DOT/FAA/AR-07/18

Air Traffic Organization
Operations Planning
Office of Aviation Research
and Development
Washington, DC 20591

Enhanced Aircraft Conspicuity to Reduce Runway Incursions

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April 2007

Final Report

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U.S. Department of Transportation
Federal Aviation Administration

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-07/18		

4. Title and Subtitle	5. Report Date
ENHANCED AIRCRAFT CONSPICUITY TO REDUCE RUNWAY INCURSIONS	April 2007
	6. Performing Organization Code AJP-6311
7. Author(s) Donald W. Gallagher	8. Performing Organization Report No.
9. Performing Organization Name and Address Federal Aviation Administration William J. Hughes Technical Center Airport and Aircraft Safety Research and Development Division Airport Technology Research and Development Branch Atlantic City International Airport, NJ 08405	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Runway Safety and Operational Services Office Washington, DC 20591	13. Type of Report and Period Covered 14. Sponsoring Agency Code ARI-200

15. Supplementary Notes

Thomas Paprocki, Oswaldo Valdivieso, James Newman of Hi-Tec Systems Inc., and Eric Nadler, Ph.D., of U.S. DOT Volpe Center provided technical support throughout the course of this evaluation.

16. Abstract

A study, which was conducted for the Runway Safety and Operational Services Office concerning controller and pilot error in surface operations, recommended increasing aircraft conspicuity when the aircraft is on the runway through the use of existing aircraft lights, thus making the aircraft more conspicuous to controllers and pilots both on the ground and on approach.

The objectives of this research effort using standard aircraft lighting were to (1) determine the best aircraft lighting configuration for making an aircraft on the active runway more conspicuous to an aircraft on final approach and (2) determine from an air traffic control (ATC) tower which aircraft lighting configuration is better for making an aircraft on a runway more conspicuous to air traffic controllers.

This research examined aircraft conspicuity from the two perspectives mentioned above, using a representative selection of aircraft types to the extent available as a target aircraft. Two aircraft were used for the approaches, one of which was equipped with an eye-tracker device that the subjects wore during the approaches.

Results of the flight test showed that, of the external aircraft lighting configurations studied (steady and pulsing landing lights), none provided enough of a visual cue for the needed conspicuity for an approaching aircraft. From the ATC tower, steady and pulsing landing lights were both effective in providing the needed conspicuity.

17. Key Words	18. Distribution Statement
Conspicuity, Landing lights, Pulsing, Visual guidance, Aircraft lights, Runway incursion, Logo lights, Visual cue	This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	29	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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LIST OF ACRONYMS

AL_2ERTS	Aircraft Landing Lights Enhance Runway Traffic Safety
ARC	Ames Research Center
ATC	Air traffic control
FAA	Federal Aviation Administration
NASA	National Aeronautics and Space Administration
nmi	Nautical miles
R&D	Research and development
RI	Runway incursions
SA	Situation awareness
TDZ	Touchdown zone

EXECUTIVE SUMMARY

The Federal Aviation Administration recognizes the importance and criticality of preventing runway incursions through the development of technologies that minimize the chance of death, injury, damage, or loss of property due to runway accidents and incidents within the civil aviation system. A report from the U.S. Department of Transportation, Volpe National Transportation Systems Center, to the 4th USA/Europe Air Traffic Management Research and Development Seminar, addressed controller and pilot error in surface operations. One recommendation of this report was to increase aircraft conspicuity when the aircraft is on the runway through the use of existing aircraft lights, thus making the aircraft more conspicuous to controllers and pilots both on the ground and on approach.

The objectives of this research effort using standard aircraft lighting were to (1) determine the best aircraft lighting configuration for making an aircraft on the active runway more conspicuous to an aircraft on final approach, and (2) determine from an air traffic control (ATC) tower which aircraft lighting configuration is better for making an aircraft on a runway more conspicuous to air traffic controllers.

This research examined aircraft conspicuity from the two perspectives mentioned above, using a representative selection of aircraft types to the extent available, as a target aircraft. Two aircraft were used for the approaches, one of which was equipped with an eye-tracker device that the subjects wore during the approaches.

Results of the flight test showed that, of the external aircraft lighting configurations studied (steady and pulsing landing lights), none provided enough of a visual cue for the needed conspicuity for an approaching aircraft. From the ATC tower, the steady and pulsing landing lights were both effective in providing the needed conspicuity.

Research should be conducted to identify the appropriate aiming angle, beam spread, and necessary intensity requirements to provide the needed conspicuity for approaching aircraft.

1. INTRODUCTION.

1.1 PURPOSE.

In support of Federal Aviation Administration (FAA) Runway Safety and Operational Services Office, the Airport Technology Research and Development (R&D) Branch at the FAA William J. Hughes Technical Center conducted research on the use of commonly installed aircraft lights to provide visual cues to pilots, vehicle drivers, and air traffic controllers to indicate the presence of an aircraft on a runway.

This report is intended to provide a description of the project effort recently completed at the FAA William J. Hughes Technical Center and a summary of results.

1.2 BACKGROUND.

The FAA recognizes the importance and criticality of preventing runway incursions through the development of technologies that minimize the chance of death, injury, damage, or loss of property due to runway accidents and incidents within the civil aviation system. In the 2000 FAA National Aviation Research Plan, the FAA identified the need to investigate options such as enhancement of visual aids (lights and signs). A report from the U.S. Department of Transportation, Volpe National Transportation Systems Center, to the 4th USA/Europe Air Traffic Management R&D Seminar, addressed controller and pilot error in surface operations. One recommendation of this report was to increase aircraft conspicuity when the aircraft is on the runway through the use of existing aircraft lights, thus making the aircraft more conspicuous to controllers and pilots both on the ground and on approach.

1.3 RELATED DOCUMENTS.

The following documents relate directly to the issues addressed herein and define the nature of the lighting system differences studied in this evaluation:

- 2000 FAA National Aviation Research Plan, http://www.faa.gov/asd/narp2000/020 airtraf.pdf.
- Advisory Circular (AC) 120-75, Parts 121, 126, and 135, flight crew procedures during taxi operations.
- AC 91-73 Part 91, pilot and flight crew procedures during taxi operations.
- Cardosi, Kim (2001), "Controller and Pilot Error in Surface Operations," 4th USA/Europe Air Traffic Management R&D Seminar, Santa Fe, NM.
- FAA Report DOT/FAA/CT-TN05/18, "Aircraft Landing Lights Enhance Runway Traffic Safety (AL_2ERTS)," March 2005.

2. DISCUSSION.

It has been suggested that use of aircraft lighting (i.e., landing lights, logo lights, rotating beacons, etc.) may assist in making aircraft more conspicuous when operated on the runway during takeoff or when in position and holding for takeoff. This issue is important for pilots, vehicle operators, and air traffic controllers. It was determined that research was needed to further validate these lighting concepts. This project resulted from such a need and was accomplished at the FAA William J. Hughes Technical Center with assistance from the Volpe National Transportation Systems Center (herein referred to as Volpe).

The research need for determining the effectiveness of aircraft lights for ground operations had been demonstrated in earlier efforts and has been documented in FAA report DOT/FAA/CT-TN05/18 titled "Aircraft Landing Lights Enhance Runway Traffic Safety (AL_2ERTS)." The executive summary of that report is included as appendix A.

3. RESEARCH OBEJCTIVES.

The objectives of this research effort (using standard aircraft lighting) were to:

- Determine the best aircraft lighting configuration for making an aircraft on the active runway more conspicuous to an aircraft on final approach.
- Observe from an air traffic control (ATC) tower which aircraft lighting configuration is better for making an aircraft on a runway or taxiway more conspicuous to air traffic controllers.

4. EVALUATION APPROACH AND METHOD.

This research examined aircraft conspicuity from two perspectives, using a representative selection of aircraft types to the extent available as a target aircraft:

- Perspective I—that of the pilot of an aircraft on final approach with the target aircraft holding in takeoff position on the runway. An aircraft capable of maintaining air carrier aircraft approach speeds was used as the approach aircraft to assess the conspicuity of the target aircraft displaying various combinations of commonly installed exterior lighting.
- Perspective II—that of ATC in the tower with the target aircraft on a taxiway and runway. Actual observations and video recordings were made from the local ATC tower with target aircraft located at various on-runway locations on the airport.

Four specific types of target aircraft were available and used for this effort:

- Boeing 727—Typical of large-size jet, aircraft.
- Convair 580—Typical of medium-size, turbo-prop, commuter and business aircraft.

- Beechcraft 200 Kingair—Typical of the medium-size, twin-engine, general aviation aircraft.

- Piper Aztec—Typical of the small, twin-engine, general aviation aircraft.

Two aircraft were used for the approaches, the FAA's Kingair (N35) and Volpe's Aztec (N327DR). The Volpe's aircraft was equipped with an eye-tracker device, which was worn by their subjects during the approaches. The results of the Volpe's eye-tracker data analysis are included in appendix B.

While aircraft exterior lights are known by varying names, according to industry, the most commonly used aircraft exterior lighting includes combinations of:

- Rotating anticollision lights (omnidirectional red or white flashing beacons located either on top of the vertical stabilizer or on top of the fuselage)

- Position (navigation) lights (wingtip red and green lights and rear-aimed white lights, either flashing or steady burning)

- Logo lights (unidirectional white lights illuminating the vertical stabilizer, usually mounted at the wingtip or engine pods, steady burning)

- Landing lights (high-intensity unidirectional white lights aimed forward and down, usually wing mounted, either pulsing or steady burning)

- Taxi lights (high-intensity white lights aimed forward and down, can be wing or nose wheel mounted, steady burning)

- Strobe lights (condenser discharge flashing, omnidirectional lights, usually mounted on top of the fuselage facing rear on the tail cone or at the wingtips)

- Turnoff lights (unidirectional white lights mounted in the wing root to provide guidance during taxi turns, steady burning)

- Ice lights (unidirectional white lights mounted in the fuselage to illuminate the leading wing edge, steady burning)

Subjects for this project were recruited from locally based aviation organizations and/or facilities and had, as a minimum requirement, a valid U.S. private pilot certificate. They had no prior knowledge of the nature of the research effort and were not apprised of project details until being briefed immediately before the testing session began.

Runway 13 Centerline, Touchdown Lighting System was energized at normal night settings of step 3, and the Medium Intensity Approach Light Systems was energized at step 2 (medium intensity) during all approaches.

4.1 PERSPECTIVE I—FROM AN AIRCRAFT ON APPROACH.

The subject pilot occupied the right (copilot) seat in the FAA's approaching aircraft, while the FAA's safety pilot flew the aircraft and handled communications throughout the approach. The subject pilot occupied the left (pilot) seat in the Volpe's approaching aircraft and actually flew the aircraft, while the Volpe's safety pilot handled all communications throughout the approach. The subjects in Volpe's aircraft were fitted with eye-tracking devices to record where they were looking. The analysis of this data was performed by Volpe.

Just prior to boarding the aircraft, the subjects had been briefed (figure 1) that there might be aircraft, ground vehicles, or a combination of both within the safety area during these approaches. They were also told that there might possibly be neither aircraft nor vehicles in the safety area. If during the approach they identified anything that might be considered a hazard to landing, they were instructed to immediately announce and describe what they saw. Each subject was afforded the opportunity to observe multiple approaches. During this time, a different lighting configuration was displayed on the target aircraft, and a ground vehicle was stationed at one of two runway holding positions of the runway within the safety area alternating positions per approach. The subjects announced their observations to a data collector in the aircraft, who noted acquisition distances from the distance measuring equipment display in the cockpit electronically and/or manually. The reference point for this distance information was the threshold of runway 13.

The subjects were required to complete a postflight questionnaire (figure 2) immediately after finishing the flight session.

4.2 PERSPECTIVE II—FROM AN ATC TOWER.

Authorization to station a video team in the ATC tower during the test activity was obtained to permit taping of the target aircraft's appearance while positioned at all four takeoff locations on the airport and with varying lighting configurations. Special consideration was given to the choice of time and traffic conditions to minimize impact on normal tower operation.

5. RESULTS.

The airborne acquisition distance data and pilot comments were tabulated (table 1) and considered together in determining these results.

Results of the subject postflight questionnaire are provided as figure 3. The answers of the nonflying subjects on the questions of lights, and particularly landing light adequacy, was more favorable (mildly inadequate) than the answers for the flying subjects (extremely inadequate). This is reasonable since the nonflying subjects are dedicated to the task of making sure the runway environment is clear. The flying pilot also has that task as well as the task of flying the approach.

Average acquisition distance to the runway threshold were tabulated and provided as table 2. These averages were based on the number of points collected (subject identification) and not on the total number of opportunities presented. Thus, the distances were based only on the number approaches that a subject had "seen" something during an approach. To quantify this, the Percent "Seen" of Total Approaches row was added to table 2. For example, the average distance from threshold to acquire the rear navigation lights or strobes was 2.3 nautical miles (nmi), which was identified 8% of the total opportunities offered (48 approaches).

The Break-In TDZ column indicated pilot's comments—that they saw dark spots within the touchdown zone (TDZ) lighting array. When asked what that meant, they thought in could be a vehicle or aircraft, but were not certain.

So as not to impact ATC operations, only video was taken from the ATC tower. However, observers noted that the aircraft could be seen at each runway end. This was due, in part, to the geometry of the test site. At all runway ends (13, 31, 4, and 22), the aircraft lights were facing the tower that made the lighting more effective.

6. SUMMARY.

The following list summarizes the information that was collected.

- Sufficient data was collected from a representative group of pilots to allow valid interpretation of the results obtained. Additional data would not impact the results.

- Of the external aircraft lighting configurations studied, only those lights directed or partially visible to the rear of the target aircraft contributed to conspicuity for approaching aircraft. However, they do not provide enough of a visual cue to provide the needed conspicuity.

- Landing/taxi lights, while most valuable in providing aircraft conspicuity in the forward and side directions, provide very little identification to the rear. Since the light reflected to the rear is a function of runway surface texture and color, which can vary considerably from airport to airport, it cannot be depended upon for conspicuity.

- Pulsing landing/taxi lights, likewise, do not provide sufficient conspicuity to the rear of the aircraft. However, when seen, the pulsing landing lights were identified much sooner than the steady burning landing/taxi lights.

- The highest conspicuity seems to result from the use of lights that provide the human eye with a change of state by flashing or pulsing. The two aircraft lights identified during this evaluation were (1) the anticollision lights (aircraft beacon), which are required but not always visible from approaching aircraft, as commented on by subjects during this evaluation and (2) strobe lighting, which is not required by regulation currently. Thus, this form of lighting cannot be expected to be displayed by all aircraft.

Considering only the line in table 2 that provides the average acquisition distances for the various lighting configurations can be somewhat deceiving. A closer look at the table as a whole reveals that a number of subjects never saw any lights, and that they would have continued the approach to a landing with the target aircraft on the runway. The averages given are those of the sightings recorded, and do not take into consideration the instances when the subjects never saw those light on other approaches.

As an example, one subject never saw any lights on any of the four approaches, and another subject did not see anything on three of the five approaches. By average figures alone, the anticollision lights would have to be considered the most effective configuration (2.5 nmi) with rear navigation lights or strobes second with 2.3 nmi. However, the anticollision lights were sighted and commented upon by all 12 subjects during 31 out of 48 approaches, where the rear navigation lights or strobes were sighted and commented upon by only 3 subjects during 4 out of 48 approaches.

As viewed from the ATC tower, the lighting was adequate for identifying the aircraft at all runway ends during this evaluation. Although the observers stated they could see the aircraft with or without landing lights, the landing lights did provide added conspicuity. Due to the geometry of the test site, at all runway ends (13, 31, 4, and 22), the aircraft lights were facing the tower, which made the lighting more effective.

7. CONCLUSIONS.

Of the external aircraft lighting configurations studied (steady and pulsing landing lights), none of the configurations provided enough of a visual cue for the needed conspicuity for an approaching aircraft.

From the air traffic control tower, both standing and pulsing landing lights were effective in providing the needed conspicuity.

8. RECOMMENDATIONS.

A most significant factor is that no single light or configuration provided the necessary recognition or warning signal (i.e., conspicuity) for the situation posed. All lighting configurations available were developed for other purposes (such as providing surface illumination for landing and taxiing, recognition of airborne aircraft), and not principally for conspicuity of aircraft on the ground. Research should be conducted to identify the appropriate aiming angle, beam spread, and intensity requirements needed to provide the needed conspicuity for approaching aircraft.

Conspicuity Fight Evaluation
Pilot Briefing Sheet

The purpose of this evaluation is to determine the extent to which a pilot while flying a VFR approach can determine if there is a presence of aircraft in the safety area surrounding the active runway.

You will be an observer serving as the co-pilot in the FAA's Beechcraft 200 Kingair (N35). The pilot-in-command, and FAA Test Pilot, will fly multiple approaches to the active runway 13. There may be instances during these approaches when aircraft and/or ground vehicles will be somewhere within the safety area of the active runway. There also may be nothing in the safety area during an approach.

Your participation will consist of observing the runway area during each normal 3 degree approach to runway 13 to determine that the runway is clear.

If your perceive something in the safety area please announce the fact immediately and describe any details of what you see.

Figure 1. Sample Subject Pilot Preflight Briefing Material

Aircraft Conspicuity
Subject Pilot Questionnaire

Six point adequacy scale

Extremely adequate = 1
Considerably adequate = 2
Mildly adequate = 3

Mildly inadequate = 4
Considerably inadequate = 5
Extremely inadequate = 6

1. The illumination of lights was adequate for identifying the presence of an aircraft on the departure end of runway 13. ____________

2. The illumination of the Landing Lights was adequate for identifying the presence of an aircraft on the departure end of runway 13. ____________

3. The illumination of the LOGO Lights was adequate for identifying the presence of an aircraft on the departure end of runway 13. ____________

4. The pulsing of lights was adequate for identifying the presence of an aircraft on the departure end of runway 13. ____________

5. The pulsing of the Landing Lights was adequate for identifying the presence of an aircraft on the departure end of runway 13. ____________

6. The pulsing of the LOGO Lights was adequate for identifying the presence of an aircraft on the departure end of runway 13. ____________

7. The pulsing of the Landing Lights combined with the LOGO Lights was adequate for identifying the presence of an aircraft on the departure end of runway 13. ___________

Figure 2. Subject Postflight Questionnaire

Table 1. Acquisition Distances in Nautical Miles to Threshold

Run No.	Target A/C Tail No.	Break-in TDZ	Taxi/Landing Lights	Anticollision Lights	Wingtip Strobes	Rear Navigation Light or Strobes	Aircraft	Maintenance Vehicle	Comments
1	N40			0.4				0.2	Called rotating beacon
2	N40	2.3	0.8					4.1	Break in lights at 2.3 miles
3	N40			3.8		1.5			Something there
4	N40	1.2	0.8		1.5		0.5	4.1	White light on wingtip
5	N40	2.8	0.5				3.7		
6	N40			5.5		5.5			Red and white flashing light
7	N40			4.1			2.6		Red beacon on numbers
8	N40			2.9			7.6	0.7	Saw red beacon light
9	N40		4.1	5.3			4.1	4.7	Red beacon & Landing Lights
10	N49			0.4	0.4		0.4		
11	N49	0.4					0.4		Interruption of light pattern after T/H
12	N49	2.0			0.4		2.0		
13	N49			2.1	1	3.3	3.3		
14	N49								Looks clear to land
15	N49			1.9					Rotating red beacon, unsafe
16	N49								Looks clear to land
17	N49			1.7					Red light flashing, like A/C beacon
18	N39			0.3	1.4				

Table 1. Acquisition Distances in Nautical Miles to Threshold (Continued)

Run No.	Target A/C Tail No.	Break-in TDZ	Taxi/Landing Lights	Anticollision Lights	Wingtip Strobes	Rear Navigation Light or Strobes	Aircraft	Maintenance Vehicle	Comments
19	N39		0.6		0.9		0.6		
20	N39	0.7		1.2	1.4		0.7		Aircraft outline at 0.7 miles
21	N39	0.7		0.9	1.6		0.7		
22	N39								R/W look clear, I'd continue to land
23	N39								No traffic in sight on runway
24	N39								R/W look clear, I'd continue to land
25	N39								R/W look clear, I'd continue to land
26	N49			0.8	0.5		0.5		
27	N49			2.1	2.1		2.1	0.8	Strobes on vehicle
28	N49			2.2	2.2		2.2	1.2	
29	N49			2	2		2.0	0.5	
30	N49			1.9					Got beacon forward of T/H
31	N49			2.8					Beacon on R/W again
32	N49			3.1					I see the beacon again
33	N49			3.8					Still had a beacon
34	N39			2.1	3.4				White Fl. Lts. at 2.8, Red Lts. at 2.1

Table 1. Acquisition Distances in Nautical Miles to Threshold (Continued)

Run No.	Target A/C Tail No.	Break-in TDZ	Taxi/Landing Lights	Anticollision Lights	Wingtip Strobes	Rear Navigation Light or Strobes	Aircraft	Maintenance Vehicle	Comments
35	N39				2.5			2.0	Concentrated on T/H excessively
36	N39								No aircraft
37	N39			1.1	2.2			1.1	No landing lights observed
38	N39		0.8	2	2.5			4.2	Gap in TDZ lights very helpful clue
39	N39			2.5					See some lights on the T/H
40	N39			2.9					There's something on the runway
41	N39			2.7					There's something on the runway
42	N39			3.7					Look like an airplane on the R/W
43	AZTEC				1.4			3.9	Coast Guard hovering @ TWY Kilo
44	AZTEC				3.1			4.5	
45	AZTEC							4.6	No aircraft in position
46	AZTEC				3.4			4.3	
47	AZTEC				4.5			4.5	No dedicated concentration on R/W
48	N35								Completed approach. Continue

Table 1. Acquisition Distances in Nautical Miles to Threshold (Continued)

Run No.	Target A/C Tail No.	Break-in TDZ	Taxi/Landing Lights	Anticollision Lights	Wingtip Strobes	Rear Navigation Light or Strobes	Aircraft	Maintenance Vehicle	Comments
49	N35								No sign of aircraft on the runway
50	N35								Nothing out of the ordinary
51	N35			3.3					See white light, could be a rudder
52	N35			4.48					White light on top of green T/H lts.
Averages		1.8	1.4	2.5	2.3	2.1		2.8	

R/W = runway
T/H = threshold
A/C = aircraft
TWY = taxiway

Aircraft Conspicuity
Subject Pilot Questionnaire
Averages

Six point adequacy scale

Extremely adequate = 1
Considerably adequate = 2
Mildly adequate = 3

Mildly inadequate = 4
Considerably inadequate = 5
Extremely inadequate = 6

1. The illumination of lights was adequate for identifying the presence of an aircraft on the departure end of runway 13.
   Mildly Adequate - non-flying, Mildly Inadequate -flying

2. The illumination of the Landing Lights was adequate for identifying the presence of an aircraft on the departure end of runway 13.
   Mildly Inadequate - non-flying, Extremely inadequate - flying

3. The illumination of the LOGO Lights was adequate for identifying the presence of an aircraft on the departure end of runway 13.
   Considerably inadequate - non-flying, Extremely Inadequate, - flying <u>(2 subjects)</u>

4. The pulsing of lights was adequate for identifying the presence of an aircraft on the departure end of runway 13.
   Considerably Adequate non-flying, Considerably Adequate - flying

5. The pulsing of the Landing Lights was adequate for identifying the presence of an aircraft on the departure end of runway 13. _
   Considerably Adequate non-flying, Considerably Adequate - flying

6. The pulsing of the LOGO Lights was adequate for identifying the presence of an aircraft on the departure end of runway 13. ____**N/A**_____

7. The pulsing of the Landing Lights combined with the LOGO Lights was adequate for identifying the presence of an aircraft on the departure end of runway 13. ____**N/A**____

<u>NOTE</u>: A TOTAL OF 12 SUBJECT PILOTS COMPLETED THE QUESTIONNAIRES

Figure 3. Subject Postflight Questionnaire Responses

Table 2. Average Acquisition

	Break in TDZ	Taxi/Landing Lights	Anticollision Lights	Wingtip Strobes	Rear Navigation Lights or Strobes	Aircraft	Maintenance Vehicle
Average Distance to Threshold	1.8	1.4	2.5	1.9	2.3	2.1	2.8
Percent “Seen” of Total Approaches	15%	10%	65%	42%	8%	35%	33%

APPENDIX A—AL_2ERTS EXECUTIVE SUMMARY

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. This document describes the simulation, which was a proof-of-concept study, termed Aircraft Landing Lights Enhance Runway Traffic Safety (AL_2ERTS). The purpose of this study 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 simulation team, comprised of researchers from the FAA William J. Hughes Technical Center and the National Aeronautics and Space Administration (NASA) Ames Research Center (ARC), conducted a real-time, human-in-the-loop simulation from October 2003-January 2004. The simulation used NASA ARC's Crew Vehicle Systems Research Facility level D certified, Boeing 747-400 simulator. Sixteen crews composed of a Captain and First Officer participated in this study in which they were instructed to taxi, depart, or land in 16 scenarios. Half of the crews operated in a baseline condition that had no standard procedures for using landing lights to indicate that aircraft were cleared to depart (no standard condition); the other half operated in an environment with standard procedures (standard condition). Both conditions included four scenarios in which a scripted confederate aircraft committed an error or followed erroneous instructions that resulted in an RI with the potential to result in an accident if not detected by the subject crew. Crews were compared in the no standard condition and the standard condition in terms of their response to these scripted RIs. In general, the pattern of results supports the standardized use of aircraft landing lights to indicate that aircraft are cleared to depart. The data showed 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. Crews generally experienced incursions that were less severe when operating with a standard use of landing lights. Overall, landing lights provided a faster cue that there was a potential for a collision than movement alone, and crews in the standard condition reported that their first cue of an impending incursion were the landing lights. Standardization of the use of landing lights also showed some benefits for SA. The three-dimensional Situation Awareness Rating Technique rating trend of responses showed a slight increase in SA for Captains. Initial response times to departing aircraft were significantly faster for crews taxiing in the standard condition. Given accurate knowledge of events in the environment (namely, an aircraft departing), a faster response means greater safety. Finally, all pilots in the standard condition indicated that the standard use of landing lights increased safety. This simulation demonstrated the benefits of the procedure in an ideal environment where the complexity was relatively low and the lights were always visible. Further studies are suggested to determine the effects of other factors such as consistency of the message, message conspicuity, and effects of the message on other human system elements. Evaluating alternatives such as pulse lighting and the potential value of cues to air traffic control may reveal additional benefits.

APPENDIX B—EYE MOVEMENT RESULTS

In November 2004, the FAA Technical Center conducted a study of the effectiveness of various lighting conditions on aircraft conspicuity with the participation of pilots in an instrumented Volpe Center aircraft. The results of an analysis of the eye movement recordings that the Volpe Center obtained from subject pilots are described in this appendix.

Six subject pilots flew four or five night visual approaches in the Volpe Center Piper Aztec. Their instructions indicated that an aircraft, ground vehicle or both might be located in the safety area and to report any hazard to landing. In fact, aircraft were holding in takeoff position on all approaches except on one approach (the third) for three pilots. These target aircraft included N40 (Boeing 727), N39 and N49 (Convairs), and N35 (Beechcraft King Air). These aircraft were lighted using a variety of lights (anti-collision lights, wingtip strobes, and rear navigation lights or strobes) on all approaches. On some approaches additional taxi/landing lights were turned on and on other approaches they were turned off. The experimental design is shown in Table 1.

Visual scanning data were collected using an ISCAN, Inc. (Burlington, MA) Model AA-ETL-500 Eye Tracking Laboratory with the Headband Mounted Eye/Line of Sight Scene Imaging System and accompanying computer and analysis software. This approximately 300-gram device uses the pupil corneal reflection method to record the pilot's visual point of regard. It records data at 60 Hz. The manufacturer has determined its accuracy to be at least one-half degree over a +/- 25- degree horizontal to a 20-degree vertical range. Dwells of the participants' left eye were recorded to provide measures of visual attention. Eye fixations were assigned to one of two areas of interest, the instrument panel or the forward window.

Two types of analyses were conducted. The first consists of a description of how visual attention was allocated between the instrument panel (Panel) and forward window (Window). The second analysis consisted of the application of inferential statistics to dwell times on these areas of interest. The factors included in the statistical models were Subject, Target (N35, N39, or N40, or N49), Run (i.e., the approach number for the pilot), Landing Lights (on, off, or no target). Results for Subject are not reported. Multiple pair wise comparisons were conducted using Tukey's HSD method to control Type 1 Error. The No Target condition was analyzed as a lighting condition because, like Landing Lights, it was manipulated within subjects, whereas Target was manipulated between subjects. The first subject was exposed to somewhat different conditions than the remaining subjects: Target logo lighting was turned on for Runs Three through Five, and on Run Five, "pulse" was used as the Landing Lights condition. Because the first pilot was reportedly able to see the runway area through the side window while on the base leg, the flight pattern was altered for the remaining five pilots to lengthen the final approach course. Due to these differences the results were analyzed both including the data obtained from the first pilot and without them.

Allocation of visual attention.

The results of the allocation analysis are clear. As shown in Figure 1, precisely the same percentage of visual attention was allocated to the Window (89%) and Panel (11%) under both the Landing Lights On and Landing Lights Off conditions. The allocation for the conditions where no aircraft was on the runway showed a shift of three percent to the panel. Since only three of the six pilots were presented (on one approach) with a clear runway, whereas six were presented with the two target present conditions, it is possible that this difference between target present and target absent was due to differences in pilots rather than conditions. To determine whether this was the case, the allocation was re-analyzed with only these three pilots' data included. The results for the Landing Lights On and Landing Lights Off conditions were indeed closer to those of the No Target conditions: they now differed from the No Target conditions by only one percent. Again the same percentage of visual attention was allocated to the Window (87%) and Panel (13%) under both the Landing Lights On and Landing Lights Off conditions.

Subject Pilot	Run	Target	Landing Lights
1	1	N40	Off
1	2	N40	On
1	3	N40	Off
1	4	N40	On
1	5	N40	Pulse
2	1	N49	Off
2	2	N49	On
2	3	N49	Off
2	4	N49	On
3	1	N49	Off
3	2	N49	On
3	3	N49	Off
3	4	N49	On
4	1	N39	Off
4	2	N39	On
4	3	N39	No Target
4	4	N39	Off
5	1	N39	Off
5	2	N39	On
5	3	N39	No Target
5	4	N39	Off
5	5	N39	On
6	1	N35	Off
6	2	N35	On
6	3	N35	No Target
6	4	N35	Off
6	5	N35	On

Table 1. Experimental Design.

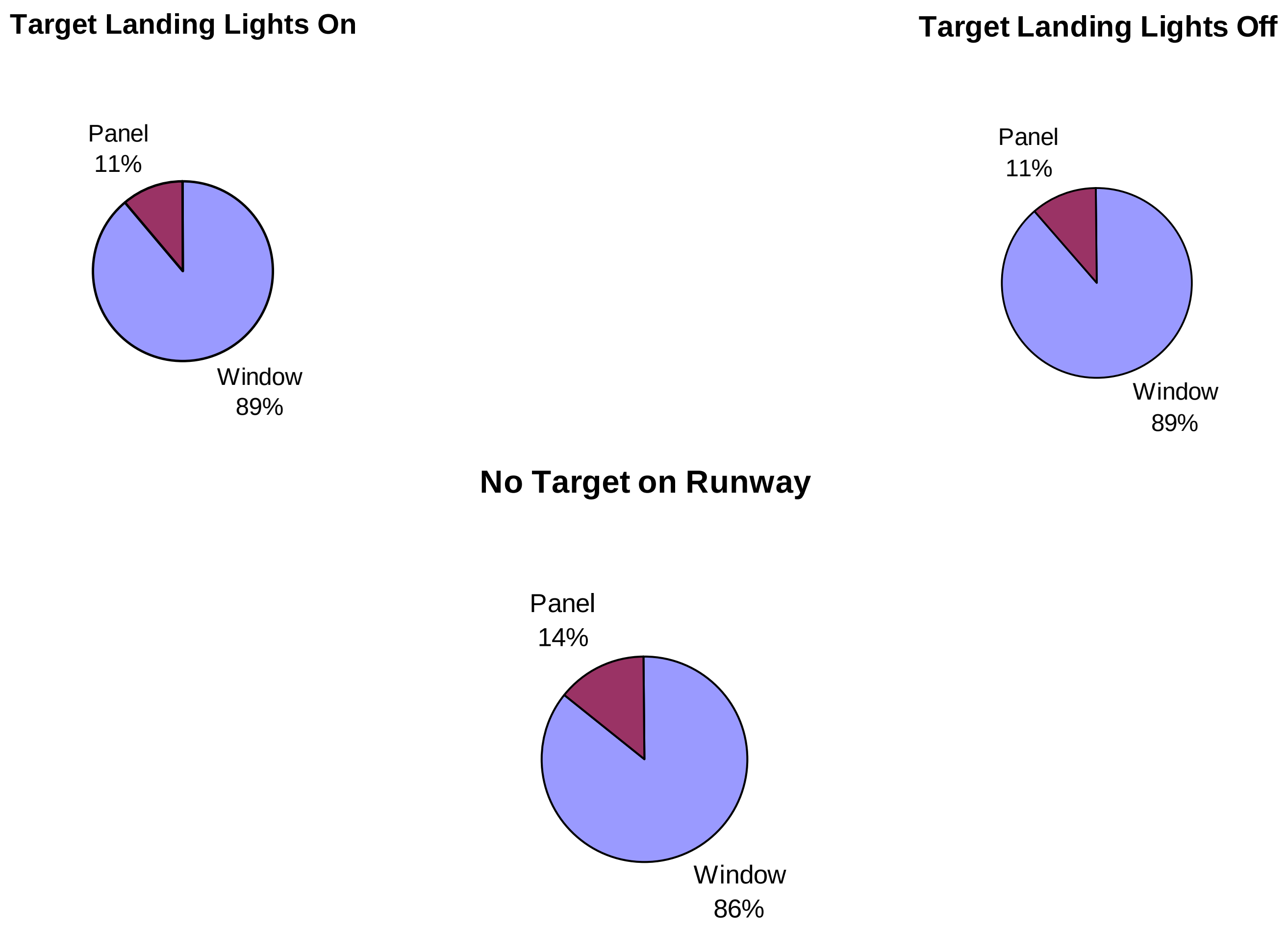

Figure 1. Allocation of Visual Attention to Window and Panel.

Dwell Duration.

Dwell duration was defined as the time the point of regard remained within a given area of interest prior to leaving it. Mean dwell durations for significant differences are indicated in parentheses.

The mean dwell time on Window 4.9 s. No significant main or interaction effects of Landing Lights on Window dwell duration were found. The analysis revealed significant main effects of Target, $F\ (3, 647) = 11.96$, $p < .0001$ and Run, $F\ (4, 647) = 2.57$, $p = .037$. The Window dwell durations were significantly longer for N49 (6.9 s) than N40 (4.6 s), N35 (4.4 s), or N39 (4.3 s).

The mean dwell time on Panel was .66 s. The analysis of Panel dwell times also found no significant main effects or interaction effects due to Landing Lights. A significant effect of Target on Panel dwell times was found, $F\ (3, 653) = 6.33$, $p = .0003$. The Panel dwell durations when the target was N40 (.71 s) or N39 (.71 s) were significantly longer than when the target was N49 (.55 s).

Additional analysis was conducted on the dwell duration data for Subjects Two through Six because of the alteration in flight pattern described earlier. Data from the single run where “pulse” landing lights were used were excluded from these analyses. The mean Window dwell for Landing Lights for these subjects and conditions was 5.1 s. The mean Panel dwell was .63 s.

No significant main effects of Landing Lights or Run on Window dwell duration were found for Subjects Two through Six. The interaction of Landing Lights and Target was significant, $F\ (5, 558) = 6.86$, $p < .0001$ and it is shown in Figure 1. The mean Window dwell with Landing Lights On was 5.2 s and with Landing Lights Off it was 5.1 s. The mean dwell durations for N35, N39, and N49 were 4.4 s, 4.3 s, and 6.9 s, respectively. There were insufficient data to further analyze this interaction statistically. However, examination of Figure 1 suggests that the pilots may have dwelled longer on the Window for N35 than for the larger N39 when they were not on the runway.

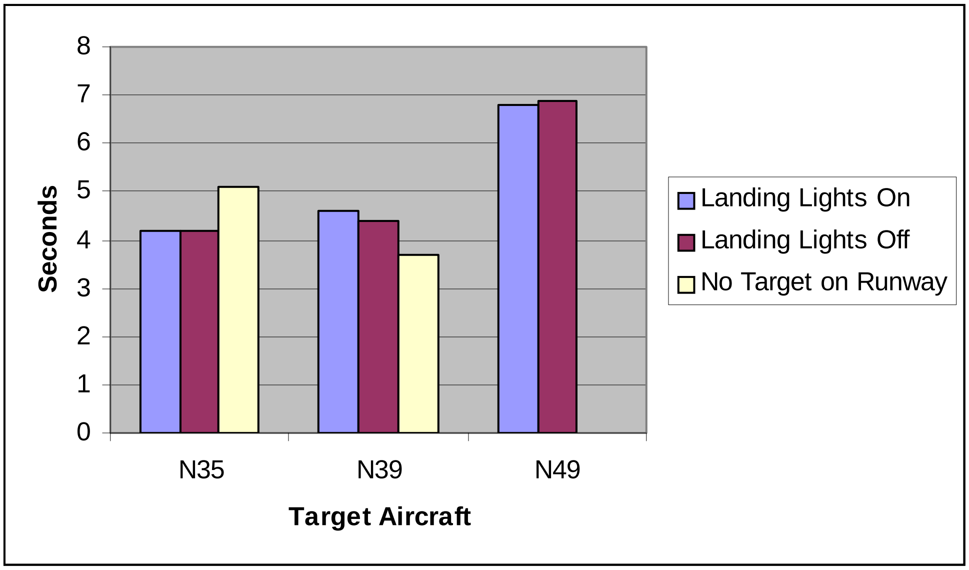

Figure 1. Effect of Landing Lights and Target on Window Dwell Duration.

A significant main effect of Target on Panel dwell durations was found for Subjects Two through Six, $F(2, 547) = 9.21$, $p < .0001$. Multiple pair wise comparisons found that the mean Panel dwell for N39 (.71 s) was significantly longer than the mean Panel dwell for N49 (.55 s). No significant main or interaction effects of Landing Lights on Panel dwell duration were found.

<u>CONCLUSION</u>.

No evidence was found to suggest that landing lights would increase the conspicuity of target aircraft in take off position for pilots approaching the airfield at night in a Piper Aztec. The percentage of visual attention allocated to the forward window and instrument panel were the same when the landing lights were turned off and when they were turned on. Furthermore, the allocation was similar (within three percent) when the target was in position for take off and when it was off of the runway (with all lights off). Dwell duration was sensitive to differences among the target aircraft, but no differences in dwell duration could be attributed to the use of landing lights.