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RUNWAY INCURSION PREVENTION SYSTEM SIMULATION EVALUATION

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Abstract

A Runway Incursion Prevention System (RIPS) was evaluated in a full mission simulation study at the NASA Langley Research center in March 2002. RIPS integrates airborne and ground-based technologies to provide (1) enhanced surface situational awareness to avoid blunders and (2) alerts of runway conflicts in order to prevent runway incidents while also improving operational capability. A series of test runs was conducted in a high fidelity simulator. The purpose of the study was to evaluate the RIPS airborne incursion detection algorithms and associated alerting and airport surface display concepts. Eight commercial airline crews participated as test subjects completing 467 test runs. This paper gives an overview of the RIPS, simulation study, and test results.

Introduction

Runway incursions are a serious aviation safety hazard. The number of reported incursions rose from 186 in 1993 to 431 in 2000, an increase of 132 percent. The Federal Aviation Administration (FAA) has begun several initiatives to reduce the incursion rate including education, training, improved airfield infrastructure (markings, signs, and lighting), and improved procedures [1]. These efforts may have contributed to the decrease in reported incursions in 2001 to 383.

The National Transportation Safety Board (NTSB) has listed runway incursions on its ten most wanted list of transportation safety improvements every year since the list began in 1990 [2]. The NTSB has also made a specific recommendation that the FAA require, at all airports with scheduled passenger service, a ground movement safety system that provides direct runway incursion warning capability to the flight crews [3].

The FAA has been developing a runway incursion alerting system for air traffic control (ATC) since the early 1990s. Any alerts generated by this system would be relayed to flight crews by ATC via voice communications. Currently, there is no system available onboard aircraft to provide the flight crew with surface situational awareness information or timely alerts of potential runway conflicts.

The key to preventing runway incursions is to ensure that pilots know:

- Where they are located
- Where other traffic is located
- Where to go on the airport surface

In the event an incursion still occurs, the flight crew and ATC should be immediately alerted to the situation.

A Runway Incursion Prevention System (RIPS) has been developed by NASA to provide this information in all visibility conditions. RIPS integrates airborne and ground-based technologies, which include flight deck displays, incursion detection algorithms, onboard position determination systems, airport surveillance systems, and controller-pilot data link communications, with a highly accurate airport geographic database. The system can prevent runway incursions by providing the pilot with (1) enhanced surface situational awareness to avoid blunders and (2) alerts of runway conflicts.

The RIPS concept was evaluated at the Dallas-Fort Worth International airport in October 2000 [4][5][6][7][8][9]. Enhancements were made to the RIPS based on the results of that testing. A full mission simulation study was conducted at NASA Langley Research Center in March 2002 to evaluate the enhanced RIPS incursion detection algorithms and associated alerting and airport surface display concepts under two pilot crew operations. Eight commercial airline crews participated as test subjects completing 467 test runs.

RIPS System Description

The RIPS flight deck displays used for the simulation were generated using a DFW airport geographic database and simulated inputs for both ownship and traffic. The database was developed based on the requirements specified in [10].

A Head-up Display (HUD) was used for monitoring during final approach and tactical guidance during rollout, turn-off, and taxi [11]. Symbology presented during landing was similar to that used by commercial HUD vendors and was implemented solely to show how this guidance can transition to surface guidance. During landing rollout, deceleration guidance to a pilot-chosen exit was provided, along with centerline and runway edge symbology. During taxi, centerline and taxiway edge symbols were provided along with centerline tracking guidance to an assigned gate location (Figure 1). Non-conformal information depicting the taxiway centerline and aircraft gear location was shown to aid in turns. The HUD functionality was provided to enable all weather capability while reducing the likelihood of runway incursion through improved position awareness.

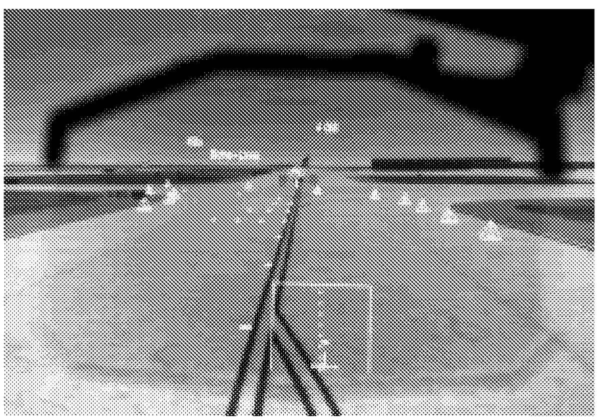

Figure 1. HUD Symbology During Taxi

An Electronic Moving Map (EMM) was displayed when selected by the pilot, or automatically at nose wheel touchdown and 80 knots. The EMM graphically depicted a perspective airport layout, current ownship position, current positions of other traffic, and ATC instructions (Figure 2). A top down overview of the airport layout was also available. Other traffic was indicated by dark blue chevrons when on the ground and cyan chevrons when airborne. Several zoom/scale levels were available to the pilot. ATC instructions were portrayed graphically and textually. Text messages were shown on a pop-up window that the pilot could remove if desired. Graphic depictions of ATC instructions included the approved route and hold-short locations. The EMM was provided to enable all weather capability while reducing the likelihood of runway incursion by supplementing awareness of position, traffic, and routing constraints.

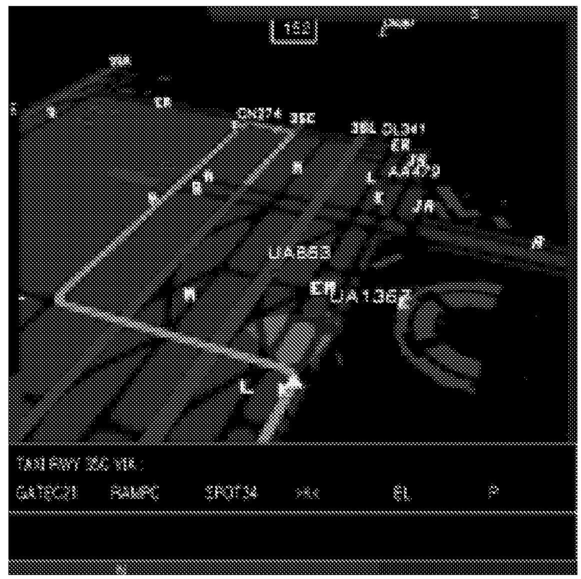

Figure 2. Electronic Moving Map

Route deviation and crossing hold alerts were also generated by RIPS and displayed to the pilot audibly. Route deviation alerts were generated if ownship left its assigned path during taxi. Crossing hold alerts were generated if ownship crossed a hold line when not cleared to do so by ATC.

Ownship position must be very accurate (<2.2m for large airports [12]) to enable both surveillance and guidance functions [8][13]. During flight testing, a Local Area Augmentation System (LAAS) was used to obtain differential Global Positioning System (GPS) corrections. The LAAS position data was then blended with inertial navigation system (INS) data and used for ownship position determination. For this simulation, ownship data was updated at 25 Hz and was extremely accurate to agree with the out-the-window database. Positional error was not introduced.

Traffic position data can be obtained by various methods. Automatic Dependent Surveillance – Broadcast (ADS-B) is a method of broadcasting data between aircraft and/or surface vehicles directly, without the use of ground-based equipment. By utilizing ADS-B, RIPS can be autonomous. Traffic data can also be sent from a ground surveillance system using Traffic Information Services – Broadcast (TIS-B). A surveillance system can acquire traffic data in the airport terminal area from several sources (Airport Surface Detection Equipment (ASDE-3) radar, Airport Target Identification System (ATIDS), ADS-B, taxiway sensor technology, etc.) and fuse this information to provide seamless coverage of the airport surface. The fused traffic data can include, baggage carts, construction equipment, etc.). For this study, data for the incurring vehicle was stored in an ADS-B data block at a 1 Hz update rate. The data was held for 1.0 second before being stored to emulate ADS-B latencies experienced during flight testing. The data for pattern traffic was stored in a TIS-B data block at a 1 Hz update rate with a 2.0 second delay to emulate TIS-B latencies experienced during flight testing. Positional error was not introduced.

Runway Incursion Alerting

RIPS monitors a runway for potential incursions anytime the ownship is to enter the runway, e.g. during final approach and landing, takeoff roll, and taxi crossing. If an incursion occurs, algorithms (that would run onboard an aircraft) generate alerts that are provided to the flight crew (audible and graphical). The RIPS algorithms do not provide maneuver guidance for taking evasive action. These aircraft-generated alerts can also be data linked to ATC so the pilots and controllers have the same information.

Two different incursion detection algorithms were evaluated during the simulation study.

The Runway Safety Monitor (RSM) incursion detection algorithm [6] takes a generic approach for generating incursion alerts and is not designed for specific incursion scenarios. The RSM monitors traffic that enters a three-dimensional virtual protection zone around a runway that is being used by the ownship. Incursion detection is based on the operational state of the ownship and traffic, as well as other criteria (separation and closure rate), to avoid false alerts. Identification, position, and altitude data is used to track the traffic in the protection zone. Velocity and heading information is calculated from position reports since, from flight test experience, these data are not always reliable. RSM generates Runway Conflict Alerts (RCA), which occur when an actual runway incursion is detected and evasive action is required to avoid a potential collision.

The PathProx detection algorithm [7] works on the same general premise as the RSM, utilizing runway zones and tracking of traffic within that zone. However, PathProx issues alerts based not only on the states of ownship and traffic, but also on criteria associated with specific scenarios. State is determined by the location relative to the runway, speed, track angle, and acceleration. PathProx is designed to handle over forty specific runway incursion scenarios and generates two types of alerts analogous to the Traffic Alert and Collision Avoidance System (TCAS) approach. A Runway Traffic Alert (RTA) cautions 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 RCAs when immediate evasive action is required.

For this simulation, the alerts were presented to the flight crew both visually (on the HUD and EMM) and audibly. An audible enunciation was made in the flight deck ("Runway Traffic, Runway Traffic" for a RTA and "Runway Conflict, Runway Conflict" for a RCA). The textual forms of these alerts were presented on both the HUD and EMM. On the EMM, the traffic symbol representing the incurring aircraft was enlarged, changed color (yellow for RTA and red for RCA), was highlighted by a target box, and included a five second projection vector. In the event the incurring traffic was not displayed on the EMM at the current zoom level, a symbol was pegged on the edge of the EMM in the direction of the traffic. Additionally, the identification tags were highlighted and information was displayed beneath the EMM ownship symbol and on the HUD indicating the distance to the incurring traffic. A target box also highlighted the incurring traffic on the HUD. Figure 3 shows the RIPS displays during a RCA.

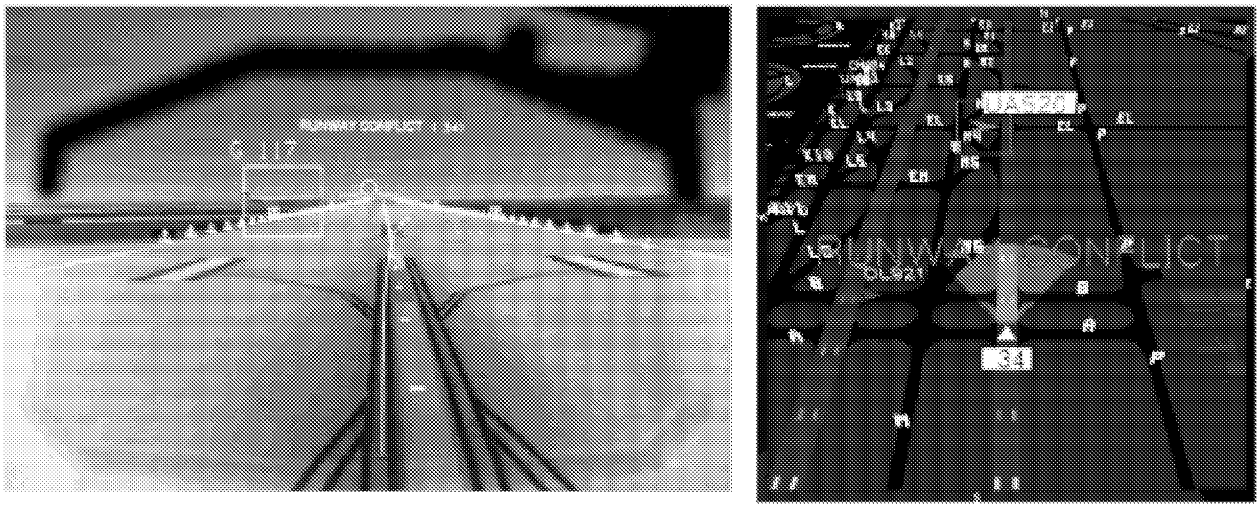

Figure 3. Incursion Alerting Flight Deck Displays

Simulation Facility

The RIPS simulation facility consisted of three stations as described below. Audio communications were maintained between all stations.

Simulator Cockpit

This study was conducted in the NASA Langley Research Flight Deck (RFD) simulator [14]. The RFD is representative of a state-of-the-art advanced subsonic transport airplane with fully reconfigurable flight deck systems. The RFD is composed of a 200° x 40° field-of-view out-the-window scenery system. The flight deck includes eight D size raster CRT displays, sidearm controllers, and multifunction display controls on the center control stand.

As shown in Figure 4, the HUD was located on the left side of the cockpit. When displayed, the EMM was located on the multifunction display for both the flying and non-flying pilot. Each crewmember had independent control of the EMM through separate control panels located on the center control stand. A Boeing 757 aircraft model with ILS autoland capability was used to provide real-time aircraft state data to the experimental system.

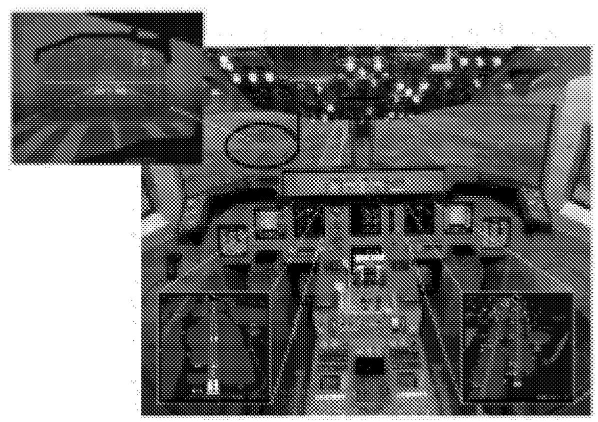

Figure 4. RFD Flight Deck

Controller Pilot Data Link Communications Station

A Controller-Communication and Situational Awareness Terminal (C-CAST) enables Controller-Pilot Data Link Communications (CPDLC) in the RIPS system [15]. C-CAST is designed to provide improved situational awareness to ATC, in addition to its CPDLC communication capabilities. A controller is shown a graphic display of the airport, overlayed with real-time airport traffic and identification (Figure 5). All traffic is tagged with an identification block that includes call sign or tail number, aircraft type, and aircraft equipment code. The map display utilizes colored identification

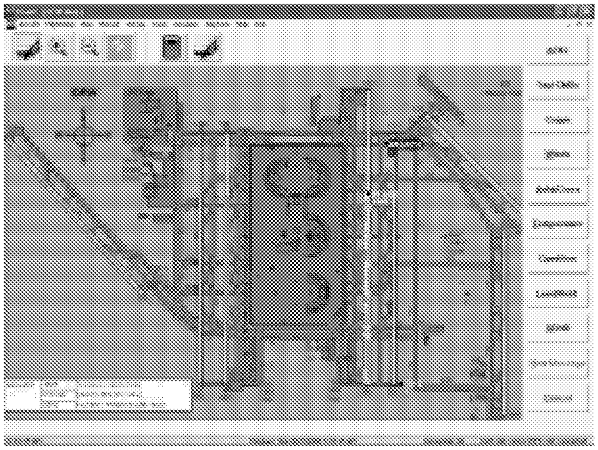

Figure 5. C-CAST Display

blocks to highlight special conditions, e.g., red indicates runway incursion alerts.

In practice, C-CAST would receive traffic information, runway hold bar information, and ground generated runway incursion alerts from a ground-based surveillance system via a TCP/IP connection. Airborne generated alerts (runway incursion, route deviation, and crossing hold) and communication messages would be downlinked to C-CAST via a CPDLC link (ICAO Aeronautical Telecommunications Network (ATN) type message transmitted via a VHF data link-Mode 2 (VDLM2) channel and transferred through a TCP/IP connection [16]). For this study, the data was simulated and sent over a network connection.

C-CAST is designed to minimize additional workload while maximizing heads-up time for tower controllers during the creation of CPDLC uplink messages through the use of voice recognition [17]. The C-CAST voice recognition system is speaker independent; therefore, the controller is not required to train the system. C-CAST also has touch screen capability that can be used to create uplink messages.

A former air traffic controller participated as test controller for the study performing the duties of both local and ground control. A realistic ATC environment was created with instructions being given to the subject pilots in the RFD and also to the recorded traffic in the pattern. A pseudo pilot gave responses for the pattern traffic. The initiation of ATC instructions was critical to the timing of the incursion scenarios.

Pseudo Pilot Station

The pseudo pilot station was established to enable verbal responses to the ATC instructions for all simulated traffic in the pattern. The pseudo pilot could view a repeater display of the EMM, HUD, out-the-window RFD simulation scene, and C-CAST to be aware of the current situation.

Simulation Operations

Data collection occurred for several different scenarios and test conditions as described below.

Test Scenarios

There were five scenarios tested during the simulation. For each scenario, the test pilot was not required to take evasive action when a RTA was issued or for any visual meteorological condition (VMC) runs. A traffic pattern was established to emulate a realistic north instrument flight rules (IFR) flow rate on the east side of DFW. The incurring traffic was interleaved into this traffic flow.

Scenario 1

The scenario began with the RFD ownship eight nautical miles (nm) from the runway threshold and on localizer and glideslope. The pilot was instructed to perform an autoland. When the ownship was 1 nm from the runway threshold, a commuter located approximately 2500 feet from the threshold was triggered to cross the runway. The pilot was to perform an automatic go-around when a RCA was issued on low visibility runs or if he felt the situation was not safe. The pilot was to bring the aircraft to a stop on the runway if landed.

Scenario 2

This scenario emulated an incident that occurred on April 1, 1999 at O'Hare International Airport. The incident occurred between two Boeing 747 aircraft. One 747 landed and after exiting the runway, made a wrong turn back onto the runway as the other 747 was departing. A collision was avoided when the departing aircraft abruptly rotated missing the crossing aircraft by 50 feet.

For this scenario, the RFD ownship emulated the departing aircraft, taxiing from the ramp to the runway for departure. A Boeing 747 landed as the ownship was approaching the runway threshold.

The 747 exited then turned back towards the runway. When the ownship reached 70 knots on takeoff roll, the 747 began crossing the runway. The pilot was to perform a rejected takeoff (RTO) when a RCA was issued on low visibility runs or if he felt the situation was not safe.

Scenario 3

This scenario emulated an incident that occurred on March 31, 1985 at the Minneapolis-St. Paul International Airport. The incident occurred between two DC-10 aircraft. One aircraft was cleared for takeoff as the other aircraft was cleared to cross the same runway. A collision was avoided when the departing aircraft rotated prematurely missing the crossing aircraft by 50 feet.

For this scenario, the RFD ownship was the incurring vehicle. The ownship was to taxi from the ramp to a departure runway, holding short of the runway along the taxi path. When, the departing Boeing 777 aircraft was approximately a fourth of the way down the runway, the ownship was cleared to cross. The pilot was to abort the crossing if a RCA was issued on low visibility runs or if he felt the situation was not safe.

Scenario 4

This scenario emulated an accident that occurred on February 1, 1991 at Los Angeles International Airport. A commuter aircraft was positioned on the runway for a mid field departure. A Boeing 737 collided with the commuter when it was cleared to land while the commuter was still holding.

The scenario began with the RFD ownship 8 nm from the runway threshold on localizer and glideslope. The pilot was instructed to perform a manual landing for the VMC visibility condition and an autoland for the low visibility condition. When the ownship was approximately two minutes from touchdown, a commuter was cleared into position and hold and remained there throughout the remainder of the scenario. The pilot was to perform an automatic go-around when a RCA was issued on low visibility runs or if he felt the situation was not safe. The pilot was to bring the aircraft to a stop on the runway if landed.

Scenario 5

This scenario was similar to scenario 4 except the ownship was the aircraft holding on the runway for departure clearance. The RFD ownship was instructed to taxi from the ramp to the departure runway and then cleared into position and hold. As the ownship was waiting for departure clearance, a Boeing 737 landed on the same runway over the ownship. The pilot was not given any instructions on how to resolve this conflict.

Test Matrix

The test matrix consisted of five control variables: subject pilot (1-16), scenario (1-5), visibility (3 nm at night (VMC), 250' daytime), detection algorithm used to drive the displays (RSM, PathProx), and display configuration (baseline (no research displays), EMM, HUD + EMM + audible alerts). Each test run contained a runway incursion event. The test was designed in this manner to give the pilots maximum exposure to the detection algorithms in order to obtain feedback. After several repetitions of a scenario, the pilots did come to anticipate the incursion; therefore, pilot reaction times will not be evaluated. Before each run, the pilots were briefed on the run conditions, e.g. approach or departure, visibility, alerting system availability, displays available, and manual or autoland approaches. The runs were conducted in a different random order for each pilot. A total of 467 test runs were completed using 16 commercial pilots as test subjects.

Data Collection

During the testing, data was taken in several formats. Subject pilots completed questionnaires to obtain their opinion of the system. Also, audio and video recordings of experimental displays and alerts were made during each test run for post test review. Finally, digital data was recorded for analysis.

Results

A summary of quantitative and qualitative results is presented. As discussed before, pilots did become familiar with each scenario after several repetitions and learned the potential incursion locations. The pilots also noted that during actual operations the workload would be more intense than that of the simulation and they would not be able to focus on the EMM as intently.

Quantitative Results

Table 1 summarizes the number of RIPS simulation runs conducted for each scenario. A total of 112 runs were possible per scenario. All runs included the baseline displays. The runs without alerting available to the pilots were the runs with the baseline displays only and baseline displays with EMM runs. When alerting was available, the pilots were given the baseline displays, HUD, EMM, and audible alerting. Even though alerting was not always displayed to the pilots, the incursion detection algorithms were running in the background during each test run to obtain data for performance analysis purposes. Many runs were omitted from the data collection due to time constraints. Most of the omitted runs were those that did not display alerts to the pilots. Note that each baseline display run was only conducted for the 3 nm visibility condition.

Table 1. RIPS Runs Conducted

	# of Runs Without Alerting Available	# of Runs With Alerting Available	# of Runs Omitted
Scenario 1	32	64	16
Scenario 2	30	64	18
Scenario 3	30	62	20
Scenario 4	32	64	16
Scenario 5	27	61	24

Scenario 1 Findings

Scenario 1 was designed so the commuter aircraft would cross the runway in enough time for the ownship to land without conflict. Many of the test subjects stated that if this same situation occurred in actual operations they would most likely land the aircraft.

The pilots completed 11 runs with the baseline display condition with seven runs ending in a landing and four runs ending in a go around.

The pilots would generally have the EMM in overview mode during the approach. For the 21 EMM display condition runs, the pilots performed a go around on six runs. Of the 15 runs where the pilot landed the aircraft, seven landings occurred in the low visibility condition. This high rate of low visibility (250') landings was most likely due to pilot familiarity with the scenario.

RSM and PathProx alerts were generated during 64 runs. The RSM RCA alert occurred when the ownship was approximately 0.75 nm from the threshold. PathProx generated RTA alerts nominally when the ownship was 0.80 nm from the runway threshold and RCA alerts when 0.60 nm from the threshold. Fifty-eight (90 percent) of these runs ended in a go around, whereas, only 31 percent of the non-alert (baseline and EMM) runs ended in go around.

Figure 6 shows the average of the go around (when go around button was pressed) and minimum altitudes for the various display and alerting conditions for all pilots. The average altitudes that the RSM and PathProx alerts occurred are also indicated. The incurring aircraft was triggered to cross the runway when the ownship was at approximately 370 feet altitude. Runs that ended in the pilot landing the aircraft are not included in the figure.

When provided with RSM alerts, the pilots generally performed a go around sooner than when provided with PathProx alerts. This can be attributed to the fact that RSM RCA alerts occurred sooner than PathProx RCA alerts. It is shown that alerting provided a greater safety margin over using the EMM alone in the low visibility condition.

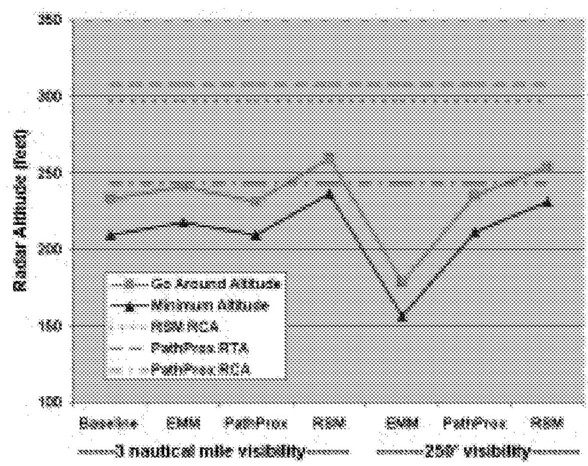

Figure 6. Scenario 1 Results

Scenario 2 Findings

Ten baseline display runs were conducted. The pilots saw the traffic out the window and were able to perform a RTO on seven runs. During the other three runs, the pilots did not see the crossing traffic until they were rotating the aircraft and taking off.

During the 20 EMM display runs, the pilots took off on 10 runs with seven occurring in low visibility conditions. The pilots either did not see the traffic at all or noticed the traffic too late on the EMM or out the window to perform a RTO. During the 10 RTOs, half of the pilots noticed the traffic crossing out the window while the other half noticed the traffic moving on the EMM.

RSM (32 runs) and PathProx (32 runs) alerts were generated during 64 runs. The pilots performed a RTO on all of these runs. The RSM alert was generated when the ownship reached approximately 92 knots. PathProx generated RTA alerts nominally when the ownship reached 90 knots and RCA alerts at 98 knots.

Figure 7 shows the average distance from the threshold that the ownship came to a stop after the RTO for all pilots. The average distance the RSM and PathProx alerts occurred from the threshold are also indicated. The incurring aircraft crossed the runway approximately 5500’ from the threshold. Runs in which the pilot took off are not included in the figure.

On average, the ownship was brought to a stop sooner when the pilots were provided with incursion alerts than when using the baseline configuration or EMM only. The most notable difference occurred in the low visibility condition, where the ownship came to a stop, on average, 1000 feet earlier with incursion alerts displayed.

The pilots were able to stop the aircraft a few hundred feet sooner when provided with RSM alerts versus PathProx alerts. This can be attributed to the fact that RSM RCA alerts occurred sooner than PathProx RCA alerts.

During the PathProx runs, the pilot performed the RTO after the RTA 40 percent of the time. For this scenario, the RCA occurred very soon after the RTA (approximately three seconds). On one run a RTA was not generated and the pilot was alerted directly with a RCA.

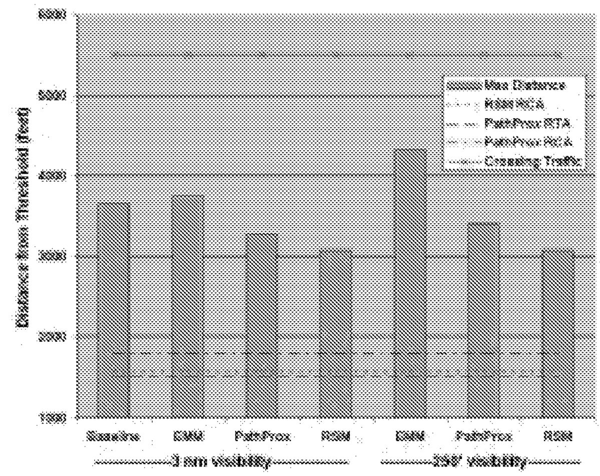

Figure 7. Scenario 2 Results

Scenario 3 Findings

Most crews worked out a procedure that the non-flying pilot would scan the EMM, if available, for departing traffic before crossing a runway. Both crew members would visually scan out the window.

Ten baseline display runs were conducted. For three of these runs, the pilots crossed the runway in front of departing traffic. The pilots noticed the traffic on takeoff roll out the window for the other seven runs and did not cross the hold line.

For the 20 EMM display condition runs, the pilots crossed the runway only twice during the low visibility condition. During the other 18 runs, the pilots noticed the departing traffic either on the EMM (14 runs) or out the window (four runs) and did not cross into the runway.

The pilot had the capability of receiving incursion alerts on 62 runs. Interestingly, pilots crossed the hold line and alerts were generated on only nine of these runs. Three of these crossings were made at the principal investigator’s request so the pilots would have the opportunity to evaluate the alerting criteria and display symbology. For the remaining 53 runs, the pilots saw the departing traffic on the EMM (48 runs) or out the window (five runs) and did not cross the hold line.

These results show that the EMM was very effective in preventing runway incursions for the ownship taxi crossing scenario as long as the departing traffic is visible on the EMM.

Scenario 4 Findings

The pilots were able to acquire the traffic in position and hold visually on the runway for each of the 10 baseline display runs and performed a go around maneuver.

During the 22 EMM display runs, the pilots saw the traffic holding on the runway on the EMM overview and performed a go around for 20 runs. On two VMC runs, while performing manual landings, the pilots did not notice the traffic on the EMM or out the window and landed, hitting the runway traffic.

Alerting was available to the pilots on 64 runs. During most of these runs, the pilots were monitoring the EMM overview display on approach and viewed the traffic either entering or holding on the runway. The pilots performed a go around before any alerts were generated on 14 runs (13 RSM and one PathProx run). On 12 other runs, the pilots performed a go around prior to alerts being displayed; however, PathProx generated RTA and RCA alerts after the go around. The pilots commented that it is not desirable for alerts to occur after a go around is initiated. For the remaining runs, even if the pilot saw the runway traffic on the EMM or out the window, they continued until after receiving alerts before performing a go around. Go around maneuvers were initiated after the RTA alert for 31 percent of the PathProx runs.

Figure 8 shows the average of the go around and minimum altitudes for the various display and alerting conditions for all pilots. The average altitudes that the RSM and PathProx alerts occurred are also indicated. Runs that ended in the pilot landing the aircraft are not included in the figure.

On average, for the baseline display condition, a go around was not conducted until around 100 ft altitude. The EMM and incursion detection algorithms increased the go around altitude by approximately 200 feet, providing a greater safety margin.

As with scenario 1, the pilots generally performed a go around sooner when provided with RSM alerts than when provided with PathProx alerts. This can be attributed to the fact that RSM RCA alerts occurred sooner than PathProx RCA alerts.

The results show that the EMM in overview mode was very effective in giving the pilots early awareness of runway traffic while on approach. In 58 percent of the low visibility EMM display condition runs, the pilots performed a go around before reaching 600 feet altitude when they had visual uncertainty. Use of the EMM only, however, still resulted in two runway collisions.

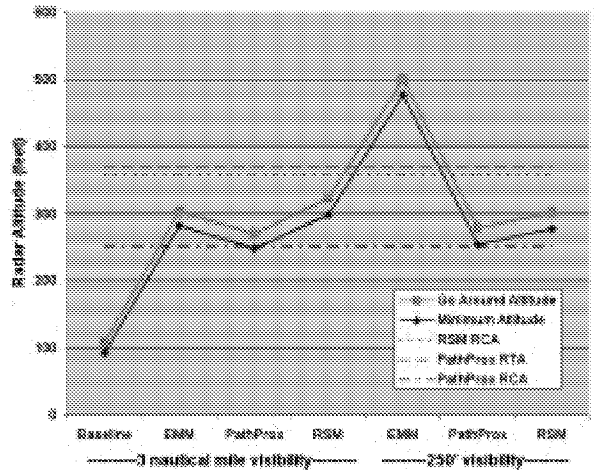

Figure 8. Scenario 4 Results

Scenario 5 Findings

During the eight baseline display runs, the crew was not aware that an aircraft was landing on the same runway until it passed overhead. Once the pilots became familiar with the scenario, they would sometimes notice the aircraft on final out the window as they were taking the runway.

Nineteen EMM display runs were conducted. Most pilots had the EMM set on the 5 nm zoom level with the ATC message window removed to have the maximum rear viewing distance (approximately 0.62 nm). The pilots noticed the traffic on final out the window when taking the runway during four runs, saw the traffic on the EMM while in position and hold during 11 runs, and did not notice the traffic until it passed overhead on four runs.

The pilots received both RSM (31 runs) and PathProx (30 runs) alerts on 61 runs. The alerts provided more advance warning than using the EMM only. For RSM, alerts were generated when the approaching traffic was approximately 1 nm from the threshold. PathProx also generated RTA alerts when the approaching traffic was approximately 1 nm from the threshold and RCA alerts when 0.6 nm from the threshold. Initially, since the approaching traffic was out of the range displayed on the EMM, the audible alert would be sounded and a traffic symbol would be pegged on the EMM behind the ownship symbol.

The procedure all pilots followed when they first became aware of the landing traffic was to notify ATC of the situation in the hope that there would be enough time for ATC to instruct and the landing aircraft to perform a go around. This was all that there was time to do, even with alerting. Some pilots tried to pull off the runway, and were successful occasionally; however, it takes time for the engines to spool up enough to move the aircraft. All of the pilots recommended that the detection algorithms be modified to provide the alerts sooner in this situation.

Qualitative Results

Qualitative questionnaire data and comments were obtained from the subject pilots during the simulation study and will be incorporated into future evaluations of the system.

Several comments and suggestions were made regarding the HUD, EMM, and alerting display symbology. On the HUD, 81 percent of the pilots thought the taxi turn symbology was effective in providing guidance during turns. Seventy-five percent of the pilots stated that nosewheel touchdown and 80 kts were the proper criteria to use for displaying the EMM automatically. Other suggestions were to use speed brake or spoiler deployment as criteria. All pilots stated that it was important to indicate direction of travel of traffic on the EMM and that the chevron shape was preferred. Eighty-one percent of the pilots thought that using dark/light blue to color code traffic when on the ground and airborne was appropriate; however, some suggested a more dramatic color difference such as brown/blue. Half of the pilots commented that a prediction vector provided useful information for the incurring traffic and that they would like to see prediction vectors used for traffic of concern in the vicinity of the ownship or for rapidly accelerating traffic. Sixty-three percent of the pilots thought that using an edge symbol to indicate the direction of incurring traffic that is off the current EMM scale was adequate and automatic zooming was not recommended. Most pilots stated that the target box was a very effective method of highlighting the incurring traffic on both the HUD and EMM. The effectiveness and usefulness of displaying the distance to incurring traffic is questionable with half of the pilots indicating they did not use the information and an additional 25 percent indicating they did not notice the information.

Regarding the three types of alerting displays, the audible alert was the first to bring the incursion to the pilot's attention. Half of the pilots indicated they noticed the audible alert in conjunction with alerting on the HUD, EMM, or HUD and EMM depending on their seat location. Fifty-six percent of the pilots stated that the audible alert and EMM combination would provide a minimal effective incursion prevention configuration, while 69 percent stated the audible alert combined with the HUD and EMM would be an optimal configuration. Eighty-one percent felt that using an EMM alone without alerting would be effective in detecting potential runway incursions. Some pilots commented that pilots might take unnecessary action or miss incursions without alerting.

Seventy-five percent of the pilots thought that it would be beneficial to have a two-stage alerting system like PathProx where the first alert received was cautionary in nature and corrective action was not required. This allows crew members to become aware of potential conflicts early and gives more time to evaluate the situation and strategize solutions. When asked if the alerts generated were provided in a timely manner, allowing sufficient time to react to the potential conflict, 75 percent stated the PathProx alerts were timely and 69 percent stated the RSM alerts were timely. All pilots thought that both algorithms alerted too late in the situation where the ownship was in take-off position while another aircraft was landing on the same runway. The pilots also did not want any alerts to occur after a go around maneuver was initiated. Most pilots did not want the algorithms to provide maneuver guidance because too many variables are involved.

All of the subject pilots were complimentary of the RIPS. The pilots stated that RIPS was an effective situational awareness and safety system. They all felt safer with RIPS onboard.

Summary

A Runway Incursion Prevention System was evaluated in a full mission simulation study. The purpose of the simulation was to evaluate incursion detection algorithms and alerting and airport surface display concepts under two pilot crew operations for various scenarios and test conditions.

Results of the simulation study indicate that providing pilots with incursion alerts increases the safety margin over use of the EMM or baseline displays alone, particularly for the low visibility condition. While pilot monitoring of the EMM was very effective in preventing incursions on approach and during taxi, this requires close monitoring of the display. An incursion detection system will eliminate missed detections due to human error.

Determining when to alert pilots to a potential incursion situation is very critical. Chances of unnecessary maneuvers (go arounds or RTOs) increase if alerts are provided too early. Conversely, chances of collisions increase if alerts are provided too late. Incursion alerting proved to occur in a timely manner, allowing sufficient time to react to potential conflicts for the scenarios tested, except for the situation where the ownship is located on the runway waiting for take off clearance and an aircraft is landing on the same runway.

The subject pilots offered many suggestions for modifications to the detection algorithms and alerting and airport surface displays. The RIPS will be enhanced based on the results of this study for future system evaluations.

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