

Runway incursion prevention system testing at the Wallops Flight Facility

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ABSTRACT

A Runway Incursion Prevention System (RIPS) integrated with a Synthetic Vision System concept (SVS) was tested at the Reno/Tahoe International Airport (RNO) and Wallops Flight Facility (WAL) in the summer of 2004. RIPS provides enhanced surface situational awareness and alerts of runway conflicts in order to prevent runway incidents while also improving operational capability. A series of test runs was conducted using a Gulfstream-V (G-V) aircraft as the test platform and a NASA test aircraft and a NASA test van as incurring traffic. The purpose of the study, from the RIPS perspective, was to evaluate the RIPS airborne incursion detection algorithms and associated alerting and airport surface display concepts, focusing on crossing runway incursion scenarios. This paper gives an overview of the RIPS, WAL flight test activities, and WAL test results.

Keywords: Runway incursion prevention, airport surface safety, synthetic vision, airport surface map

1. INTRODUCTION

Runway incursions are a serious aviation safety hazard. According to the Federal Aviation Administration (FAA)¹, during the four year period from fiscal year (FY) 2000 through FY 2003, there were over 262 million aircraft operations and 1,475 runway incursions reported at United States towered airports – approximately 5.6 runway incursions for every one million operations. This averages out to about one runway incursion per day. During this period seven incursions resulted in collisions with one of those resulting in four fatalities.

The FAA is committed to reducing the number and rate of runway incursions and has begun several initiatives including education, training, improved airfield infrastructure (markings, signs, and lighting), and improved procedures. None of these initiatives involve technology solutions *for the aircraft*.

The National Transportation Safety Board (NTSB) also considers runway incursions to be a serious issue and has included runway incursion on its most wanted list of transportation safety improvements since the list began in 1990². The NTSB has 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 crew³.

NASA has developed a Runway Incursion Prevention System (RIPS) to improve airport safety by providing supplemental surface situational awareness information and guidance cues, and alerts of runway conflicts and route deviations directly to the flight crew. RIPS integrates airborne and ground-based technologies, which include advanced flight deck displays, incursion detection algorithms, onboard positioning systems, airport surveillance systems, and controller-pilot data link communications (CPDLC), with a highly accurate airport geographic database.

The RIPS concept was evaluated at the Dallas-Fort Worth International airport in October 2000⁴ and during a full mission simulation study at NASA Langley Research Center in March 2002⁵. The focus of these studies was to evaluate the system under single runway incursion situations. Enhancements were made to RIPS based on the results of this testing. The system was also modified to enable incursion detection for crossing runway incidents.

This paper describes the results of a flight test conducted in the summer of 2004 at the RNO and WAL airports, entitled the Gulfstream-V Synthetic vision system Integrated Technology Evaluation (GVSITE) flight test. This study, from the RIPS perspective, was to evaluate the RIPS airborne incursion detection algorithms and associated alerting and airport surface display concepts, focusing on crossing runway incursion scenarios.

2. SYSTEM DESCRIPTION

The research system included several test vehicles and technology subsystems that are described below.

2.1. Test vehicles

A Gulfstream-owned and operated G-V aircraft was used as the test platform for the RIPS (Figure 1). This G-V has been used extensively for flight test research and development. The cabin of the G-V was modified by Gulfstream to contain pallets that were outfitted with NASA research equipment. The G-V is a Mach .87, 90,000 pound aircraft, with a maximum cruise altitude of 51,000 feet (ft) MSL.

A NASA Beech Be-200 aircraft was used primarily as the incurring traffic. The Be-200 is an 8,420 pound, 10 passenger aircraft, with a certified ceiling of 35,000 ft. The aircraft was outfitted with a Universal Access Transceiver (UAT) data link system that enabled transfer of Automatic Dependent Surveillance – Broadcast (ADS-B) positioning data with the G-V.

A NASA van was also used during the testing as incurring traffic on selected scenarios and for false alert testing, by parking up to but behind hold lines. The van was also outfitted with a UAT data link system for transfer of ADS-B positioning data with the G-V.



Figure 1. Flight test vehicles

2.2. Research displays

The RIPS flight deck displays were integrated with the SVS flight deck displays resulting in one display system for all phases of flight – from enroute to landing to taxi to take-off. The displays were shown to the Evaluation Pilot (EP) seated on the left side of the G-V on a Head-up Display (HUD) and on a head-down Primary Flight Display (PFD) and multifunction display. The multifunction display could show either a Navigation Display (ND) or an Electronic Moving Map (EMM) of the airport surface. The research displays were generated using a 53 by 64 nautical mile hybrid terrain database of the WAL area and a WAL airport geographic database developed to RTCA standards⁶.

Four displays conditions were evaluated during the WAL testing – Baseline with and without FLIR imagery on the HUD and Advanced SVS with and without the HUD.

2.2.1. Baseline display condition

The Baseline condition (Figure 2) was designed to be representative of currently available displays. Standard stroke symbology was shown on the HUD. The head-down displays represented a conventional PFD and ND. The ND was co-planar with a map-centered Terrain Awareness Warning System (TAWS) display and a Vertical Situation Display (VSD). An airport surface map could be shown in place of the ND, if manually selected by the EP. The Baseline surface map showed the airport layout from a top-down view and displayed the locations of the G-V and traffic. Runway incursion alerts and synthetic terrain information was not presented on any of the displays for the Baseline condition.

The Baseline Enhanced Vision System (EVS) condition consisted of the same symbology used for the Baseline condition with the addition of FLIR imagery on the HUD through the raster channel.

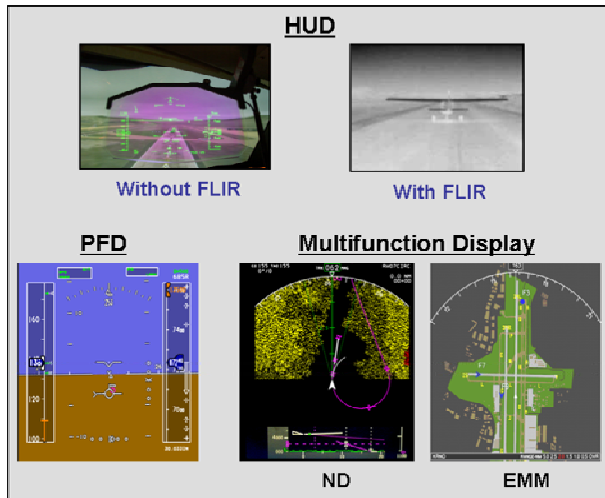


Figure 2. Baseline display condition

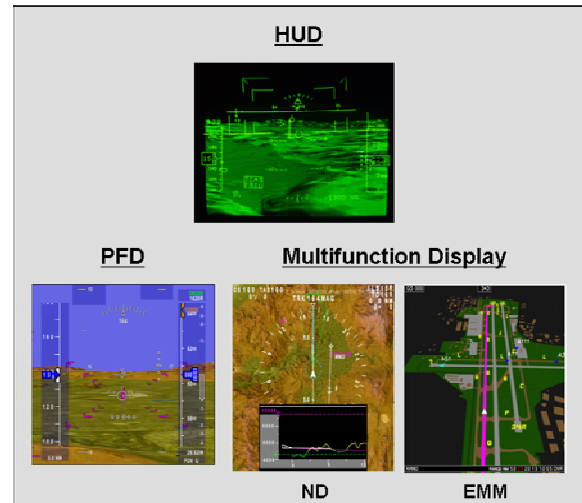


Figure 3. Advanced SVS display condition

2.2.2. Advanced display condition

The Advanced SVS display condition (Figure 3) combined the advanced SVS display system with the full functionality of the RIPS. The PFD and HUD showed terrain information; conventional flight symbology; advanced pathway, approach, rollout, turn-off and taxi guidance; non-conformal taxi turn symbology; airborne and surface traffic; and RIPS alerts. The ND showed terrain information in addition to the TAWS warning and caution overlays, VSD, airborne and surface traffic, and RIPS alerts. Upon landing and during taxi, the EMM was displayed in place of the ND. The EMM showed a perspective track-up view of the airport layout, current G-V and traffic locations, air traffic control (ATC) instructions (including the approved taxi route and hold short locations), and RIPS alerts. Previous testing demonstrated the ability to data link ATC instructions to the aircraft from ground systems^{4,7}. For this testing, the ATC instructions were entered into the system from a workstation onboard the G-V. A top down North-up overview of the airport layout was also available on the EMM.

The Advanced SVS-No HUD condition was exactly the same as the Advanced SVS condition except the HUD was not utilized. The EPs primary flight reference was strictly head-down.

2.3. RIPS alerting

2.3.1. Runway incursion alerting

RIPS monitored a runway for potential incursions any time the G-V was to enter the runway – during final approach and landing, take-off roll, and taxi crossing. Algorithms were running onboard the G-V that monitored for incursions based on ownship and traffic state information. If an incursion was detected, alerts were generated and presented to the flight crew (audible and graphical). The RIPS algorithms do not provide maneuver guidance for taking evasive action. Although not done for this test, these aircraft-generated alerts could be data linked to ATC so the pilots and controllers would have the same information.

Two different incursion detection algorithms were evaluated during this testing.

The Runway Safety Monitor (RSM) incursion detection⁸ algorithm took a generic approach for detecting and generating incursion alerts and was not designed for specific scenarios. The RSM monitored traffic that entered a three-dimensional virtual protection zone around the runway that was being used by the G-V. Incursion detection was based on the operational state of the G-V and traffic, as well as other criteria (including separation and closure rate), to avoid false alerts. Identification, position, and altitude data was used to track the traffic in the protection zone. Traffic data

projections were calculated since updates were not received at consistent intervals. RSM generated Runway Conflict Alerts (RCA), which occur when an actual runway incursion is detected and evasive action is required to avoid a potential collision. Information provided with each alert included identification of the incurring traffic and separation distance to potential conflict.

The PathProx incursion detection algorithm⁹ was designed to handle over 40 specific runway incursion scenarios. Alerts were issued based on the states of the G-V and traffic and on conditions including position, speed, and track angle. PathProx generated two types of alerts analogous to the Traffic Alert and Collision Avoidance System (TCAS) approach. A Runway Traffic Alert (RTA) cautioned the flight crew of a potential incursion or an incursion where the conflict did not yet require evasive action. The crew could take evasive action, however, at their discretion. PathProx also generated RCAs when immediate evasive action was required. Information provided with each alert included identification of the incurring traffic, the runway associated with the traffic, and separation distance between the traffic and G-V.

The alerts were presented to the flight crew both visually on the displays 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 the HUD, PFD and ND/EMM. On the ND and EMM, the traffic symbol representing the incurring vehicle was enlarged, changed color (yellow for RTA and red for RCA) and was highlighted by a target designator box. The identification tag was also highlighted. A target designator box also highlighted the incurring traffic on the HUD and PFD. In the event the incurring traffic symbol was not shown because of the display scale or field-of-view, a symbol was pegged on the edge of the display in the direction of the traffic. The distance to the conflict was also shown on all the displays. Figure 4 shows the PFD and EMM during a RCA.



Figure 4. PFD and EMM during RCA

2.3.2. Other alerting

Audible route deviation and crossing hold alerts were also generated by RIPS. Route deviation alerts were generated if the G-V left its assigned path during taxi. Crossing hold alerts were generated if the G-V crossed a hold line when not cleared to do so by ATC.

2.4. Position sources

2.4.1. Ownship position determination

An AshTech Global Positioning System (GPS) was used to obtain differentially corrected position information onboard the G-V. The one second updates of latitude, longitude, and altitude were blended with inertial accelerations to compute high rate position updates.

2.4.2. Traffic position determination

All of the test vehicles were equipped with ADS-B - a method of broadcasting state information between aircraft and/or surface vehicles directly, without the use of ground equipment. The messages contained position, altitude, ground speed, track, air/ground status, navigation uncertainty, flight identifier, aircraft ICAO address, and aircraft type. For this test, ADS-B messages were broadcast and received by the G-V, Be-200, and test van at a normal rate of twice per second using a UAT data link.

3. FLIGHT TEST OPERATIONS

The GVSITE flight test was conducted in July and August of 2004 at RNO and WAL. Since GVSITE RNO testing was performed during normal airport operations, a subset of RIPS test conditions were conducted due to ATC restrictions in place. A full matrix of RIPS testing was completed at WAL and the following data analysis is restricted to the WAL test phase.

During the WAL testing, the EP occupied the left seat of the G-V, where the research displays were located. A safety pilot (SP) occupied the unmodified, right seat G-V station. The EP was kept “in the blind” to the greatest extent possible during the testing. The RIPS tests were conducted during other SVS technology tests to keep the EP from knowing when and which scenarios were forthcoming. Data collection occurred for several different scenarios and test conditions as described below.

3.1. Test scenarios

Seven incursion scenarios were developed for the WAL testing. Four of these represent the most common types of crossing runway incursion situations. All the scenarios were implemented in a NASA simulator prior to flight testing in order to determine the proper timing and procedures for all vehicles involved to ensure safety.

The EP was trained to perform a rejected take-off (RTO) if an incursion alert (“Runway Conflict”) was given during take-off, perform a go-around if an incursion alert was given while airborne, and stop if an incursion alert was given during taxi. These instructions were reviewed during pre-test simulation training and briefed before each flight.

3.1.1. Scenario 1 – departure/departure

Scenario 1 tested the incursion situation in which two aircraft are departing simultaneously on crossing runways (Figure 5). The scenario began with the G-V in position and hold for departure. As soon as the G-V initiated its take-off roll, the Be-200 emulated a departure on Runway 35 by accelerating to and holding 45 kts to 50 kts for as long as possible. The G-V EP was trained to perform an RTO if an incursion alert was issued. Otherwise, the SP took control and initiated an RTO by 80 kts if using Runway 10 or 60 kts if using Runway 28. Both aircraft were required to stop before reaching the crossing runway.

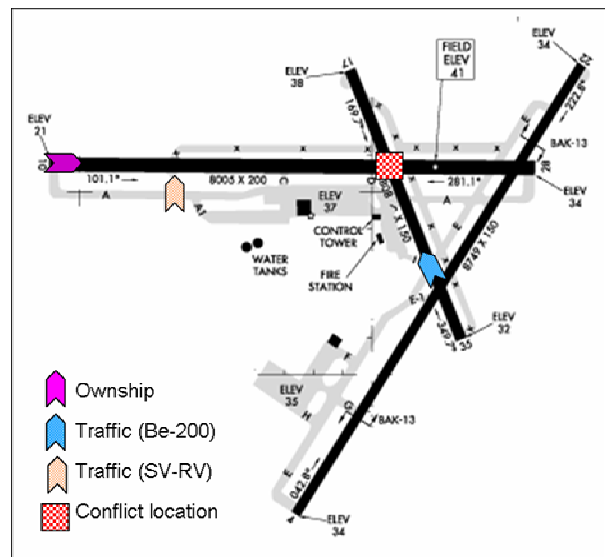


Figure 5. WAL Scenario 1 configuration

3.1.2. Scenario 2 – departure/arrival

Scenario 2 tested the case where one aircraft is departing and at the same time another aircraft is landing on an intersecting runway. The EP was instructed by the SP to begin the departure when the Be-200, unbeknownst to the EP,

was 1.5 nm from the threshold of Runway 17. The EP was trained to perform an RTO if an incursion alert was issued. Otherwise, the SP took control and performed an RTO by 80 kts if using Runway 10 or 60 kts if using Runway 28, stopping before reaching Runway 17. The Be-200 was required to initiate a go-around at 200 ft AGL.

3.1.3. Scenario 3 – arrival/departure

Scenario 3 was similar to Scenario 2 except the G-V was arriving and the Be-200 was departing. The Be-200 began a “take-off roll” on Runway 35 when the G-V was approximately 1.5 nm from the runway threshold. The Be-200 accelerated to and held 45 kts to 50 kts for as long as possible, stopping before reaching the crossing runway. The EP was trained to initiate a go-around (using the Take-off, Go-Around (TOGA) button) if an incursion alert was issued. The EP was then instructed to either continue the go-around or land the aircraft in order to expedite the testing. On test runs where alerting was not presented in the flight deck, the SP was required to perform a go-around no lower than 200 ft AGL (approximately 0.5 nm from the threshold) if the EP did not see the traffic and perform the go-around.

3.1.4. Scenario 4 – arrival/arrival

Scenario 4 tested the incursion scenario where two aircraft are arriving simultaneously to crossing runways. The G-V was approaching Runway 28 while the Be-200 was approaching Runway 22. The Be-200 made speed adjustments so both aircraft would be approximately 2 nm from the threshold at the same time. The EP was trained to initiate a go-around when an incursion alert was issued. Otherwise, the SP was required to perform a go-around no lower than 200 ft AGL. The Be-200 was required to conduct a go-around at 200 ft AGL.

3.1.5. Scenario 5 – taxi crossing/departure

Scenario 5 was designed to evaluate the taxi crossing situation. The G-V was taxiing on Taxiway A toward Runway 10. When the G-V was approximately 900 ft from Runway 17 (just crossing Taxiway E), a call was made from the control tower for the Be-200 to begin its ‘departure’. This call was made on a radio frequency not monitored by the EP. The Be-200 accelerated to and held 50 kts for as long as possible, stopping before Taxiway A. The EP was trained to stop if an incursion alert was issued. Otherwise, the SP was required to stop the G-V before reaching Runway 17.

3.1.6. Scenario 6 – take-off hold/arrival

Scenario 6 was developed to evaluate the situation where an aircraft is in position and hold while another aircraft is approaching the same runway for a landing. As the G-V was in position and hold, the Be-200 approached the runway. The EP was instructed to not maneuver upon receiving an incursion alert. The Be-200 was required to conduct a go-around no lower than 200 ft AGL.

3.1.7. Scenario 7 – arrival/take-off hold

Scenario 7 was similar to Scenario 6 except the G-V was on approach and the Be-200 or NASA test van was in position and hold. The EP was trained to initiate a go-around if an incursion alert was issued and to not over-fly the traffic on the runway. Otherwise, the SP was required to perform a go-around no lower than 200 ft AGL.

3.2. Test matrix

The test matrix consisted of four control variables: evaluation pilot (1-8), scenario (1-7), detection algorithm used to drive the displays (RSM, PathProx), and display configuration (Baseline, Baseline EVS, Advanced SVS, Advanced SVS - No HUD). The test runs were conducted in both day and night conditions. A total of 81 test runs were completed using eight commercial, FAA, and manufacturer pilots as test subjects.

4. RESULTS

A summary of quantitative and qualitative results is presented. Distances presented for the G-V are relative to the nose of the aircraft. There is a certain amount of variability in the results due to the timing of the scenarios and vehicle performance. Although every attempt was made to conduct each test run for each scenario in the same manner, it is impossible for the vehicles to begin in the exact same position, use the same approach speeds, use the same acceleration rates, stay on the same path, etc. repeatedly.

4.1. Quantitative results

During each test run, data were simultaneously collected on the performance of both incursion detection algorithms, however, only one method was chosen to drive the flight deck displays when required by the display configuration. Of the 81 test runs completed, 51 required alerts be displayed to the EP. During these 51 runs, the RSM was chosen as the alert source 84 percent of the time. The decision was made to primarily show the RSM alerting due to a traffic data interface issue with PathProx. PathProx was designed under the assumption that the traffic data block would be cleared with each new data update, as been done for previous NASA testing. For this test, however, the data was not cleared and PathProx would sometimes use erroneous data for the traffic. This issue was not determined until post-test analysis.

Table 1 summarizes the overall performance of each alerting method. The RSM algorithm alert generation rate was 100 percent with no missed or false alerts during the course of the testing. In one instance the RSM did not generate an alert because the G-V EP saw the traffic on the runway and performed a go-around early before an alert was required. PathProx alerted as expected on 41 percent of the runs, while missing alerts on 59 percent of the runs. Thirty-seven of the missed alerts were due to the data interface issue discussed above. One of the missed alerts for Scenario 2 was due to an issue with the PathProx logic, where the traffic did not transition to the proper state on arrival. The remaining nine missed alerts were due to the timing of the scenario. This most often occurred on Scenario 5 (taxi crossing/departure) where the SP would call for the EP to stop before the alerting criteria were met. Two of the false alerts were caused by a discrepancy between the PathProx alert thresholds and a WAL hold line location. The other five false alerts were caused by the data interface issue.

Scenario	Number of runs	RSM		PathProx			
		Alerts	No alert - not required	Alerts	Missed alerts	No alert - not required	False alerts
1	8	8		2	6		
2	7	7		2	5		
3	21	21		10	11		5
4	8	8		2	6		
5	7	7		0	7		
6	7	7		4	3		
7	23	22	1	13	9	1	1
Other							1
Total	81	80	1	33	47	1	7

Table 1. Alerting method performance

4.1.1. Scenario 1 departure/departure results

Figure 6 shows the distance from the threshold of the G-V when the RTO was initiated and when the PathProx and RSM alerts were generated. The figure also shows the location of the Be-200 relative to the G-V when the Be-200 began accelerating. The Be-200 was on a crossing runway 5593 ft from the threshold of the G-V runway. The RTO initiation point was determined by a reduction in the throttle position.

During the departure/departure crossing runway scenario, the RSM alert generally occurred two to four seconds after the Be-200 began accelerating. The EP generally initiated the RTO two seconds after the RSM alert was generated. As

can be seen in Figure 6, on one of the Advanced SVS – No HUD runs, the RSM did not alert until more than six seconds after the Be-200 began accelerating. In this instance, the Be-200 made a gradual, slow acceleration, not exceeding 13 kts for five seconds. The RSM alerted one second after the Be-200 accelerated rapidly.

Figure 6 also shows that PathProx only alerted on two test runs. One of these alerts occurred after the RTO. PathProx did not generate alerts on six runs due to the data interface issue described in Section 4.1.

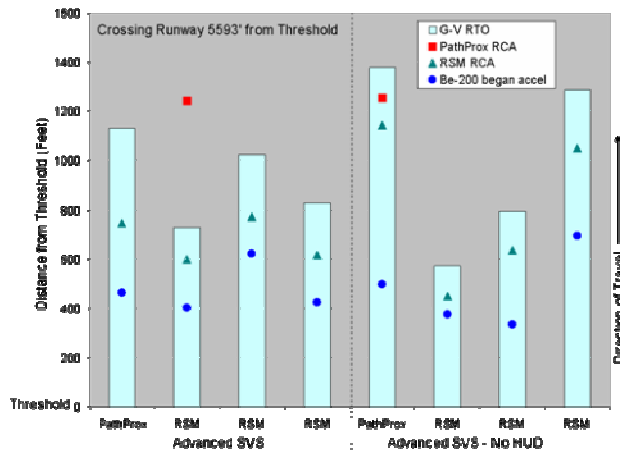


Figure 6. Scenario 1 results

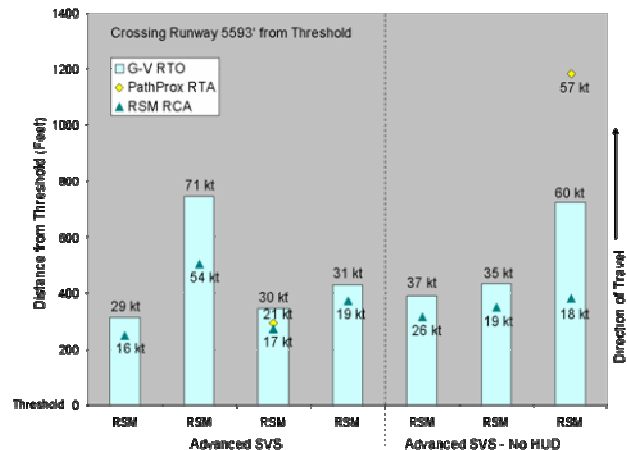


Figure 7. Scenario 2 results

4.1.2. Scenario 2 departure/arrival results

Figure 7 shows the distance from the threshold and speed of the G-V when the RTO was initiated and when the PathProx and RSM alerts were generated. The Be-200 was approaching a crossing runway 5593 ft from the threshold of the G-V runway. The RTO initiation point was determined by a reduction in the throttle position.

The RSM generated an alert very consistently on six of the departure/arrival crossing runway test runs. For these runs, the alert was generated when the G-V was an average distance of 323 ft from the threshold and at an average speed of 19 kts. On one run the RSM alerted slightly later, when the G-V was 504 ft from the threshold and at 54 kts. This was caused by an earlier departure roll by the G-V when the Be-200 was further from the threshold of the crossing runway. Overall, the EP initiated the RTO approximately two seconds after the RSM alert was generated.

PathProx alerted on two test runs, with one of the alerts occurring after the RTO. Three of the missed alerts were caused by the data interface issue. One of the missed alerts was due to a PathProx logic issue, where the Be-200 was not transitioned to the proper state upon arrival. This logic issue was resolved post-test. The final missed alert was caused by a scenario timing issue where the G-V began an early departure roll.

4.1.3. Scenario 3 arrival/departure results

Figure 8 shows the distance from the threshold of the G-V when the G-V go-around was initiated and when the PathProx and RSM alerts were generated. The go-around initiation point was determined by the moment the TOGA button was pressed, if available. Otherwise, an increase in throttle position was used.

During the arrival/departure crossing runway scenario, RSM alerted an average distance of 1.0 nm from the runway threshold and at an average altitude of 296 ft AGL. PathProx alerted on 10 runs with average alerting distances and speeds of 0.98 nm and 307 ft AGL, respectively, for the RTA and 0.77 nm and 252 ft AGL, respectively, for the RCA. Ten of the 11 missed PathProx alerts were caused by the data interface issue. The other missed alert was due to the scenario timing. PathProx also generated five false alerts that were caused by the data interface issue.

During the Baseline and Baseline EVS configuration – which did not include RIPS alerting in the flight deck - the EP saw the departing traffic and initiated a go-around on only five of the 14 (36 percent) runs at an average of 0.73 nm from the threshold. On the other nine runs, the SP initiated the go-around. The EP always initiated a go-around when an incursion alert was received (average of 0.92 nm from the threshold). This indicates that providing incursion alerting to the flight crew results in a greater safety margin and would more reliably prevent the incursion than relying on visual acuity, at least for this type of incursion situation.

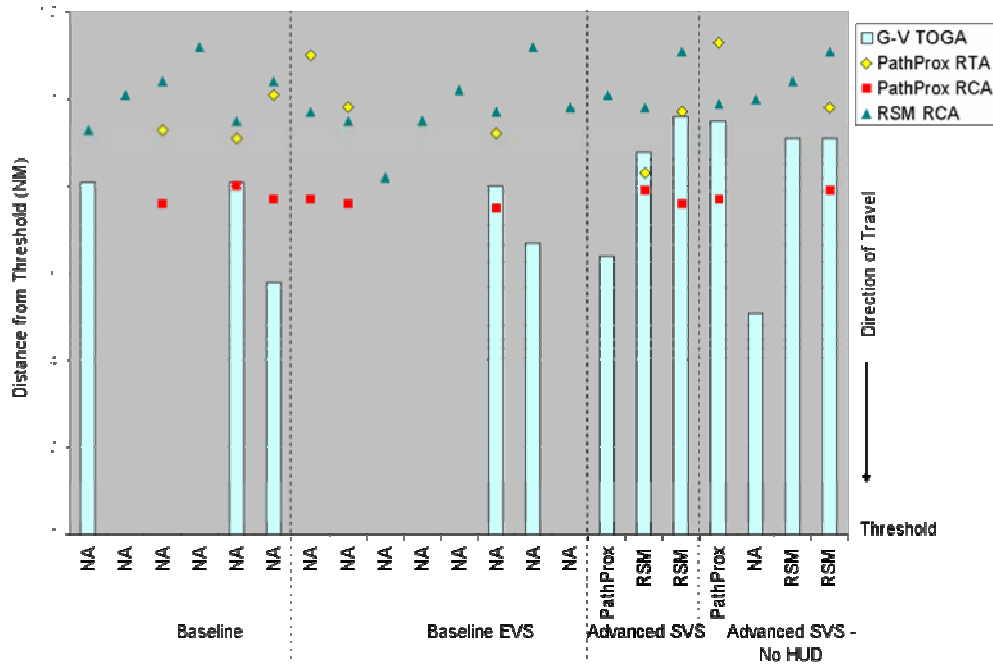


Figure 8. Scenario 3 results

4.1.4. Scenario 4 arrival/arrival results

Figure 9 shows the distance from the threshold and altitude above ground level of the G-V when the go-around was initiated and when the PathProx and RSM alerts were generated. The Be-200 was approaching a runway which crossed the G-V landing runway only 324 ft from the threshold. The go-around initiation point was determined by the moment the TOGA button was pressed, if available. Otherwise, an increase in throttle position was used.

For the arrival/arrival crossing runway scenario, the RSM generated an alert at an average distance of 1.35 nm from the runway threshold and at an average altitude of 516 ft AGL. The EP initiated the go-around 2.5 to 6 seconds after the RSM alert was generated.

On two of the test runs, PathProx generated RTA alerts at approximately the same distance from the threshold, however, one of the alerts occurred after the go-around (in response to an RSM alert in the cockpit). The six missed alerts were due to the PathProx data interface issue.

4.1.5. Scenario 5 taxi crossing/departure results

Timing for this taxi crossing/departure scenario worked well in simulation but was very difficult to achieve in practice. On numerous occasions, the SP would make the call for the EP to stop (to ensure that the G-V aircraft did not violate the safety rule to remain short of the hold line) before the alerting criteria was met for the incursion detection algorithms. The RSM algorithm was modified to generate alerts sooner than initially planned in order to obtain alerts for this scenario. The PathProx algorithm was not modified.

Figure 10 shows the G-V distance from the hold line and ground speed when the RSM alerts were generated and the distance from the hold line where the G-V stopped. For this scenario at WAL, the actual hold line was located 75 ft from the edge of the runway. A discrepancy was found post-test between the actual hold line location and the hold line location in the airport database. The database location for the hold line was 145 ft from the edge of the runway, which was the location used by the incursion algorithms, thus resulting in earlier generation of alerts.

The RSM alert was generated an average distance of 384 ft from the runway hold line. For the runs in which RSM was the selected algorithm, the average stopping distance from the hold line was 224 ft.

PathProx did not generate any alerts for this scenario. The missed alert for one run was due to the PathProx data interface issue. All other missed alerts were due to the timing of the scenario.

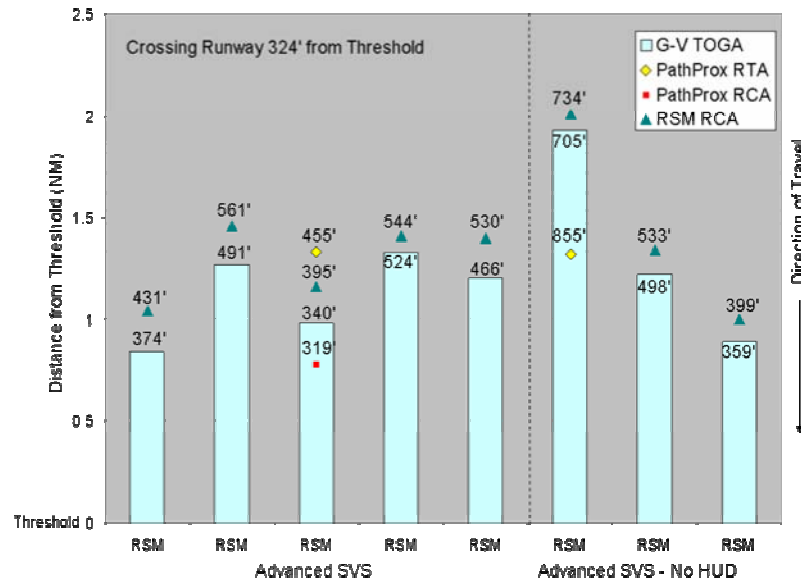


Figure 9. Scenario 4 results

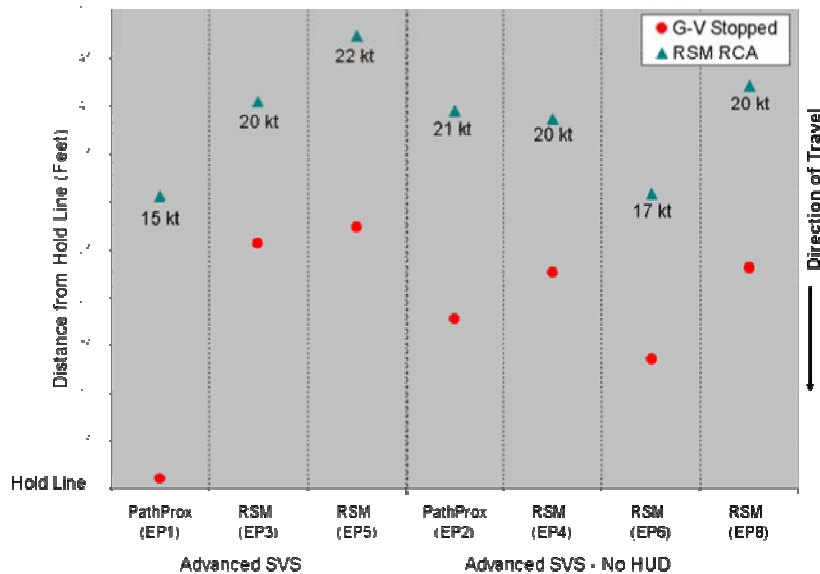


Figure 10. Scenario 5 results

4.1.6. Scenario 6 take-off hold/arrival results

Figure 11 shows the distance from the threshold and altitude of the Be-200 when the PathProx and RSM alerts were generated. The G-V was in position and holding for the entire scenario.

For six of the test runs, the RSM generated an alert when the Be-200 was an average distance of 2.24 nm from the runway threshold. The RSM alert was not generated until 1.43 nm from the threshold for the remaining scenario because the Be-200 was not lined up with the runway until 1.5 nm.

PathProx generated an RTA when the Be-200 was an average distance of 1.15 nm from the threshold and an RCA at an average distance of 0.8 nm. The three missed alerts were caused by the PathProx data interface issue.

The intent of this scenario was to determine if the incursion alerts were provided in a timely manner and if the flight crew had sufficient time to react to the potential conflict while waiting for take-off clearance on the threshold. Four of the five pilot responses indicated that the RSM alerting was timely and provided sufficient warning. No response was made relative to PathProx since RSM was chosen as the alerting source for all of these test runs.

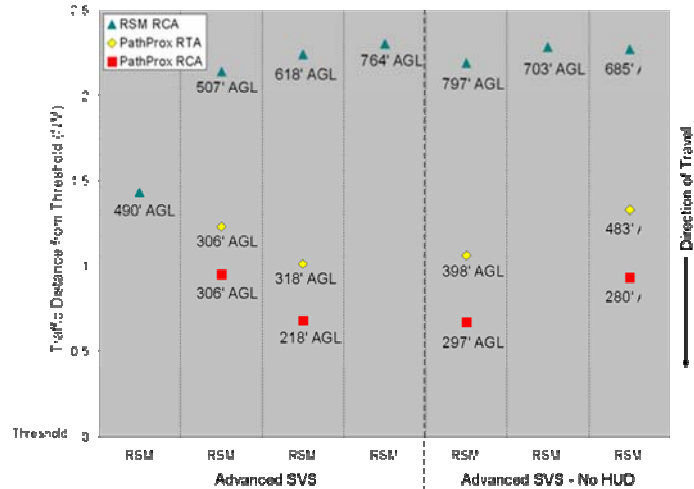


Figure 11. Scenario 6 results

4.1.7. Scenario 7 arrival/take-off hold results

Unlike the other scenarios conducted, the timing of the arrival/take-off hold scenario was very consistent because the traffic (Be-200 or test van) was parked on the runway threshold before the G-V was within 2.5 nm of the threshold. Therefore, the performance of the incursion detection algorithms was very consistent. Incursion alerts were not required on one of the Baseline EVS runs because the EP saw the traffic when approximately 2.4 nm from the runway and conducted an early go-around. RSM alerted on the remaining runs an average distance of 0.95 nm from the runway threshold (standard deviation of 0.03 nm). PathProx alerted on 13 runs with average alerting distances of 1.32 nm for the RTA (standard deviation of 0.01 nm) and 0.97 nm for the RCA (standard deviation of 0.02 nm). The nine missed PathProx alerts were caused by the data interface issue. PathProx also generated one false alert on the test van because of a discrepancy between the PathProx alert thresholds and a WAL hold line location.

Although this scenario was conducted during all four display conditions, conclusions can not be made regarding the go-around performance between the Baseline and Advanced SVS display conditions because a complete set of data were not available.

4.2. Qualitative results

Post-experiment questionnaire results and comments will be incorporated into future evaluations of the system. For many of the questions, ratings were given using a Likert-type scale of 1 (completely disagree/low likelihood) to 7 (completely agree/high likelihood).

The EPs rated the RIPS as having a higher likelihood of preventing runway incursions than the baseline condition for the scenarios evaluated (see Table 2). Five out of six pilots reported that the incursion alerts were provided in a timely manner to avoid a conflict and felt that RIPS would significantly enhanced runway incursion safety compared to current technology and procedures. All eight pilots stated that the audible enunciation provided the first indication of the incursion alert over the graphical displays. Upon receiving the alert, six pilots indicated their immediate reaction would

be to take evasive action while one pilot would confirm the hazard first. The pilots also indicated their situation awareness was higher when using the EMM than when using the baseline surface map during airport surface operations for own aircraft and traffic position awareness and cleared taxi route awareness (see Table 3).

Scenario	RIPS	Baseline
1 – departure/departure	7.0	2.4
2 – departure/arrival	6.8	1.7
3 – arrival/departure	7.0	2.6
4 – arrival/arrival	7.0	2.4
5 – taxi crossing/departure	7.0	2.4
6 – take-off hold/ arrival	7.0	2.2
7 – arrival/take-off hold	7.0	4.0

Table 2. Likelihood of incursion prevention

Sufficient awareness of ...	EMM	Baseline
Ownship position with respect to airport layout	6.7	5.4
Ownship position with respect to moving traffic	6.6	5.2
Status of taxi and runway surfaces	6.9	4.4
Cleared route	7.0	4.0
Guidance cues to follow cleared route	6.6	3.0

Table 3. Situation awareness rating

A post-run questionnaire was also given where the pilots were asked if the lead time provided by the runway incursion alert was acceptable. Ratings were given on a scale of 1 (low) to 7 (high). The ratings for the RSM algorithm for each scenario (6.7, 7.0, 6.8, 6.1, 5.4, 6.5, 6.0) indicate that the alerts provided enough warning time for the pilot to avoid the collision. PathProx was not evaluated due to insufficient data.

5. CONCLUSIONS

A Runway Incursion Prevention System integrated with a Synthetic Vision System was flight tested in the summer of 2004. The purpose of the study, from the RIPS perspective, was to evaluate incursion detection algorithms and associated alerting and airport surface display concepts, focusing on crossing runway incursion situations. The quantitative and qualitative data showed overall that RIPS has a higher likelihood of preventing runway incursions than the baseline condition for the scenarios evaluated. The incursion alerts were provided in a timely manner to avoid a conflict and RIPS would significantly enhance runway incursion safety compared to current technology and procedures. The audible enunciation was the most powerful indication of the incursion alert. The pilots also indicated their situation awareness for ownship, traffic, and taxi routes was significantly higher when using an advanced electronic moving map of the airport surface than present-day technology.

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