at
6	2	Fast orientation to top down
7	8	Focus on approach environment (for approaches only, perspective more effective)
8	5	(no comment)
9	1	Same information and equally as readable
10	0	Same effectiveness; preference is for 2D top down
11	1	(no comment)
12	3	Top down was easier to interpret, perspective items get lost
13	3	Top down gives broader view to sides & rear
14	1	(no comment)
15	0	No difference - both maps displayed the alert warnings satisfactorily
16	2	Map less cluttered
Mean	2.88	
Std. Dev.	2.73	

5. ***When traffic was presented on surface map, was incurison traffic easily discernable? Yes or No***

All 16 EPs responded Yes.

If yes, please indicate how discernable. 1 = Low, 10 = High

EP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	10	10	7.5	10	9	8	10	5	9	9	6	8	7.5	5	10	10

Mean	8.38
Std. Dev.	1.77

6. ***Is traffic presentation necessary on surface map to prevent runway incursions? Yes or No***

EPs 8 and 15 responded No. The other 14 EPs responded Yes.

If so, please indicate how much additional situation awareness is provided with the addition of traffic presentation on the surface map.

Comparing <u>surface map with ownship</u> TO <u>surface map with ownship and traffic</u>, situation awareness enhancement is: 1 = Low; 10 = High

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

Mean	8.56
Std. Dev.	1.56

7. ***Is graphical presentation of alerts necessary on surface map to prevent runway incursions? Yes or No***

If so, please indicate how much additional situation awareness is provided with the addition of graphical alerting on the surface map. 1 = Low; 10 = High

EP #	Yes	No	Rating	Comment
1	√		10	
2		√		Graphic not needed if audible alert available
3	√		3	
4		√		But is helpful
5	√		9	
6	√		8	
7	√		9	
8		√	3	
9		√		
10	√		8	
11	√		3	
12	√		4	
13	√		8	
14	√		4	
15		√		
16		√		
Total	10	6	6.27	Mean
			2.83	Std. Dev.

8. ***If a runway incursion situation occurs, which of the following is most likely to bring the event to your attention? If multiple, please indicate the rank order.***

OTW = out-the-window
Map = surface map
Audible = audible alerting

Note: For B and BMO, OTW is the only method of acquiring incursion traffic.

EP #	BMOT / OTW	BMOT / map	BA / OTW	BA / audible	BMO / OTW	BMO / audible	BAMOT/ OTW	BAMOT/ audible	BAMOT/ map	BRIPS / OTW	BRIPS / audible	BRIPS / map
1	2	1	1	2	1	2	2	3	1	2	3	1
2	1	2	2	1	2	1	2	1	3	2	1	3
3	2	1	2	1	2	1	3	1	2	3	1	2
4	2	1	1	2	1	2	2	3	1	2	3	1
5	2	1	1	2	1	2	2	3	1	2	3	1
6	1	2	2	1	2	1	2	1	3	2	1	3
7	2	1	2	1	2	1	3	1	2	3	1	2
8	1	2	1	2	1	2	1	2	3	1	2	3
9	2	1	2	1	2	1	3	1	2	3	1	2
10	1	2	2	1	2	1	3	1	2	3	1	2
11	1	2	1	2	1	2	3	2	1	3	2	1
12	1	2	2	1	2	1	2	1	3	2	1	3
13	2	1	2	1	2	1	3	1	2	3	1	2
14	1	2	1	2	1	2	1	2	3	1	2	3
15	1	2	2	1	2	1	3	1	2	3	1	2
16	2	1	2	1	2	1	3	1	2	3	1	2
Mean	1.5	1.5	1.63	1.38	1.63	1.38	2.38	1.56	2.06	2.38	1.56	2.06
Std. Dev.	0.52	0.52	0.5	0.5	0.5	0.5	0.72	0.81	0.77	0.72	0.81	0.77

9. ***Upon receiving an incursion alert, was your immediate reaction to: Confirm the hazard, Take evasive action, or Other***

Please give a reason for your answer.

EP #	Confirm	Evasive Action	Other	Reason
1		√		I saw traffic first and the audible confirmed traffic incursion and I took action.
2		√		Limited time to react
3		√		(no comment)
4	√			Evaluate what the evasive action should be
5		√		The audio alerts were given after I saw the incursion
6		√		Training that warning requires action
7	√	√		Initiate immediately and confirm, then decide
8		√		(no comment)
9		√		Need to act quickly
10		√		Wasn't in an emergency situation so was safe to get to safe altitude

11		√		Best course of action
12		√		Trusted the alert
13	√			I'm a skeptic
14		√		(no comment)
15		√		At slow speeds best to abort
16	√			May miss an approach or create a dangerous situation if hazard is not confirmed first
Total	4	13	0	

What do you feel is the appropriate procedure on receipt of a RI alert for the following? Landing, Takeoff, and Taxi

EP #	Landing	Takeoff	Taxi
1	Go around	Abort	Stop
2	Go around	Abort	Stop
3	Go around	Abort	Stop
4	Go around	Abort	Stop
5	Go around	Abort	Stop
6	Go around	Abort	Stop
7	Go around	Abort	Stop
8	Go around	Abort	Stop
9	Go around	Abort	Stop
10	Go around	Abort	Stop
11	Go around	Abort	Stop
12	Go around	Abort	Stop
13	Go around	Abort	Stop
14	Go around	Contention	Stop
15	Go around	Abort	Stop
16	Go around	Abort	Stop

10. ***Which display combination would provide a minimal configuration to be effective for runway incursion prevention.***

EP #	Audible Alert	Surface Map with Ownship only	Surface Map with Ownship & Traffic	Baseline Round Dials
1			√	
2			√	
3	√			
4	√			
5			√	
6	√			
7	√		√	
8	√			

9	√			
10				√
11			√	
12	√			
13			√	
14	√			
15	√			
16	√			
Total	10	0	6	1

For an optimal configuration?

EP #	Audible Alert	Surface Map with Ownship only	Surface Map with Ownship & Traffic	Baseline Round Dials
1	√		√	
2	√		√	
3	√		√	
4	√		√	
5	√		√	
6	√		√	
7	√		√	
8	√		√	
9	√		√	
10	√		√	
11	√		√	
12	√		√	
13	√		√	
14	√		√	
15	√		√	
16	√		√	
Total	16	0	16	0

11. ***Please rate the effectiveness of the terms used for the incursion alerts. 1 = Low; 10 = High***

EP #	"Warning, traffic on RWY"	"Caution, traffic on RWY"	" Warning, traffic departing RWY"	"Caution, traffic departing RWY"	"Warning, traffic approaching RWY"	"Caution, traffic approaching RWY"
1	10	10	10	10	10	10
2	10	10	10	10	10	10
3	5	5	8	8	8	8
4	10	10	10	10	10	10

5	9	9	9	9	N/A	N/A
6	10	7	10	7	10	7
7	9	9	9	9	9	9
8	10	10	10	10	10	10
9	9	9	9	9	9	9
10	10	10	10	10	10	10
11	10	10	10	10	10	10
12	10	5	10	5	10	5
13	9	9	9	9	9	9
14	8	8	8	8	8	8
15	8	4	4	8	3	3
16	10	10	10	10	10	10
Mean	9.25	8.44	9.13	8.88	9.07	8.53
Std. Dev.	1.29	2.06	1.54	1.41	1.83	2.10

If not "completely effective", would another term be more effective or descriptive? How could the alert term be improved (i.e.wording)?

The following EPs responded to this question:

EP 3 More specific about location of incursion traffic
EP 12 Delete cautions
EP 13 Repeat warning – may not be understood first time
EP 15 Caution traffic crossing left, to right, right to left

12a. ***For single pilot operations, was the two stage alerting ("Caution" & "Warning") more effective in preventing runway incidents than single stage alerting ("Warning" only)? Yes or No***

12b. ***Did the two stage alerting ("Caution" & "Warning") enhance your situation awareness (SA) more than the single stage alerting ("Warning" only)? Yes or No***

12c. ***If yes, please indicate how much more the two stage alert enhanced your SA compared to the one stage alert. 1 = Minimal; 10 = Substantially***

What was the reason for your rating?

What are the benefits, if any, of two stage alerting?

	12a		12b		12c		
EP #	Yes	No	Yes	No		Reason	Benefits
1		√		√			Gives the pilot time to react to threat of incursion
2		√	√		4	Increased comfort level with having more perceived time for decision making	
3	√		√		4	Felt like I had more time	Reaction time, scene evaluation
4		√	√		4.5	Allowed more time for response and reaction when giving a caution and warning	Same comment
5		√		√			Only needed if the first alert is not heard
6		√		√			Better that none, single more effective
7	√		√		8	Draws attention to hazard earlier & provides assessment + decision time advantage	Same comment
8		√		√			
9	√		√		2	Very slight improvement in timing of information	Personal option to act sooner
10	√		√		4	Gave opportunity to look at surface map to confirm	More tim to analyze situation
11	√		√		4.5	Provided more response time	Same Comment
12		√		√		Caution was confusing	N/A
13		√	√		1.5	Not a big difference	More time to confirm / consider
14	√		√		7	Single for takeoff; two stage for landing	Early warning
15		√		√			None
16		√		√			
Total	6	10	9	7	4.39	Mean	
					2.07	Std. Dev.	

13. ***For each display concept, indicate which type of alerting provides the greatest amount of runway incursion prevention awareness and the amount of situation awareness enhancement (based on the choice you selected) for the following displays: 1 = Minimal; 10 = Substantially***

S = Single stage alert T = Two stage alert SA = Situation awareness enhancement

EP #	BA + S	SA	BA + T	SA	BAMO + S	SA	BAMO + T	SA	BAMOT + S	SA	BAMOT + T	SA	BRIPS + S	SA	BRIPS + T	SA
1	1	8			1	8			1	10			1	10		
2			1	6			1	7			1	9			1	9
3			1	5			1	5			1	7			1	8
4			1	5			1	5	1	9			1	9		
5			1	5			1	5			1	9			1	10
6	1	8			1	8			1	10			1	8		
7			1	8			1	8			1	8			1	8
8	1	4			1	4			1	4			1	4		
9			1	2			1	2			1	3			1	3
10			1	3			1	3			1	3			1	3
11			1	4			1	4			1	2			1	2
12	1	10			1	10			1	10			1	10		
13			1	2			1	2			1	2			1	2
14			1	2			1	2			1	2			1	2
15	1	7			1	8			1	9			1	10		
16	1	2			1	2			1	2			1	2		
Total	6		10		6		10		7		9		7		9	
Mean		6.5		4.2		6.7		4.3		7.7		5.0		7.6		5.2
Std. Dev.		2.95		1.99		3.01		2.11		3.30		3.16		3.23		3.42

14. ***Would you like to be given escape guidance on the maneuver to take to avoid the conflict in addition to the runway incursion alert?***

	On Final Approach		On Takeoff Roll		When Taxiing Across a Runway?		What type of advisory / guidance would you like to see during landing, during takeoff, or during taxi across a runway?
EP #	Yes	No	Yes	No	Yes	No	
1	√			√		√	Safest maneuver to use to avoid collision
2	√			√		√	Missed approach instructions
3	√		√		√		Simple escape guidance (e.g. Climb right, descend left)
4	√			√		√	Guidance by heading to go behind the conflicting aircraft
5	√		√		√		Landing: direction to go around; takeoff: "abort takeoff"; taxi: "stop taxi"
6	√			√		√	Go around or missed approach, climb & steering commands
7	√		√		√		Whatever appears to provide relatively maximal probability of incident avoidance, resolution of imminent hazards, and aircraft/crew survival
8		√		√		√	If advising, simple command: "hold short"
9	√		√		√		Landing: course & climb decision; takeoff: direction change if needed; taxi: just stop
10	√		√		√		Explicit aural annunciation and display
11		√		√	√		Stop!
12		√		√		√	
13	√		√		√		If at controlled airport, issue vector, clearance etc.; if at uncontrolled field, short statement of bese evasive action
14	√		√		√		
15		√		√		√	
16	√		√		√		Direction – stop – turn – heading? Altitude?
Total	12	4	8	8	9	7	

15. ***Please provide any additional comments that will help us in our evaluation and development of the synthetic vision system concepts.***

The following EPs responded to this question:

EP 1 Increase volume on the aircraft noise in cockpit.
EP 4 Velocity vector display on map
EP 9 Value of surface map may have increased if in a different location, closer to primary displays in multifunction display area
EP 13 Why not put traffic lights at hold lines
EP 15 Location of display needs to be within pilots heads-up field of view; land-and-hold-short planning for all cross-runway landings

Appendix J: Paired Comparisons Questionnaire

Overview: This questionnaire is designed to allow statistical analysis of your subjective assessment of situation awareness and runway incursion prevention for each of the following display configurations you evaluated today. Please look at the pictures of the display concepts when making your comparisons.

Paired Comparison Rating Instructions: Each paired comparison will be listed on the left side of the questionnaire. You will be asked to make separate comparisons based on what you experienced during the flying tasks in the simulator.

Situation Awareness: If situation awareness is <u>not</u> equal, indicate the magnitude of the difference by marking the appropriate box on the scale to the right of the comparison. The following definition of situation awareness should be used for reference:

> *The pilot's awareness and understanding of all factors that will contribute to the safe flying of their aircraft under normal and non-normal conditions.*

Runway Incursion Prevention Awareness: If runway incursion awareness is <u>not</u> equal, indicate the magnitude of the difference by marking the appropriate box on the scale to the right of the comparison. The following definition should be used for reference:

> *The pilot's awareness and understanding of the dynamic environment and degree to which he or she is aware of, and can successfully avoid, potential incursions with other aircraft or vehicles in the airport environment.*

The following example shows how to make the comparisons. Do not take an excessive amount of time on each comparison; your first impression is usually best. However, please feel free to correct any comparisons. Also, the data will be checked for consistency; if the results are inconsistent, you may be asked to clarify your responses.

Situation Awareness Comparisons	If <u>not</u> equal, how much more or how much less? Barely → Substantially							
Display Concept 'X'								
Provides (_√_ more)(__ equal)(__ less) SA than							√	
Display Concept 'Y'								

Situation Awareness Comparisons	If not equal, how much more or how much less? Barely Substantially							
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) SA than								
B + surface map with ownship only (BMO)								
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) SA than								
B + surface map with ownship + traffic (BMOT)								
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible alerting only (BA)								
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible alerting + map with ownship only (BAMO)								
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting + map with ownship + traffic (BAMOT)								
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting + perspective map (BRIPS)								
B + surface map with ownship only (BMO)								
Provides (__ more)(__ equal)(__ less) SA than								
B + surface map with ownship + traffic (BMOT)								
B + surface map with ownship only (BMO)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible alerting only (BA)								
B + surface map with ownship only (BMO)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible alerting + map with ownship only (BAMO)								
B + surface map with ownship only (BMO)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting + map with ownship + traffic (BAMOT)								
B + surface map with ownship only (BMO)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting +perspective map (BRIPS)								

Situation Awareness Comparisons	If not equal, how much more or how much less? Barely Substantially							
B + surface map with ownship + traffic (BMOT)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible alerting only (BA)								
B + surface map with ownship + traffic (BMOT)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible alerting + map with ownship only (BAMO)								
B + surface map with ownship + traffic (BMOT)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting + map with ownship + traffic (BAMOT)								
B + surface map with ownship + traffic (BMOT)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting + perspective map (BRIPS)								
B + audible alerting only (BA)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible alerting + map with ownship only (BAMO)								
B + audible alerting only (BA)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting + map with ownship + traffic (BAMOT)								
B + audible alerting only (BA)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting +perspective map (BRIPS)								
B + audible alerting + map with ownship only (BAMO)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting + map with ownship + traffic (BAMOT)								
B + audible alerting + map with ownship only (BAMO)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting +perspective map (BRIPS)								
B + audible alerting + map with ownship + traffic (BAMOT)								
Provides (__ more)(__ equal)(__ less) SA than								
B + audible & graphical alerting +perspective map (BRIPS)								

Runway Incursion Prevention	If not equal, how much more or how much less? Barely							Substantially
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + surface map + ownship only (BMO)								
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + surface map + ownship + traffic (BMOT)								
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible alerting only (BA)								
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible alerting + map + ownship (BAMO)								
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible & graphical alerting + map + ownship + traffic (BAMOT)								
Baseline round dials only (B)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible & graphical alerting + perspective map (BRIPS)								
B + surface map + ownship only (BMO)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + surface map + ownship + traffic (BMOT)								
B + surface map + ownship only (BMO)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible alerting only (BA)								
B + surface map + ownship only (BMO)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible alerting + map + ownship (BAMO)								
B + surface map + ownship only (BMO)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible & graphical alerting + map + ownship + traffic (BAMOT)								
B + surface map with ownship only (BMO)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								

B + audible & graphical alerting +perspective map (BRIPS)	

Runway Incursion Prevention	If not equal, how much more or how much less? Barely Substantially							
B + surface map + ownship + traffic (BMOT)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible alerting only (BA)								
B + surface map + ownship + traffic (BMOT)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible alerting + map + ownship (BAMO)								
B + surface map + ownship + traffic (BMOT)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible & graphical alerting + map with ownship + traffic (BAMOT)								
B + surface map + ownship + traffic (BMOT)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible & graphical alerting + perspective map (BRIPS)								
B + audible alerting only (BA)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible alerting + map + ownship (BAMO)								
B + audible alerting only (BA)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible & graphical alerting + map + ownship + traffic (BAMOT)								
B + audible alerting only (BA)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible & graphical alerting +perspective map (BRIPS)								
B + audible alerting + map + ownship (BAMO)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible & graphical alerting + map + ownship + traffic (BAMOT)								
B + audible alerting + map + ownship only (BAMO)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible & graphical alerting +perspective map (BRIPS)								

B + audible alerting + map + ownship + traffic (BAMOT)								
Provides (__ more)(__ equal)(__ less) potential for RI prevention than								
B + audible & graphical alerting +perspective map (BRIPS)								

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14. ABSTRACT

A Runway Incursion Prevention System (RIPS) has been designed under previous research to enhance airport surface operations situation awareness and provide cockpit alerts of potential runway conflict, during transport aircraft category operations, in order to prevent runway incidents while also improving operations capability. This study investigated an adaptation of RIPS for low-end general aviation operations using a fixed-based simulator at the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC). The purpose of the study was to evaluate modified RIPS aircraft-based incursion detection algorithms and associated alerting and airport surface display concepts for low-end general aviation operations. This paper gives an overview of the system, simulation study, and test results.

15. SUBJECT TERMS
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