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General aviation accounted for 74 percent of runway incursions but only 57 percent of the operations during the four-year period from fiscal year (FY) 2001 through FY2004. Elements of the NASA Runway Incursion Prevention System were adapted and tested for general aviation aircraft. Sixteen General Aviation pilots, of varying levels of certification and amount of experience, participated in a piloted simulation study to evaluate the system for prevention of general aviation runway incursions compared to existing moving map displays. Pilots flew numerous complex, high workload approaches under varying weather and visibility conditions. A rare-event runway incursion scenario was presented, unbeknownst to the pilots, which represented a typical runway incursion situation. The results validated the efficacy and safety need for a runway incursion prevention system for general aviation aircraft.

Introduction

The Problem

The FAA defines Runway Incursions as, "any occurrence at an airport involving an aircraft, vehicle, person or object on the ground that creates a collision hazard or results in loss of separation with an aircraft taking off, intending to take off, landing or intending to land." Runway incursions are a serious aviation safety hazard, particularly for general aviation operations. According to the Federal Aviation Administration (FAA, 2005), during the four year period from fiscal year (FY) 2001 through FY 2004, there were approximately 257 million aircraft operations and 1,395 runway incursions reported at United States towered airports – approximately 5.4 runway incursions for every one million operations. General aviation accounted for 74 percent of these incursions but only 57 percent of the operations. Seventy-six percent of the most severe incursions (114 of 150 incursions) involved at least one general aviation aircraft.

The Etiologies

Statistics show the causes of these incursions are principally pilots (62%) followed by air traffic controllers (35%), meaning that the leading causes of runway incursions both involve human factors. The main causal factor (56%) for pilot-related occurrences was the pilot's failure to follow an ATC clearance (Khatwa, 2002). Further, the FAA has analyzed runway incursion data and has shown the following correlating factors:

- Weather not a factor (89%)
- Pilots taxiing w/o clearance (62%)
- Landing/ departing w/o clearance (23%)
- Landing on the wrong runways (10%)
- Pilot distractions (17%)
- Pilots disoriented or lost (12%)
- Unfamiliarity w/ ATC procedures (22%)
- Unfamiliarity with the airport (19%)

The Solutions

These statistics provide a sobering view of the need for solutions to the problem of runway incursions, in general, and one with a focus involving the human on the flight deck. The FAA has voiced its commitment to reducing the severity, number, and rate of runway incursions by implementing a combination of technology, infrastructure, procedural, and training interventions. These solutions include Airport Movement Area Safety System (AMASS); Airport Surface Detection Equipment Model 3 (ASDE-3), ASDE Model X (ASDE-X) radar; multi-lateration systems; in-pavement loops; Runway Status Lights; (RWSL); enhanced controller training; airport surface operations advisory circulars; improved airport surface markings; improved education, training and awareness; and revised pilot/controller communications phraseology.

These efforts target improved awareness and enhanced surveillance, but none of these initiatives directly involve technology solutions for the flight deck. Taken together, the proposed FAA solutions may still not provide a comprehensive solution without addressing the flight deck. The NTSB currently lists the 6 "most wanted" aviation safety improvements, including "stop runway incursions/ground collisions of aircraft" and has specifically recommended that the FAA implement technology that, "give immediate warnings of probable collisions/incursions directly to flight crews in the cockpit" (cf. NTSB, 2000; 2006). The NASA Runway Incursion Prevention System has been designed to provide a flight deck solution to the problem of runway incursions.

NASA Runway Incursion Prevention System

Leveraging on NASA research (e.g., McCann et al., 1998), RIPS integrates airborne and ground-based technologies to provide: (1) enhanced surface situation awareness to prevent blunders and errors and, (2) runway conflict alerts to prevent runway incidents if blunders or errors do occur.

As presently envisioned, RIPS provides enhanced situation awareness using the pilot's head-up display (HUD), Primary Flight Display (PFD), and an Electronic Moving Map (EMM) by displaying airport map information, surface traffic, and graphical guidance during rollout, turn-off, and taxi. The system also continuously monitors for potential incursions and pilot blunders, and if detected, provides aural and graphical alerts. These alerts are presented visually on the displays and aurally throughout the cockpit. Research during both simulation (e.g., Young & Jones, 2001) and flight tests (e.g., Jones, 2001) for commercial and business aircraft operations have demonstrated that these technologies can significantly increase situation awareness and reduce the occurrence of runway incursions.

Research Objectives

The greatest incidence of runway incursions is attributable to general aviation (GA) aircraft operations; therefore, mitigating the occurrences for the GA operator could significantly enhance safety. Because RIPS has demonstrated tremendous potential for eliminating the causes of runway incursions for commercial and business aircraft operations, the research turns naturally toward system efficacy for GA operations. The objective of the present experiment was to evaluate several candidate RIPS elements, adapted for GA operations, and compare them to current electronic flight bag (EFB) capability for prevention of GA runway incursions.

Method

General Aviation Pilots

Sixteen GA pilots served as participants in the experiment with an equal distribution of flying experience used to represent the Part 91 population: low-time (< 400 hours) visual flight rules (VFR), high-time (> 400 hours) VFR, low-time (< 1000 hours) instrument-rated and high-time (> 2000 hours) instrument-rated.

Facilities/Equipment

The simulation experiment was conducted at NASA Langley Research Center (LaRC) using the Integration Flight Deck (IFD) transport category fixed-base high-fidelity flight simulator (Figure 1). The IFD, normally a Boeing 757 cockpit, was adapted for the experiment to take advantage of its excellent visual, tactile, and audio capabilities. A six-degree of freedom non-linear simulation model of the Cessna 206 (C-206) was used for this experiment. A collimated out-the-window scene was produced by an Evans and Sutherland ESIG 4530 graphics system providing approximately 200 degrees horizontal by 40 degrees vertical field of view at 26 pixels per degree.

An electronic flight bag (EFB) display was used to present the airport surface map display concepts described below (Figure 1). This display was 10.4" (26.4 cm) diagonal with a resolution of 1280 x 1024 pixels.

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" (26.4 cm) diagonal liquid crystal displays and simulated the "Baseline Round Dials" – that is, the standard set of Cessna-206 aircraft instruments: airspeed, attitude, altitude, vertical speed, directional gyro, turn and bank indicator, tachometer, and Instrument Landing System indicators (Figure 2).

Figure 1. Integration Flight Deck

Experimental Design

The experiment was designed as a 4 (display) by 4 (weather) by 6 (task) partially factorial, mixed-subjects design. The between-subject factor was display and each participant pilot flew 19 approaches with the one of the four display concepts. On the last approach, a runway incursion was staged to assess the utility of the display concept for runway incursion prevention. The evaluation subject was not expecting a runway incursion.

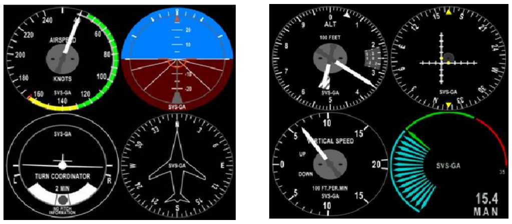

Figure 2. Baseline Instruments

Display Concepts

Four display concepts were evaluated:

(a) Baseline with a Moving Map and Own-ship (BMO),
(b) BMO + Traffic Display (BMOT),
(c) BMO + audible runway incursion alerting (BAMO),
(d) BMOT + audible and graphical runway incursion alerting (BAMOT).

Figure 3 presents an example of the plan-view surface map with traffic displayed (BMOT).

These display concepts were designed to represent a range of Electronic Flight Bags (EFB) and alerting applications, typical of GA aircraft. As shown in Figure 3, “Traffic Display” refers to the graphical representation of surface traffic on the moving map display. “Runway incursion alerting” involves the addition of computer-generated audible and/or graphical alerting (e.g., “Warning, Traffic Departing Two Five”) (Figure 4).

Figure 3. Plan-View Surface Map with Traffic (BMOT)

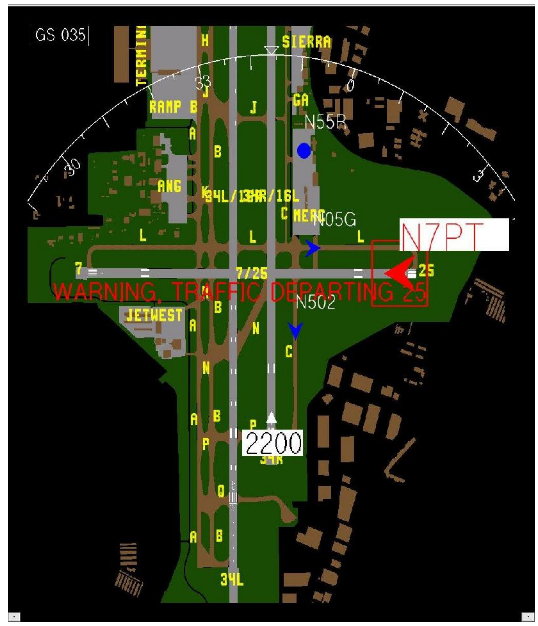

Figure 4. Plan-View Surface Map with Traffic and Alerting (BAMOT)

When traffic data was provided, it was “broadcast” at a 1 Hz rate. Own-ship position data was updated at a 20 Hz rate. Positional errors, noise, or uncertainties were not introduced into these data.

Evaluation Tasks

During the 19 experimental trials, pilots performed 6 approach tasks at the Reno/Tahoe International Airport (KRNO): (1) 3-nm straight-in approach to Runway 34R with a full-stop landing; (2) 3-nm straight-in to 34R with wave-off initiated at 200 ft Above Field Level (AFL); (3) 3-nm straight-in approach to 34L, with sidestep to 34R for a full-stop landing; (4) 3-nm straight-in to Runway 25 with a full-stop landing; (5) Circle-to-land on Runway 25; from a Runway 34L approach and, (6) 9.56-nm straight-in approach with go-around initiated at 200 ft AFL.

Weather

Four weather conditions were used to create the experimental scenarios: (1) 3 miles visibility, 1000 ft. ceiling; (2) 3 miles visibility, 2000 ft. ceiling; (3) 1 mile visibility, 1000 ft ceiling; and (4) 1 mile visibility, 400 ft. ceiling.

Procedure

Each pilot participated in an extensive briefing and training session that was designed to mask the runway incursion focus of the experiment. Pilots flew approach tasks designed specifically to set-up the necessary conditions for presentation of the runway incursion scenario. The runway incursion scenario was presented on the last experimental run. Pilots were not informed of the total number of runs. Post-run scales (i.e., Situation Awareness Rating Technique, NASA-Task Load Index) and questionnaires were administered.

Simulated ATC clearances were given to all traffic to recreate the ATC communication "party line" environment for participant pilots. Surface and airborne traffic were simulated to represent typical operations at KRNO (Reno).

Runway Incursion Scenario

The scenario began with the C-206 on approach aligned with Runway 34R, 3 nm from the threshold at 1010 ft AFL and 90 knots. The weather condition was day with 1000 ft ceiling and 3 miles visibility. The incursion traffic started at the Runway 34R hold line near the Runway 34R threshold. The incursion traffic then taxied into position on the active runway while the participant pilot was on final approach (approximately 2 nm from the threshold). The incursion is categorized as a pilot deviation (i.e., incursion traffic not cleared for departure on 34R). The runway incursion scenario represents the most prevalent type of GA runway incursion (i.e., taxiing onto runways or taxiways without clearance) during weather conditions when they most often occur (i.e., day VMC). This scenario would engender at least a "category D" severity rating (see below) from the FAA dependent upon pilot response to the event.

Runway Incursion Alerting

The Runway Safety Monitor (RSM) incursion detection algorithm (Green, 2006) was used to generate the alerting function for the BAMO and BAMOT display concepts. The RSM monitors traffic that enters a three-dimensional virtual protection zone around the runway that is being used by the own-ship. Incursion detection is based on the operational state of the own-ship and traffic, as well as other criteria (separation and closure rate). Identification, position, and altitude data is 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. RSM was developed for NASA by Lockheed Martin.

Results

FAA Runway Incursion Severity Ratings

The FAA performed an independent analysis of the experimental data, using an FAA runway incursion severity rating (FAA, 2005), and categorized the runway incursion incident data from this study.

- 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.

Using these classifications, the 16 "rare event" runway incursions produced fourteen scenarios in the less hazardous Category C and D incursions, one resulted in a Category A incursion, and one resulted in a Category B incursion (see Table 1). 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. Traffic awareness was provided by either the display concepts or visual acquisition out-the-window.

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, over-flew the traffic and landed.

The Category B incident occurred when the EP over-flew the runway traffic (at 146 ft AFL) 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.

Table 1. Results Categorized by the FAA Runway Incursion Severity Ratings

Pilot	*Display*	*Rating*
#1	BMO	D
#2	BMOT	C-
#3	BAMO	B+
#4	BAMOT	D
#5	BMO	D
#6	BMOT	D
#7	BAMO	D
#8	BAMOT	C
#9	BMO	C
#10	BMOT	A
#11	BAMO	D
#12	BAMOT	C
#13	BMO	D+
#14	BMOT	D+
#15	BAMO	D
#16	BAMOT	D

Runway Incursion Detection Reaction Time

As shown in Figure 5, the incursion traffic was typically acquired sooner when the EP was provided with a traffic display on the surface map and/or incursion alerts, but the differences were not statistically significant at the $\alpha = 0.05$ level.

No statistically significant differences were found between the display concepts for the distance to the incurring traffic when the pilots initiated a go-around or for the EP's reaction time from the incursion event occurrence (based on a Multivariate Analysis of Variance (MANOVA) test $p > 0.05$).

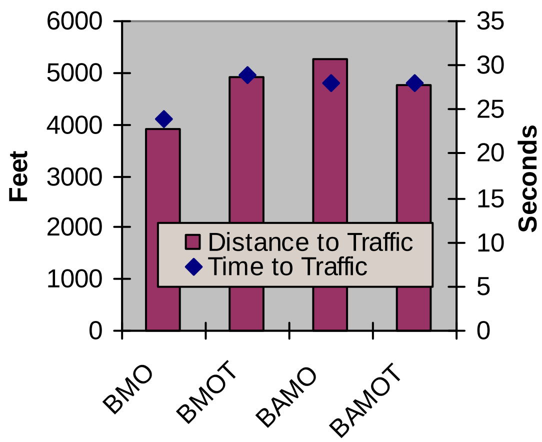

Figure 5. Initial Traffic Awareness

Mental Workload and Situation Awareness

After the incursion scenario, no statistical differences were found for overall mental workload or situation awareness, $p>.05$, between the display configurations. Subjectively, the EPs gave significantly better ratings for audible alerting displays for runway incursion detection, $F(3,15) = 17.955$, $p<.05$; likelihood of runway incursion prevention in real-world, $F(3,15) = 10.948$, $p<.05$; and level of perceived safety, $F(3,15) = 8.814$, $p<.05$.

Pilot Preference

For those displays that had alerting (BAMO, BAMOT), there were no significant differences in 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 ($F(3,15) = 10.948$, $p<.05$) and the additional safety value added ($F(3,15) = 8.814$, $p<.05$) analyses revealed significant effects between the displays. Subsequent post-hoc Student Newman Keuls tests showed that pilots reported that the BMO display condition was significantly poorer than the other three display conditions, which were not significantly different from each other.

Conclusions

The experimental objective was to determine how different EFB and alerting concepts supported pilot situation awareness and resolution of runway incursions. The results show large individual differences in response to an incursion event regardless of display concept. However, only one pilot's performance was judged as a severe runway incursion risk for collision (with the BMOT display). Despite having traffic on the display and other cues, the pilot was unaware of the traffic and landed just beyond the incursion aircraft, resulting in a near-miss.

The addition of audible alerting was found to enhance runway incursion detection. Furthermore, had the experiment simulated the alerting system also being installed on the incursion aircraft, it is less likely that situation would have become a runway incursion event (i.e., category "D"); since the incursion aircraft would have received an alert before taxing onto the active runway.

The results generally match past research on commercial and business aircraft operations - the incursion alerts provided sufficient time and awareness to avoid a potential incursion conflict. Post-run briefings revealed that a surface map with own-ship and traffic along with audible alerts was considered an optimal incursion prevention display for GA aircraft, while an audible alert alone was considered a minimally effective display. Over half of the pilots evaluated would have liked maneuver guidance for conflict resolution in conjunction with incursion alerting. In general, the pilots reported feeling substantially safer during runway incursion incidents with onboard alerting.

There is tremendous potential to significantly enhance safety for all classes of aircraft by using flight deck awareness and alerting for runway incursion prevention, such as that demonstrated herein using the NASA Runway Incursion Prevention System. Future research will further refine the system concepts with targeted enhancements toward support of GA operations.

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