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EFFECTS OF A STANDARD LANDING LIGHTS MESSAGE ON RUNWAY SAFETY

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The Federal Aviation Administration Office of Runway Safety and Operational Services formed a simulation team to investigate the safety effects of standardizing the use of aircraft landing lights in the airport environment. Specifically, the simulation team explored the procedural use of landing lights as a direct message to other pilots indicating that aircraft were cleared to depart. Thirty-two pilots participated in the study as either the Captain or First Officer of a B747-400 simulator crew. The simulator crews were divided into two groups or crews. Each crew flew either a set of 16 scenarios in an environment with a standardized use of landing lights or scenarios using current practices. In four of the scenarios in each environment, a confederate aircraft made an error that resulted in a runway incursion (RI) that could have resulted in an accident with the B747-400 simulator if not detected by the subject crews. Multidimensional measures of RI severity and situation awareness (SA) were made after each scenario. In general, the pattern of results suggest that standardizing the use of aircraft landing lights to indicate that aircraft were cleared to depart prevented or reduced the severity of RIs or accidents, and increased pilot SA. The data shows that crews in the standard condition held-short more frequently, generally experienced less severe incursions, initiated a response to RIs significantly faster, used the landing lights effectively as a first cue, and unanimously felt that safety was increased because of the standardized procedures.

Introduction

The Federal Aviation Administration (FAA) Office of Runway Safety and Operational Services formed a simulation team to investigate the safety effects of standardizing the use of aircraft landing lights in the airport environment. The purpose of this investigation was to gather subjective and performance data from flight crews as they operated in scenarios with and without standard exterior lighting procedures. Specifically, the simulation team explored the procedural use of landing lights as a direct message to other pilots indicating that aircraft were cleared to depart. The necessary data included a measure of runway incursions (RI), accidents, and pilot situation awareness (SA).

The goal of this study was to investigate whether standardizing the use of aircraft landing lights to indicate that aircraft were cleared to depart (1) prevented or reduced the severity of RIs or accidents, and (2) increased pilot SA. We expected greater safety, SA to increase, and positive pilot reactions to the procedure because landing lights are a more salient visual cue than the motion of aircraft. In some cases, this visual cue is available earlier than motion.

This paper describes the simulation, which was a proof-of-concept study. In this study, we explored a baseline condition representing current use of procedures and a condition with the new Standard Operating Procedure (SOP). In each condition, four data collection scenarios included a scripted error by a confederate pilot (a simulated aircraft whose crew was under our control) that induced a potential RI/accident. The simulation utilized the Crew Vehicle Systems Research Facility (CVSRF) at NASA Ames Research Center. In particular, the study employed NASA's Level D certified, Boeing 747-400 simulator. The simulation team and sponsor selected San Francisco International Airport (SFO) and Chicago O'Hare International Airport (ORD) as the emulated airports.

Background

The Runway Incursion Joint Safety Implementation Team (RI JSIT) was chartered by the Commercial Aviation Safety Team (CAST) and General Aviation Joint Steering Committee to develop a plan to effectively reduce the severe threat of fatalities and loss caused by commercial and general aviation RI accidents/incidents. CAST's goal is to reduce the US commercial aviation fatal accident rate by 80% by the end of the year 2007. To help accomplish this goal, the RI JSIT brought together expert representatives from across the aviation community including participants from government, industry, and pilot and controller unions. These experts developed, prioritized, and coordinated a plan to implement the most effective analytically data-driven intervention strategies recommended by the Runway Incursion Joint Safety Analysis Team. RI JSIT analyzed those intervention strategies to determine the feasibility of gaining significant safety benefits through implementation. They incorporated twenty-two Safety Enhancements into seven detailed Implementation Plans (FAA, 2002). One of these plans is to develop SOPs for ground operations; more specifically, SOPs relating to aircraft taxi operations and use of aircraft lighting during taxi operations.

Approach

Our approach was to use a between-subjects design to compare the outcome of scenarios operating under the current practices and those using the SOPs relating to the use of aircraft lighting during taxi operations. This approach was as close as the team could get to the actual outcomes without risk to the participants. We looked for differences in safety, situation awareness, and pilot reactions. We took a variety of measurements to indicate differences in these constructs between the groups. We expected greater safety, situation awareness to increase, and positive pilot reactions to the SOP.

Method

Participants

Thirty-two pilots participated in the study as either the Captain or First Officer of the B747-400 simulator during the simulation. The simulation team recruited pilots from sources such as the airlines, the Airline Pilots Association, and the Allied Pilots Association. Participants were current or retired/furloughed (9 months or less) B747-400 type-rated Captains or First Officers.

It was desirable that both pilots of each crew were from the same company; however, 4 of the 16 crews were from different or 'mixed' companies. Twelve of the crews were from United Airlines (UAL); therefore, we instructed the crews to use the B747-400 cockpit configuration and a checklist from UAL. The mixed crews used the Captain's configuration and checklist, when possible, and we provided additional training to the First Officer to mitigate any potential effects. If the Captain's configuration and/or checklist were not available, the pilots used UAL's and we trained one or both members of the crew (as appropriate) to mitigate any potential effects. The FAA and NASA personnel provided familiarity and procedural training as needed.

In this study, we instructed the crews to taxi, depart, or land in 16 scenarios. Sixteen crews composed of a Captain and First Officer participated in this study. Eight of the crews operated in an environment that had no standard procedures for using landing lights to indicate that aircraft are cleared to depart; the other eight operated in an environment with standard procedures. In half of the scenarios that every crew experienced, a confederate aircraft made an error that resulted in an incursion with the potential to result in an accident if not detected by the subject crews. Four of these scenarios for each crew were included in the final analysis.

Apparatus

The CVSRF is a unique national research facility dedicated to studies of aviation human factors and airspace operations and their impact upon aviation safety. An integral component of the CVSRF is the B747-400 simulator.

CAE Electronics built NASA's B747-400 simulator to meet the FAA Level D certification requirements (Sullivan & Soukup, 1996). The Boeing 747-400 has an advanced level of automation available to the pilots. The visual system uses photo texturing and offers superior scene quality depicting out the window scenes in night, day, dusk, or dawn conditions. In addition, the simulator has an advanced digital control loading and a six degree-of-freedom motion system. Data collection was available for user interaction with all subsystems, including the autopilot system and communication devices.

Procedure

Instructions to Participants. During the initial briefing, we provided crews with minimal information about the study objectives. In particular, they were not made aware of planned incursions, nor were they given feedback regarding whether an incursion occurred unless they elicited feedback about an event as they would during actual operations. We instructed crews to taxi, depart, and land aircraft using the same consideration for efficiency and vigilance for safety that they would in a real-world environment. We then trained crews to use the aircraft lighting procedures corresponding to their condition assignment (standard or no standard). We also reviewed the procedures during the simulator orientation. We instructed eight of the crews, those in the no standard condition, to follow the current aircraft policies (including lighting policies) of the Captain's company. All other aircraft (i.e., other than the Boeing 747-400) in the no standard conditions also complied with their appropriate company policies. We instructed the other eight crews, those in the standard condition, to follow the SOP for light usage as written in Advisory Circular (AC) 120-74A. After completion of two training scenarios, we assessed the participants' understanding of the lighting SOP with a written test. All other aircraft in the standard conditions followed the same SOP.

Experimental Manipulations. This study design included the 'Standardization' factor and it had two levels. The first level, no standard, represented a taxi environment in which the aircraft used the present policies and culture of selected airlines for aircraft lighting during taxi operations. The second level, standard, represented a taxi, position and hold, and takeoff environment in which the recommended standardization of procedures for the use of aircraft lighting were in effect per the AC 120-74A. The AC advises that to signal intent to aircraft downfield, turn on landing lights when cleared for takeoff. All aircraft were scripted to comply correctly with the SOPs contained in AC 120-74A during the standard condition without exception.

The study design included independent groups. We chose this design instead of a within-subjects design because it was considered unreasonable to expect flight crews to switch from using one set of rules during taxi to the current practice without being influenced by the preceding conditions they received. The levels of *Standardization* (no standard and standard) constitute the independent (between-subjects) groups. We divided the study crews into two groups: half of the crews were placed in the no standard condition and the other half were placed in the standard condition.

Control Features. The simulation team used counterbalancing to neutralize the effects of order as well as to provide a washout period after incursions. Practice effects (e.g., carryover, sensitization, and practice effects) were not the objects of study and the presence of practice effects could reduce the sensitivity of the design. Therefore, we used a Latin square arrangement of the airports (namely, SFO & ORD) and a random arrangement of the scenarios.

After the initial briefing, the participants signed an Informed Consent Form and completed a Background Questionnaire. The participants experienced two training runs and then completed the 16 test scenarios. During the scenarios, subject matter experts (SMEs) collected event information. The participants completed a Situation Awareness Rating Technique (SART) Questionnaire (Taylor, 1990) at the end of each scenario. The SMEs completed an Observer Rating Form after each test scenario. After completion of the last scenario, the participants completed a Post-Simulation Questionnaire and participated in a final debriefing.

Results

Hold Short

We used the Fisher exact probability test to determine whether there was a difference in terms of the number of prevented incursions between the Standardization conditions. The null hypothesis was that the crews did not hold short as a function of standardization group. The alternative hypothesis was that the crews using standard lighting procedures were able to prevent more incursions.

We counted the number of crews that held short for each scenario. Crews taxiing in the standard condition held short more frequently than crews with no standard for 3 of the 4 scenarios. When we determined the probability of the outcomes using the Fisher exact probability test, the respective probabilities (p) for ORD 1, ORD 2, SFO 1, and SFO 2 were .23, .07, .30, and .23. Thus, we could not reject the null hypothesis at an alpha level of .05.

Number of Runway Incursions and Accidents

We used the robust rank-order test to determine if the severity of incursions in the no standard group was higher than those in the standard group. The null hypothesis was that the sum of the severity ratings across the four scenarios was the same for the standard and no standard groups. The alternative hypothesis was that the sum of the standard group's ratings was higher than those of the no standard group.

We counted the number of incursions that resulted in each type of scenario. Of the 64 incursions that were planned in the data collection scenarios, 29 resulted in actual incursions and the rest did not meet the criteria for a RI. The incursions were divided into three different descriptive categories: stopped short of runway edge, crossed the runway and exited the runway, and collision. Overall there were 11 RIs in the standard condition and 18 (or 63% more) in the no standard condition. In 3 of 4 scenarios, the no standard crews were involved in more incursions. Furthermore, the no standard crews were also involved in 3 collisions compared to 1 collision in the standard group. The probabilities of these outcomes did not reach statistical significance.

Initiating a Response

The data set was characterized by unequal samples and variances. Therefore, we chose nonparametric statistics to analyze the data. We used the Kolmogorov-Smirnov two-sample test to determine whether the two samples were drawn from the same population or populations with the same distribution. The null hypothesis was that there was no difference in the reaction times between the standard and no standard conditions. The alternative hypothesis was that there was a difference in the reaction times between the environments. Results were in favor of rejecting the null hypothesis ($D_{m,n}$ = .86, $p < .05$). There was a statistically significant difference in reaction times between the two conditions indicating that the standard condition (i.e., SOP) reduced crew initial response times to RIs (see Figure 1).

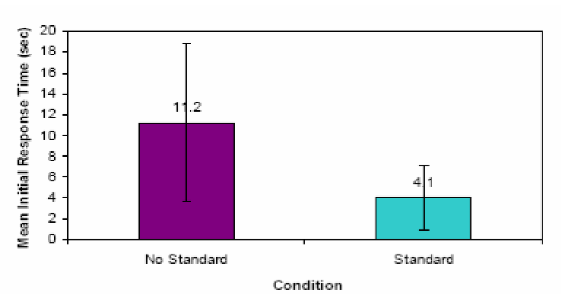

Figure 1. Mean (+/- standard deviation) Initial Response Times in Seconds

Initial response time results suggest that an optimal level of SA occurs sooner. The 3D SART rating trend of responses showed a slight increase in SA for Captains, although there may not have been enough power to detect the difference statistically. However, the objective supplementary measure to SA, initial response times to impending incursions involving a departing aircraft, were significantly faster for crews taxing in the standard condition. Given accurate knowledge of events in the environment (namely, an aircraft departing), a faster response means greater safety.

Use of Landing Lights as a First Cue

When we looked at the data by scenario and determined the probability of the outcomes using the Fisher exact probability test, the respective probabilities (p) for ORD 1, ORD 2, SFO 1, and SFO 2 were .54, .02, .03, and .02. Thus, results for three of the scenarios were statistically significant. Crews in the standard condition reported more frequently that their first cue of an impending incursion was "lights."

Pilot Reactions

One hundred percent of the standard group participants indicated that they believed that the SOPs increased safety to some degree and felt confident using the new procedures. Participants' median response was 7 (1=Decreased Safety, 7=Increased Safety), or Increased Safety, when asked what effect, if any, the standardized landing light procedures had on runway traffic safety.

Furthermore, none of the respondents indicated a neutral response or felt that safety was degraded in any way. These scores are consistent with debriefing comments and questionnaire feedback provided by the participants. When asked to expand upon the safety aspect of using standardized lighting procedures, 100% of the participants said that another aircraft's intent was more clearly indicated with a universal lighting system. They also indicated that they were able to react more quickly to potential situations than if they had to ascertain that there was a conflict by using the movement cue alone.

Confidence in Standardized Procedures. Participants reportedly felt confident using the SOPs. One hundred percent of the participants responded 5 or higher, with a median of 7, when asked if they were confident utilizing the standardized lighting procedures (1=Not at All, 7=A Great Deal). Scores strongly suggest that no participants had reservations relying on the lighting procedures as a messaging system in the simulation. These scores were also consistent with debriefing comments. Participants often commented that with good training and consistent use of the lighting procedures, the SOPs would provide a tremendous benefit overall.

Crew Debriefing Commentary. As previously mentioned, the focus of this study was to provide objective data as evidence to support or disprove the value of implementing a standard use of exterior aircraft lighting, particularly the use of aircraft landing lights. However, some subjective comments are included in the results as supplementary information. As such, we drew several observations from the debriefing sessions of the crews that experienced the standard conditions. In general, pilot reactions to the SOPs were very positive.

- All crews commented during the debrief sessions that they experienced increased SA when using the standard lighting procedures. They contributed the increase to clear communication of other aircrafts' intent.

- All crews agreed the overt signals communicated by the standard lighting procedures would provide a great benefit in the real world as long as the procedures were used correctly and consistently.

- All crews thought it was a good idea to implement the standard lighting procedures across all airlines and aircraft.

We also extracted pilot feedback from post-simulation questionnaires. In particular, pilots that flew in the standard conditions were asked how the standardized landing light procedures affected runway traffic safety during the simulation, if at all. All replies were positive and included responses such as the following: "You were able to have better situation awareness and increased reaction time", "Once the light system is understood, detection of movement is enhanced. Also, flight crew's intentions are indicated earlier," "Lights visible long before movement," "Provided early indication of intentions of other aircraft to either cross a runway or commence takeoff roll," and "Gave a good overt indication of what to expect from other aircraft."

This feedback from the professional pilots that had the opportunity to experience the affect of the new SOP in a high fidelity simulation environment clearly indicates favorable views toward the procedures.

Discussion

Subjective and performance data were analyzed to explore the procedural use of aircraft landing lights as a direct message to other pilots indicating that aircraft were cleared to depart. In general, the pattern of results supports the standardized use of the landing lights. Conclusions for this study are largely supported by the combination of observed patterns and trends in the data and subjective information gathered from the participants. In summary, the data shows that crews in the standard condition held-short more frequently, generally experienced less severe RIs when those occurred, initiated a response to RIs significantly faster, used the landing lights effectively as a first cue, and unanimously felt that safety was increased because of the standardized procedures.

The data showed with marginal significance that crews taxiing in an environment with a standard use of landing lights held-short more frequently (thereby preventing more incursions) than those with no standard. Crews with no standard crossed the runway with greater frequency and were involved in more collisions. As observed in the descriptive data, crews generally experienced incursions that were more severe when operating without a standard use of landing lights. The effect of having and not having a standardized use of the landing lights showed itself through repeated safe behaviors and unsafe behaviors respectively.

Landing lights provided a faster cue that there was potential for a collision than movement. When examining an aircraft on an intersecting runway, the primary concern of the crew was whether that aircraft was moving. If movement were easy to perceive, it would be sufficient as a cue that there is a potential for a collision. However, movement of the other aircraft is difficult to perceive because it is at such a great distance and its speed increases exponentially as it takes off (Regan, 1997). The standard procedure if applied correctly, however, provides an easy message: landing lights on means the aircraft is moving and landing lights off means that it is not moving. Given that landing lights are more easily detected than movement (as simulated), they provide a message faster than movement.

Feedback from the professional pilots who had the opportunity to experience the effects of the new procedure in this high fidelity simulation environment clearly indicated favorable views toward standardizing the use of landing lights. They felt it contributed to safety, increased their awareness of the intentions of other aircraft, and that it conveyed the intended message effectively.

The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Air Traffic Organization, Federal Aviation Administration, or the Department of Transportation.

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