USING A COCKPIT DISPLAY OF TRAFFIC INFORMATION WITH INDICATIONS AND ALERTS TO PREVENT RUNWAY INCURSIONS

Peter M. Moertl, Ph.D.
Kathleen McGarry, Ph.D.
MITRE/CAASD
McLean, VA

This paper presents the results of a human in the loop simulation that evaluated the display of runway safety relevant traffic and runway indications and alerts on a cockpit display of traffic information (CDTI). The simulation investigated differences between directive versus non-directive alert types and between an airport map with and without taxiway information. 24 pilots evaluated the CDTI in 18 airport surface scenarios that contained conflict opportunities. Findings indicate that with directive alerts, pilots avoided all conflict opportunities, while with non-directive alerts 90 % of conflicts were avoided. Response to directive alerts was generally faster than to non-directive alerts. Limitations for non-directive alerts became apparent in scenarios where pilots had to respond under time pressure. While pilots preferred taxiway information to be displayed on the CDTI, no performance differences were found compared to CDTI's with taxiway information. The paper concludes with implications for the development of avionics standards.

Runway incursions have been a major area of concern for the worldwide aviation community. The International Civil Aviation Organization (ICAO) and the Federal Aviation Administration (FAA) both define Runway incursions (RIs) as any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and takeoff of aircraft (FAA 2008). RIs at airports in the United States have been a major area of concern for the U.S. National Airspace System (NAS) for the past several years.

Extensive human factors research has been performed to understand the causes leading to runway incursions and identified the primary causes for runway incursions by pilots, controllers (e.g. FAA 1998, Adam and Kelly 1996, Bales, Gillian, & King, 1989; Steinbacher, 1991), or surface vehicle operators.

Numerous methods have been applied to reduce runway incursions and collisions in the United States (see e.g. FAA, 2003a, 2003b, 2005, 2006a, 2006b, 2007, Honeywell, 2010). A significant amount of research and development activities has been performed on flight deck-based airport surface safety systems (e.g. Jones 2002, 2005; Jones & Prinzel, 2006; Young & Jones 2000) and avionics standards have been defined (RTCA, 2003, 2009). International efforts have included the development of an Advanced Surface Movement Control Guidance System (A-SMCGS) to provide surface traffic management, guidance, and alerting functionality to Air Traffic Control (ATC) and pilots (see IFATCA 2003; Roeder et al., 2008 and Vernaleken, Urvoy, Klingauf, 2007).

In 2000 the National Transportation Safety Board (NTSB) has recommended the development of a ground movement safety system with direct pilot warning capabilities to prevent runway incursions (NTSB, 2000). This recommendation motivated the formation of an RTCA sub-working group under the Special Committee 186 for Automatic Dependent Surveillance – Broadcast (ADS-B) with stakeholders from aviation industry, user communities, and governmental organizations to develop a flight deck application to provide direct runway safety alerts to the flight crew on a CDTI. The application is named Enhanced Traffic Situational Awareness on the Surface with Indications and Alerts (SURF IA). The application development was completed and approved in Dec 2010 (RTCA 2010, DO-323). This paper presents the results of a human in the loop simulation that investigated critical human factors questions associated with the development of the SURF IA application.

SURF IA Application Description

The SURF IA application enhances CDTIs to increase their effectiveness in preventing runway incursions. While basic CDTIs increase the situation awareness of pilots under many situations, Moertl, McGarry & Nickum (2009) identified situations where pilots were not able to use a CDTI to prevent runway incursions. Specifically, during take-off operations, and while on final approach and landing on a runway, pilots were sometimes unable to detect runway safety problems even with a CDTI available to them. In addition, while CDTIs display large amounts of information under many situations, this abundance of information on a relatively small display, requires pilot cognitive resources to extract the relevant information. During times when pilots have less “spare” cognitive resources available, such as during critical flight phases, the usefulness of a CDTI for incursion preventions appears limited.

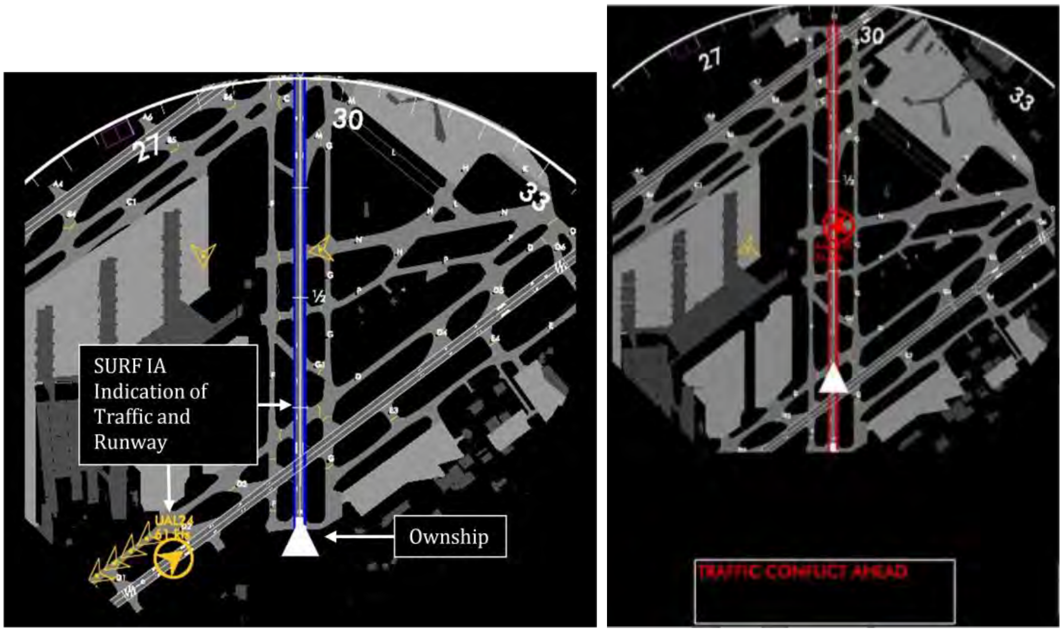

Figure 1 Example for a SURF IA Indication (left) and a SURF IA Warning Alert (right)

The SURF IA application addresses these limitations in two ways. First, the SURF IA application “indicates” to pilots safety relevant traffic. SURF IA indications increase saliency of runway safety relevant traffic under normal operational situations. Second, SURF IA alerts facilitate pilots’ immediate awareness and immediate response once an actual collision hazard has been detected. SURF IA provides caution and warning type alerts that are compatible with FAA guidance on the design of alerts on the flight deck (FAA 2011). Both alert types provide immediate flight crew awareness but require different pilot responses. While warning alerts require an immediate flight crew response, caution alerts require a subsequent pilot response. See Figure 1 for example SURF IA indications and alerts.

The simulation the MITRE Corporation’s Center for Advanced Aviation System Development (CAASD) performed were preceded by a series of three human in the loop simulations that assessed various aspects of SURF IA and are described elsewhere (see Moertl, McGarry & Nickum, 2009, and McGarry & Helleberg, 2011). These initial simulations evaluated various design characteristics of SURF IA indications and alerts that were implemented for the simulation described below.

Simulation Research Questions

This simulation focused on two primary research questions:

1. Should SURF IA alerts be directive or non-directive? Directive alerts include information for the flight crew on how to resolve a conflict, whereas non-directive alerts inform the flight crew only about the existence of a detected conflict. It was hypothesized that directive alerts would be more effective and preferred by pilots over non-directive alerts because they would decrease pilots’ demand on cognitive resources during response selection. Also, it was hypothesized that pilots would seek more confirming information when responding to non-directive alerts than to directive alert where they may just follow the resolution. Accordingly, pilots should be better able to recover from a false non-directive alert than from a false directive alert because they are expected to utilize additional visual or auditory information.
2. Is it permissible for the SURF IA system to be displayed on a CDTI with just runway information or does it require a complete airport surface map (including taxiways)? It was hypothesized that CDTIs with taxiway information would be more effective and preferred by pilots over CDTIs without taxiway information.

In the remainder of this paper, the two display conditions are referred to by their names as avionics standards as defined in RTCA DO-317, RTCA (2009). The term FAROA (Final Approach Runway Occupancy Awareness) is used for a CDTI that displays runway but not taxiway information. The term ASSA (Airport Surface Situational Awareness) is used for a CDTI that includes runway and taxiway information.

Method

The simulation was performed in MITRE/CAASD's fix-based simulator with a 120 degree out the window view and configured with a primary flight and navigation displays. The simulator did not replicate a specific aircraft type but resembled a large, transport category aircraft.

The CDTI was shown on an Electronic Flight Bag (EFB) mounted in the left forward field of view for the left seat pilot and in the right forward field of view for the right seat pilot. Both displays could be seen without need for extensive head turning. Pilots listened to radio communication with other traffic from which they could form a mental image of the traffic environment. A former air traffic controller gave them clearances. The crew used a standard printed checklist that prompted questions and responses between the two pilots. Preflight preparations were simplified and did not include weight and balance calculations or programming the Flight Management System (FMS).

Experimental Design

Two independent variables were used. The variable "alert type" consisted of two levels, "directive alerts" versus "non-directive alerts" and was a within-subjects variable. The second variable "display type" had also two levels, "ASSA" (runway and taxiways) versus "FAROA" (runway only) and was a between-subjects variable. Alert type and display type conditions were counterbalanced and randomized across participants to account for order effects.

Scenarios

After having completed two initial familiarization scenarios, participants completed eight scenarios in each alert type condition. One group of pilots saw these 16 scenarios with the ASSA display type, the other group of pilots saw them in the FAROA display type. Visibility conditions were such that pilots could not determine conflict traffic by looking out the window. After completion of all 16 scenarios, participants completed two additional scenarios. The first additional scenario showed pilots the alternate display type to what they had seen previously. The final scenario was a "false alert" scenario where a warning alert was presented to pilots after take-off initiation, without the existence of an actual conflict. In that scenario, visibility conditions were such that pilots could visually determine that no conflict existed by looking out the window.

Participants

Twenty-four pilots participated between February and March, 2009. All pilots had experience as airline pilots and averaged 11,000 logged flight hours (ranging from 1,300 hrs to 21,800 hrs). Pilots flew a variety of airplanes including Boeing 717, 747, 777, 767, 757, MacDonald Douglas 80, Airbus 320/319, CRJ 700/900, EMB145, and CL-65. Two of the pilots were female; the rest were male. Participants were assigned by the study director to their role as pilot flying or pilot not-flying, depending on their qualifications and prior experience. The pilot flying took the left seat and the pilot not-flying took the right seat.

Results

Directive versus Non-Directive Alerting

The effectiveness of pilot response to the alerts was measured by counting flight crew responses that were appropriate to remove the safety hazard that the scenarios introduced. Safety hazards included conflict aircraft moving onto the runway ahead of ownship, accelerating toward ownship, or failing to clear a runway. Pilots could avoid such safety hazards by aborting their take-off, initiating a go-around, or clearing the runway. Such responses were counted as "effective." Any other response was counted as "ineffective."

Overall, pilots responded effectively to non-directive alerts in 53 of 59 conflict trials (90 %). Originally 60 conflict trials were presented but in one trial the auditory alert did not sound and this trial was dismissed. In comparison, the same pilots responded effectively to directive alerts in all 60 conflict trials (100%). The difference of 10 % is statistically significant between the two types of alert responses (Fisher's exact test, $p < 0.05$). This supported the hypothesis that directive alerts would lead to more effective alert responses than non-directive alerts.

Four of the ineffective responses to the non-directive warnings occurred during departure scenarios, when pilots had little time to decide on an action and therefore had to response under time pressure. These pilots continued their take-off even with the non-directive alerts coming on. Those flight crews reported that they were aware of the conflict aircraft ahead, but were avoiding an abort at high speed. The alerts sounded when ownship was above 80 knots but before reaching V1 speed (takeoff decision speed). Two crews mentioned they thought the remaining runway length was insufficient to stop the aircraft.

The two remaining ineffective alert responses occurred during approach and landing scenarios. In these cases, pilots either did not initiate go-around maneuvers, or did not attempt to exit the runway in time to clear the runway for an approaching aircraft from behind. During the final phase in an approach scenario, one of the pilots misattributed the alert to a proximate aircraft that in fact had not caused the conflict. In another scenario, the flight crew had landed and was taxiing on the runway when the alert was triggered by an aircraft behind them. The alert surprised the flying pilot who did not immediately comprehend that the conflict was caused by an approaching aircraft from behind. Therefore, the pilot decided to stop on the runway.

Ineffective responses did not appear to result from lack of familiarity with the alerting system. Half of the ineffective responses occurred during the first half of the simulation and the other half occurred during the second half. Therefore, run order apparently did not have an impact on response effectiveness.

Though overall, there were no differences in response times to directive versus non-directive alerts, response times were different only between types of operations. Response times were defined as the time between the onset of the alert and changes in throttle position resulting from a go-around or aborted take-off. Over all types of scenarios combined, there were no significant differences in response times to directive and non-directive alerts (3.7 sec vs. 4.5 sec, respectively). For departure operations it was found that pilots responded to directive alerts significantly faster than to non-directive alerts ($F(1, 34) = 9.63$, $p<.01$, 2.9 sec vs. 4.0 sec respectively). No response time differences were observed during arrival scenarios. Average alert response times in arrival scenarios were slower (4.8 sec) than in departure scenarios (3.5 sec) but this was not a statistically significant difference. In the arrival scenarios, pilots tended to have more time available to respond when the alert came on, as compared to in the departure scenarios.

Pilots generally thought directive alerts were more useful than non-directive alerts, though this trend only reached statistical significance for landing and exit scenarios where flight crews reported directive alerts to be more useful than non-directive alerts (Fisher's exact test, $p < 0.05$). Also, pilots indicated that directive alerts were easier to respond to than non-directive alerts (Fisher's exact test $p < 0.001$). Based on the described performance, pilot perceptions, and response time differences, it appeared that directive alerts led to faster, easier, and more effective responses than non-directive alerts.

Responses to False Alerts. To measure the extent to which flight crews relied on the displayed alert information versus seeking other confirming information (e.g., via out the window, CDTI, or radio) when selecting their response, flight crews saw a false alert in their last simulation scenario. Only two flight crews did not abort their take-off in response to the alert. One aborted in the directive alerting condition and the other one in the non-directive alert condition. This contradicts the hypothesis that pilots would be better able to recover from false non-directive alerts than from false directive alerts.

ASSA versus FAROA Display

Most pilots (21 of 24) preferred the ASSA display over the FAROA display. Pilots thought that the ASSA displays supported the task of navigating on the airport surface better with taxiway and runway information. Accordingly, the majority of pilots (20 of the 24 pilots, i.e. 83 %) found taxiway information on the ASSA display was useful when specifically asked about the value of taxiway information. A few pilots indicated during interviews that while taxiway information was useful when operating on the ground, it was not needed when flying an approach to the runway.

While pilots subjectively preferred the ASSA display, no evidence was found that pilots exhibited superior performance over the FAROA display. There was no significant difference between the number of ineffective responses between the ASSA and FAROA display conditions (3 ineffective responses using ASSA versus 2 using FAROA). Also, self-reported workload as measured by questions from the NASA task load index (TLX) showed no differences between ASSA and FAROA and ranged between 3 and 4 on a scale from 1 (lowest) to 10 (highest). The average situation awareness rating was 5.5 on a scale from 1 (lowest) to 10 (highest), and there were no differences between the display conditions.

Conclusions

The pilots in this simulation were able to successfully avoid 90 % of the presented runway safety conflicts using non-directive alerts, less than when presented with directive alerts when they avoided all conflicts. Limitations of non-directive alerts only became apparent in situations when pilots had to respond under time pressure or the appropriate response was not immediately apparent. Response times to non-directive alerts tended to be slower than to directive alerts and responses, but were only significantly slower during departure scenarios. During takeoff, pilot responses to a false alert were similar for both directive and non-directive alerts, with most pilots aborting their take-off. Pilots did not retrieve other confirming visual or auditory information (e.g. via out-the-window, CDTI, or radio) that would have let them know there was no actual conflict. This could be caused by the fact that, under time pressure, information search cannot be exhaustive. These findings suggest that the tested directive alerts were more effective than non-directive alerts for the prevention of runway incursions in the given scenarios and conditions, and that pilots did not recover any better from false non-directive alerts than they did from false directive alerts. System implementations that opt for directive alerting will need to consider the technical feasibility of directive alerting which was not part of this study.

The pilots in this simulation subjectively preferred a CDTI with taxiway information over a CDTI without taxiway information. However, there were no significant differences in observed pilot workload, situation awareness, and performance found between the two different CDTI display conditions. Therefore, while an ASSA display with taxiway appears desirable, a FAROA display without taxiway information appeared to be acceptable for the tested scenarios.

The results of this simulation were used as input into the development of safety and performance standards for the SURF IA application (RTCA DO-323, Dec 8, 2010). To support generalization of these simulation findings and to further validate the SURF IA application requirements, these simulation results should be combined with a larger body of research that evaluates the certification requirements for a surface cockpit alerting capability.

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