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L-853 Cylindrical Runway and Taxiway Retro-Reflective Markers Study

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Final Report

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EXECUTIVE SUMMARY

This report describes the evaluation of L-853 cylindrical retro-reflective markers that are used on airports to increase night identification of runway edges, centerline, and taxiway edges. Approved retro-reflective markers use either retro-reflective sheeting or tape, which are mounted on plastic-molded material that are cylindrical or flat surfaces. The minimum standard size for a cylinder-mounted marker is 96 square inches. This evaluation was performed to determine if increasing the standard size to 200 square inches would improve the markers' conspicuity to aircraft and ground vehicles and to determine if the location of aircraft-mounted landing lamps have any effect on the visibility of the retro-reflective markers. Based on the results, it was determined that 96-square-inch retro-reflective material is adequate. The results of this study also indicated that aircraft landing lamps mounted closer to the observer's eye gave the best visibility of the retro-reflective markers, whereas the aircraft landing lamps mounted at the wing tips gave the worst visibility of the retro-reflective markers.

1. INTRODUCTION.

1.1 PURPOSE.

This evaluation effort was undertaken in response to a request from the Office of Airport Engineering Division, AAS-100, March 10, 2002. The Airport Technology Research and Development Branch, AAR-410, at the Federal Aviation Administration (FAA) William J. Hughes Technical Center performed tests to determine the effectiveness of an increase in size of the L-853 runway and taxiway cylindrical retro-reflective marker material.

The objectives of this evaluation were:

- To determine if increasing the minimum size of the cylindrical retro-reflective markers from 96 square inches to 200 square inches would improve the markers' conspicuity to aircraft and ground vehicles.
- To demonstrate the relationship between the location of landing and taxiway lamps mounted on the aircraft and the effect it has on the pilot's view of the retro-reflective markers.

1.2 BACKGROUND.

Retro-reflective markers have been used for several years to mark the edges of highways and to mark traffic lanes. Since this type of reflector is inexpensive, relatively efficient, and easy to install, it has been used on airports to increase night identification of the runway edges, centerlines, and taxiway edges. Retro-reflective markers are used (1) to supplement runway and taxiway edge lamps and (2) used at low-activity airports in lieu of runway and taxiway edge lamps. There are two types of approved runway and taxiway retro-reflective edge markers: those using retro-reflective sheeting or tape, which are mounted on plastic-molded material that are cylindrical or flat surfaces.

The present minimum standard size (i.e., surface area) for cylindrical retro-reflective markers is 96 square inches. It was suggested that to increase effectiveness and improve safety, the minimum surface area should be increased to 200 square inches. This investigative effort addressed this issue.

1.3 RELATED DOCUMENTS.

Related documents dealing with this evaluation project are:

- FAA Advisory Circular 150/5345-39B, "FAA Specification L-853, Runway and Taxiway Retroreflective Markers," December 9, 1980.
- FAA Advisory Circular 150/5345-53B, "Airport Lighting Equipment Certification Program," October 23, 1998.

- Specification L-S-300C, “Sheeting and Tape, Reflective: Nonexposed Lens,” (Cancelled and Superseded by ASTM D4956).
- ASTM D4956, “Standard Specification for Retroreflective Sheeting for Traffic Control,” 2001.
- VAP-WG/WHL/4-DP/4, “Apron Marking/Retro-Reflective Markers,” June 11, 2003 for Visual Aids Panel (VAP) Working Group of the Whole Fourth Meeting.
- Report No. FAA RD-66-71, “Testing of Reflective Markers for Indicating the Threshold and Centerline of Runways for Small Airports,” 1996.
- Report No. FAA NA-69-25, “Retro-Reflective Markers as Taxiway Visual Aids,” 1969.
- Report No. FAA NA-79-44-LR, “Evaluation of Retroreflective Taxiway Edge Markers,” 1979.
- Report No. FAA CT-81-173, “Evaluation of Retroreflective Pavement Markers for Precision and Non-Precision Runways,” 1981.
- Report No. FAA RD-82-91 and FAA CT-83-5, “Identification of Exit Taxiways (Retroreflective Markers only),” 1983.
- Report No. FAA RD-82-80 and FAA CT-82-131, “Evaluation of Wind-Driven Retroreflective Taxiway Edge Markers,” 1982.
- Report No. FAA CT-82-112 and FAA CT-82-83, “Evaluation of Retroreflective Pavement Markers for Precision and Non-Precision Runways,” 1982.
- Report No. FAA CT-82-164, “Evaluation of Retroreflective Pavement Markers for Precision and Non-Precision Runways,” 1983.

2. EVALUATION APPROACH.

2.1 METHOD.

Two tests were performed: an objective luminance photometric comparison test and a subjective retro-reflective marker size comparison test involving human evaluators.

2.1.1 Photometric Comparison Test.

For the luminance comparison test, two styles of blue retro-reflective markers (type III and type IX) and two styles of white retro-reflective markers (type III and type IX) were evaluated.

Figure 1 shows, from left to right, a blue type IX marker, a blue type III marker, a white type III marker, and a white type IX marker.



FIGURE 1. L-853 CYLINDRICAL RUNWAY AND TAXIWAY RETRO-REFLECTIVE MARKERS

Type III is a high-intensity retro-reflective sheeting that is, typically, an encapsulated glass bead retro-reflective material. The retro-reflective characteristics are shown by R_A values in table 1 at different observation angles.

Type IX is a super-high-intensity retro-reflective sheeting that is, typically, an unmetalized microprismatic retro-reflective element material. The retro-reflective characteristics are shown by R_A values in table 2 at different observation angles.

Each cylindrical marker used for the test had 200 square inches of retro-reflective sheeting around its circumference. The pilot could not see the entire 200 square inches when taxiing down the runway or taxiway. The pilot only sees about 50% of the retro-reflective sheeting area.

To obtain the 96 square inches of retro-reflective sheeting, the 200-square-inch cylindrical marker was masked off to show only 96 square inches of retro-reflective sheeting. Once again, the pilot could not see the entire 96 square inches when taxiing down the runway or taxiway. The pilot only sees about 50% of the retro-reflective sheeting area.

TABLE 1. TYPE III RETRO-REFLECTIVE SHEETING^a

Observation Angle	Entrance Angle	White	Blue
0.1 ^{ob}	-4°	300	24
0.1 ^{ob}	+30°	180	14
0.2°	-4°	250	20
0.2°	+30°	150	11
0.5°	-4°	95	7.5
0.5°	+30°	65	5.0

^a Minimum coefficient of retroreflection (R_A) $\text{cd}/\text{fc}/\text{ft}^2(\text{cd}\cdot\text{lx}^{-1}\cdot\text{m}^{-2})$.

^b Values for 0.1° observation angles are supplementary requirements that shall apply only when specified by the purchaser in the contract or order.

TABLE 2. TYPE IX RETRO-REFLECTIVE SHEETING^a

Observation Angle	Entrance Angle	White	Blue
0.1 ^{ob}	-4°	660	30
0.1 ^{ob}	+30°	370	17
0.2°	-4°	380	17
0.2°	+30°	215	10
0.5°	-4°	240	11
0.5°	+30°	135	6.0
1.0°	-4°	80	3.6
1.0°	+30°	45	2.0

^a Minimum coefficient of retroreflection (R_A) $\text{cd}/\text{fc}/\text{ft}^2(\text{cd}\cdot\text{lx}^{-1}\cdot\text{m}^{-2})$.

^b Values for 0.1° observation angles are supplementary requirements that shall apply only when specified by the purchaser in the contract or order.

The retro-reflective markers were evaluated at a 100- and 300-foot acquisition range. Three landing lamp locations were evaluated (figure 2). The first lamp was located at the center, simulating an aircraft with a nose cone-mounted lamp. The second lamp was located 5 feet to the right of center, simulating an aircraft with wing root lamps. The third lamp was located 15 feet to the right of center, simulating an aircraft with wing tip lamps. Readings were taken with a Minolta LS-100 luminance meter, recorded, and charted.

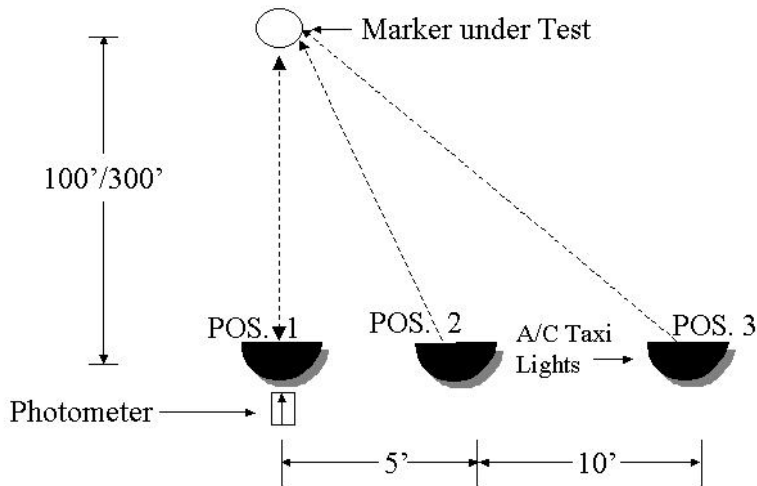


FIGURE 2. PHOTOMETRIC TEST SETUP

2.1.2 Subjective Retro-Reflective Marker Size Comparison Test.

For the retro-reflective marker size comparison test, type III and type IX white and blue retro-reflective markers were used. The standard 96-square-inch retro-reflective marker and the 200-square-inch retro-reflective marker were evaluated. A circular course for the evaluation (figure 3) was set up at the FAA ramp, taxiway Juliet, taxiway Bravo, and taxiway Kilo. In the clockwise direction, six white and six blue 96-square-inch retro-reflective markers were displayed, and in the counterclockwise direction, six white and six blue 200-square-inch retro-reflective markers were displayed.

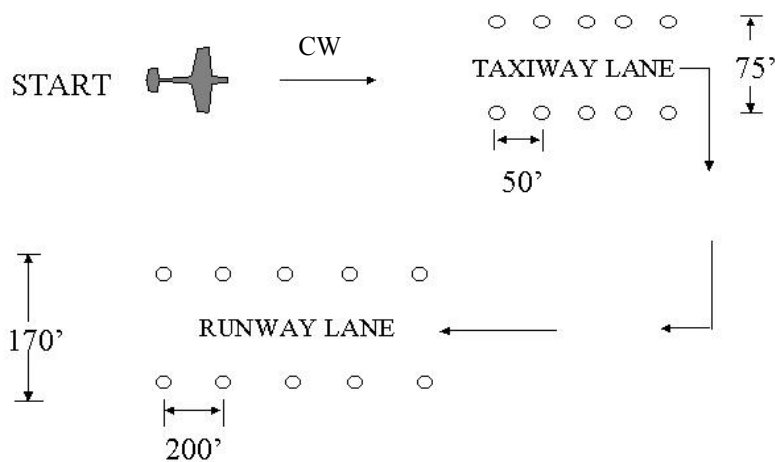


FIGURE 3. TAXIWAY AND RUNWAY MARKER LANES

The evaluation subjects were required to complete a postsession questionnaire (figure 4), with the resultant data charted and used to evaluate both sizes of cylindrical retro-reflective markers.

RETRO-REFLECTIVE MARKERS EVALUATION FORM (NIGHTTIME)

Subject's Name: _____ Date: _____ Weather: _____

Type of vehicle: Convair 580 _____ King Air _____ Aero Commander _____ Van _____

Please express your opinion concerning the effectiveness of retro-reflective markers

1. Do the BLUE 96-square inch retro-reflective markers adequately delineate the edges of the taxiway? Yes _____ No _____
2. Do the BLUE 200-square-inch retro-reflective markers adequately delineate the edges of the taxiway? Yes _____ No _____
3. Do the WHITE 96-square-inch retro-reflective markers adequately delineate the edges of the runway? Yes _____ No _____
4. Do the WHITE 200-square-inch retro-reflective markers adequately delineate the edges of the runway? Yes _____ No _____
5. Does the increase in marker size, from 96-square inches to 200-square inches, significantly improve acquisition ranges and taxiing cues? Yes _____ No _____

Please provide us any additional comments or opinion that you may have:

Thanks for your assistance in accomplishing this evaluation!

FIGURE 4. SAMPLE QUESTIONNAIRE

2.2 EVALUATION SUBJECTS.

The project team was comprised of engineers and pilots. Individuals from the AAR-411 organization, along with contract support personnel, supervised the efforts conducted at the Atlantic City International Airport.

A total of 11 subjects completed the subjective evaluation form. They are identified, according to their job titles, as follows:

- Two FAA professional test pilots employed at the FAA William J. Hughes Technical Center
- Two U.S. Coast Guard pilots assigned to Coast Guard Air Station Atlantic City
- Two FAA employee private pilots
- Two civilian (contractor) private pilots
- Three FAA airport lighting engineers

2.3 EQUIPMENT REQUIREMENTS.

The following equipment was used for testing:

- Retro-reflective markers from Valley Illuminator (P/N AR-100 that had type IX reflective sheeting and a specially made marker with type III reflective sheeting)
- Luminance Meter, Minolta LS-100
- Digital camera
- Beechcraft King Air Aircraft
- Convair 580 Turboprop Aircraft
- Aero Commander Aircraft
- Ford Walk-in Van with a King Air General Electric (GE) taxi lamp mounted to the front bumper
- GE Aircraft Taxiing Lamp for King Air, P/N 4587, PAR-36, 28 Volt

The following is a further explanation of some of the equipment used in this evaluation.

2.3.1 Beechcraft King Air Aircraft.

The Beechcraft King Air BE-200 is a twin-engine aircraft with one GE aircraft taxiing lamp, 250-watt, PAR-36, 28 Volt, mounted in the nose cone.

2.3.2 Convair 580 Turboprop Aircraft.

The Convair 580 is a turboprop conversion of the Consolidated/Vultee Aircraft Company (hence Con + V + Air) earlier series of piston-powered airliners. The Convair 580 turboprop aircraft has a 600-watt taxi lamp mounted on the nose wheel strut.

2.3.3 Aero Commander Aircraft.

The Aero Commander (AC-500S) is a high-winged, twin-piston engine aircraft. The Aero Commander has two 250-watt taxi lamps mounted on either side in the nose cone.

2.3.4 Ford Walk-In Van.

A Ford walk-in van with a King Air 250-watt GE taxiing lamp mounted on the bumper was used to evaluate the retro-reflective markers.

3. DISCUSSION.

3.1 PHOTOMETRIC COMPARISON TEST.

Figures 5 and 6 show the results of the photometric comparison test performed for blue and white retro-reflective markers, respectively, to demonstrate the degree of reduced effectiveness that may be expected when the lamps illuminating the markers are placed at different distances from the observer's eye. The placements selected are those typical for aircraft taxi lamps located in the nose (center), on the wing root (5 feet), and in wing tip tanks (15 feet), or mid-wing on larger aircraft.

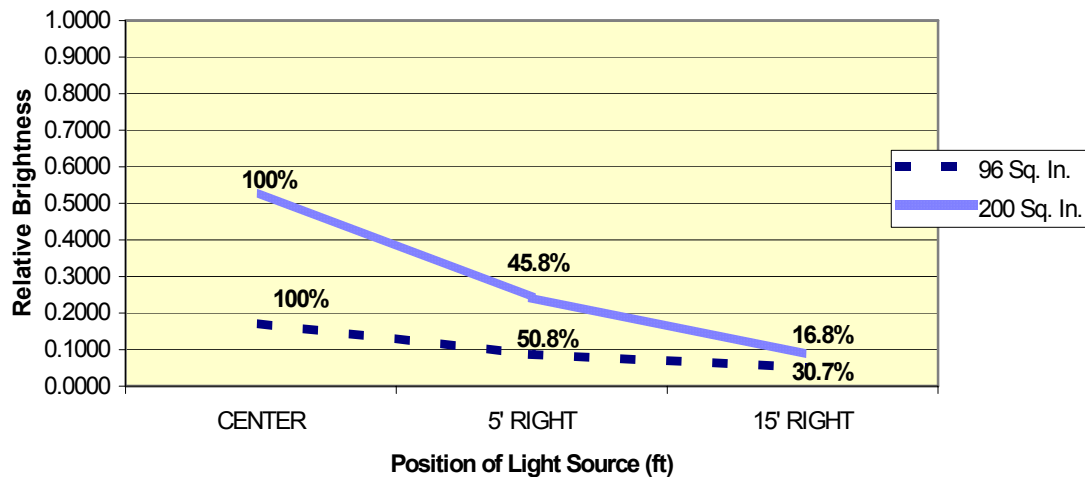


FIGURE 5. COMPARISON TEST OF BLUE RETRO-REFLECTIVE MARKERS

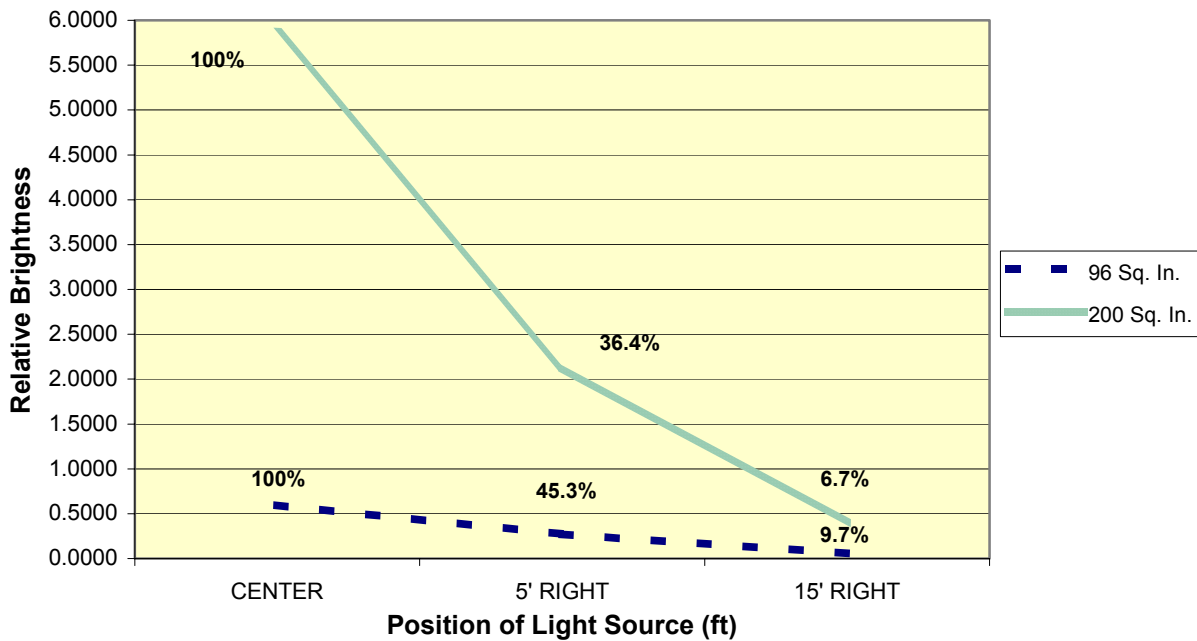


FIGURE 6. COMPARISON TEST OF WHITE RETRO-REFLECTIVE MARKERS

It should be noted that the intensity values were obtained with an LS-100 Minolta luminance meter and, as such, are not absolute intensity readings (candela) but rather indications of relative brightness (foot lamberts). So long as the ambient conditions (distance, surrounding light, etc.) are kept constant, as they were for this test, the comparative values for differing light source locations are valid. The average percentage of light drop-off in retro-reflectivity is shown.

As shown in figure 5, the 96-square-inch blue retro-reflective markers start out at 100%, but at 5 feet right of center, the readings dropped to 50.8%, and then to 30.7% at 15 feet right of center. The 200-square-inch blue retro-reflective markers start out at 100%, but at 5 feet right of center, the readings dropped to 45.8% and then to 16.8% at 15 feet right of center.

In figure 6, the 96-square-inch white retro-reflective markers start out at 100%, but at 5 feet right of center, the readings dropped to 45.3% and then to 9.7% at 15 feet right of center. The 200-square-inch white retro-reflective markers start out at 100%, but at 5 feet right of center, the readings dropped to 36.4% and then to 6.7% at 15 feet right of center. The increase to a 200-square-inch surface area only shows a slight improvement in relative brightness for nose-mounted taxi lamps (center) and does not increase nearly as much with the more critical wing-mounted taxi lamp installations (15 feet right of center).

In general, it can be said that the decrease in both taxi and runway marker effectiveness, which results from aircraft taxi lamp locations other than directly in front of the pilot's eye, is significant and, in many cases, renders the markers unusable for both sizes tested. Figures 5 and 6 show this by looking at the percent readings taken with the lamp at the center and, as you move to the right, the percent readings drop.

3.2 SUBJECTIVE RETRO-REFLECTIVE MARKER SIZE COMPARISON TEST.

Results of the questionnaire responses for 18 participating subjects are provided in figures 7 and 8 by aircraft type. Note that of the 18 participants, some may have performed the evaluation in more than one aircraft.

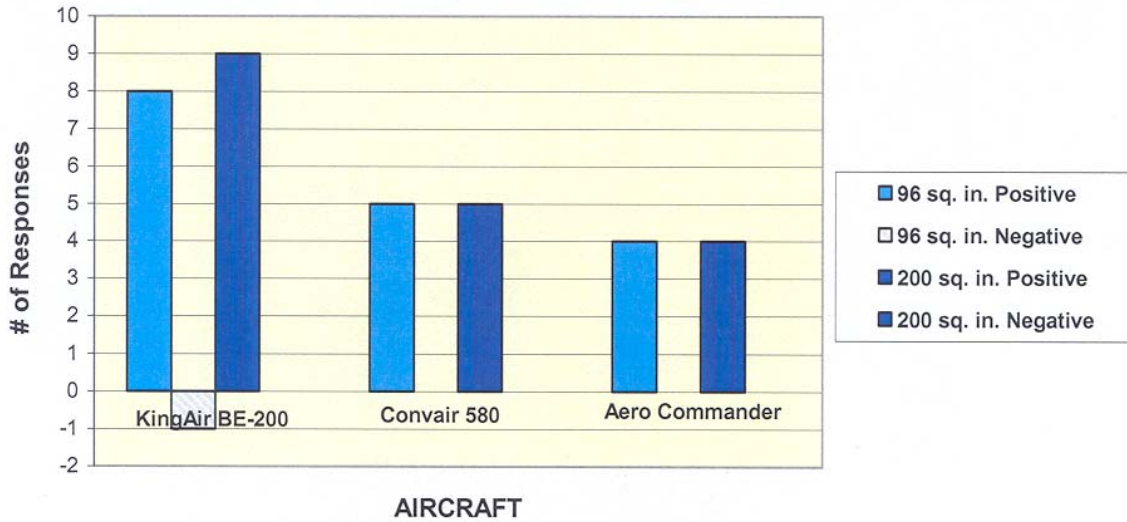


FIGURE 7. BLUE RETRO-REFLECTIVE MARKER QUESTIONNAIRE RESULTS

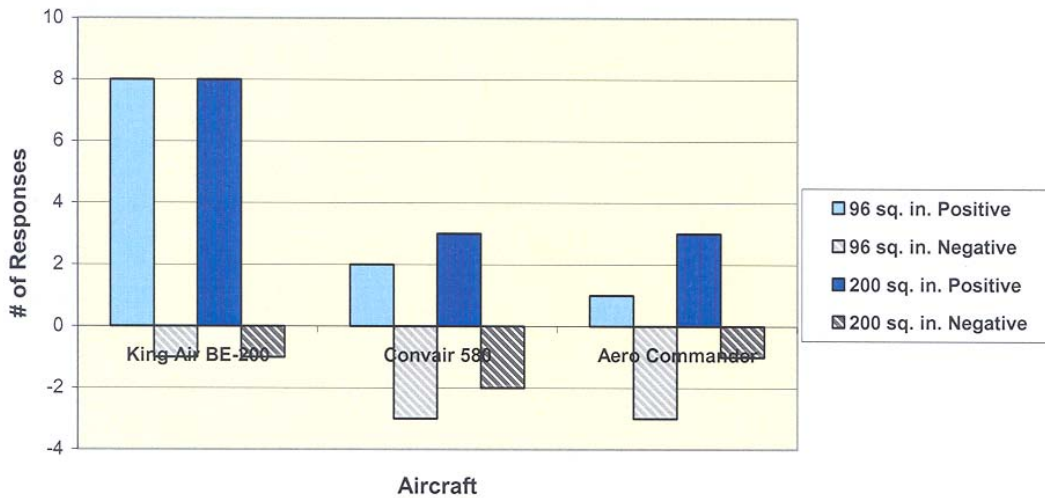


FIGURE 8. WHITE RETRO-REFLECTIVE MARKER QUESTIONNAIRE RESULTS

3.2.1 Blue Taxiway Marker Performance (Questions 1 and 2).

(Do the blue 96- or 200-square-inch retro-reflective markers adequately delineate the edges of the taxiway?) With regard to the standard (96-square-inch) blue taxiway marker, 17 out of 18 subjects rated it as adequate under the test conditions. This indicates general satisfaction with the marker performance. A pilot taxiing the King Air aircraft, who also rated the same marker size and color as adequate when viewed from the larger Convair 580, gave the only negative rating. It should be noted that the Convair has a 600-watt taxi lamp on the nose wheel strut, while the King Air uses only a 250-watt lamp in the same location.

Performance of the larger (200-square-inch) blue marker was also judged completely adequate, with all 18 subjects providing favorable responses. This was to be expected since twice the surface area should reflect more light.

It would appear that, in the opinion of the participating subjects, either size blue taxiway marker will provide adequate taxi guidance with the types of centrally located taxi lamps used for this evaluation. Such satisfactory performance may not be attained with aircraft having other taxi lamp configurations.

3.2.2 White Runway Marker Performance (Questions 3 and 4).

(Do the white 96- or 200-square-inch retro-reflective markers adequately delineate the edges of the runway?) Subject evaluation of white (runway) marker effectiveness is somewhat more difficult to interpret since neither marker was judged to be completely satisfactory. Only slightly more than half of the subjects, 11 out of 18, indicated that the standard (96-square-inch) white runway marker was adequate.

A greater percentage of favorable responses, 14 out of 18, were obtained when the marker size was increased to 200 square inches.

The participating subjects were briefed prior to each evaluation session, indicating that the effectiveness of the white runway markers was to be predicated upon performance in support of the after-landing rollout maneuver. They were specifically instructed not to consider the measure of approach guidance that the markers might provide prior to touchdown since it is recognized that any aircraft crab angle introduced as a result of wind conditions would severely reduce marker effectiveness. Furthermore, rollout maneuvering on a runway at higher taxiing speeds would require significantly greater marker acquisition range and perhaps more than either size marker could provide. At runway widths of 150 ft, the retro-reflective markers are located out of the main beam of the taxiing lamps on most aircraft.

3.2.3 Improvement Provided by Increasing Size (Question 5).

(Does the increase in marker size, from 96 square inches to 200 square inches, significantly improve acquisition ranges and taxiing cues?) While 10 of the 12 subjects expressed that the acquisition ranges and taxiway cues were improved, the pilot comments and intensity data also need to be considered. Pilots commented that the 200-square-inch retro-reflective marker only provided minimally better performance. In addition, many of the comments state that retro-

reflective markers only provide minimal guidance compared to what is required and supplied by standard lamp fixtures. Due to the location of these markers, their potential enhanced performance expected from increased size or improved materials is minimized due to the degradation of their performance at wide observation angles, as shown in figures 5 and 6.

3.3 ADDITIONAL COMMENTS AND OPINIONS.

The subjects were encouraged to provide written comments in addition to the yes or no questions. Summaries of these comments are discussed in the following sections.

3.3.1 Comments From Convair 580 Taxi and Runway Rollout Sessions.

The following were additional comments and opinions that were noted while in the Convair 580. The Convair 580 has a 600-watt taxi lamp on the nose wheel strut.

- All were barely acceptable for edge light identification. Situational awareness is much less than with lights.
- White very poor as related to blue. Blue good either direction (both sizes), 100 yards away up to about 100 feet. Then guidance is gone. Taxi speed 14 kts. Runway speed 60 kts. Intersection use is not acceptable.
- Convair left side better than right.
- You need to have “lights” (pointed) on units to see them. Taxi light is very narrow and not very effective up close. All reflectors looked good from a distance. Not good at short distances.
- The 200-square-inch size markers were a little more noticeable than the 96-square-inch. With the runway 96-square-inch markers you had to know what you were looking for to really notice them.
- Convair is brighter and higher. It has a wider field of view, since it has two lights.

3.3.2 Comments from the Aero Commander Taxi and Runway Rollout Sessions.

The following were additional comments and opinions that were noted while in the Aero Commander. The Aero Commander has two 250-watt taxi lamps on either side in the nose cone.

- A lot depends on the beam width of the light. Aero Commander narrow but both sizes still provided adequate guidance.
- White very poor as related to blue. Yes I could see them, but white is not acceptable. Blue looks good from a distance; within 100 ft blue guidance is not visible. No good at intersection when you are within 100 feet of intersection taxi speed about 10 kts. Take off speed 80 kts.

- On the Aero Commander, used both lights (taxi and landing) for white markers. Had to zigzag the taxiway to see blue markers.

3.3.3 Comments From Van.

The following were additional comments and opinions that were noted while in the van. The van had a King Air, 250-watt lamp mounted on the front bumper.

- Both the white and the blue could be seen from approximately the same distance and were adequate in marking the edges of the taxiway.
- One set of markers is not any better than the other. When the light was not on them they were not visible. The increase in size or change of color did not improve visibility.
- Prefer blue to white. The position and angle of the light (or lights) on the aircraft is a bigger factor than the size and/or color of the taxiway reflector.
- The 200-square-inch-versions were brighter but not any different in acquisition distance. Both sizes became ineffective at the same time – the point at which the light passed the fixture.

3.3.4 Comments From King Air Taxi and Runway Rollout Sessions.

The following were additional comments and opinions that were noted while in the King Air. The King Air had a 250-watt lamp mounted on the nose wheel strut.

- Light reflection was less acceptable on the King Air. Landing lights on the King Air only produces a glow from the cockpit and the reflectivity is not at all good. Slightly better than nothing.
- The 96-square-inch (marker) is adequate. Better on both (white and blue) with 200-square-inches. More enhancements in the blue.
- 200-square-inch (marker) only marginally enhanced the conspicuity.
- King Air worse than Convair.
- Photometrics for King Air light should be looked at.

3.3.5 General Comments.

The following general comments were made on the retro-reflective marker evaluation form. They were comments that were not specifically directed toward any of the aircraft used in the evaluation.

- Pathetic – Need reflectors instead of retro-reflectors.
- From a distance the retro-reflective markers look good, but as you get closer the edges disappear quickly.
- White (200 square inches) bigger not as good as white (96 square inches) smaller.
- Blue (200 square inches) bigger some better than blue (96 square inches) smaller.
- Used taxiway lights for blue markers and landing lights for white markers.
- Reflectors should be looked at.
- Situational awareness not good. Not a substitute for lights.
- When doing S turns, you can see one side, but not the other side.
- Taxiway (blue) markers – slightly better than nothing.
- Runway (white) markers – more useless.

4. CONCLUSIONS.

Increasing the size of the markers from 96 square inches to 200 square inches would provide only a slight improvement over the standard marker for most aircraft types, and even less of an increase in effectiveness for aircraft having the less advantageous wing taxi lamp placement.

For aircraft that have the taxi lamps located immediately in line with the pilot's eye, the standard 96-square-inch markers are effective and adequate. The majority of smaller aircraft, the principal users of unlighted airports, do have this central taxi lamp placement. For those aircraft having wing-mounted taxi lamps, markers of any size provide marginal guidance at best, and the pilots must primarily rely on painted surface markings. As an aircraft moves closer to the marker, the aircraft taxi lamp passes the main marker and the reduction in marker effectiveness is even more pronounced. The brightness of the standard 96-square-inch marker is decreased to approximately 40 to 50 percent when the taxi lamp is located to the side by as little as 5 feet. Locating the lamp even further away from the pilot's eye, 15 feet right of center, as in a Learjet 25 (not evaluated) wing tip tank location, decreased the returned light to only 10 to 30 percent.

In general, the acquisition ranges were found to be the following.

- 96 square inches of blue type III grade retro-reflective sheeting for cylindrical markers was seen at a distance of 500 feet away.
- 200 square inches of blue type IX grade retro-reflective sheeting for cylindrical markers was seen at a distance of 700 feet away.
- 96 square inches of white type III grade retro-reflective sheeting for cylindrical markers was seen at a distance of 400 feet away.
- 200 square inches of white type IX grade retro-reflective sheeting for cylindrical markers was seen at a distance of 500 feet away.

The range of the blue taxiway markers is from 500 to 700 feet, whereas the range for the white runway markers is 400 to 500 feet. It would appear that the blue taxiway markers, having a retro-reflectivity high enough to be seen at a minimum distance of 300 feet, provided adequate taxi guidance. To be effective at much higher rollout speeds, the white runway markers will need to have acquisition ranges of 800 to 1000 feet, considerably greater than the ranges provided by the white markers evaluated in this test.