PILOT VISIBILITY STUDY

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# TABLE OF CONTENTS

**EXECUTIVE SUMMARY** .......................................................................................... 3  
1.0 Introduction........................................................................................................4  
2.0 Background.........................................................................................................6  
3.0 Objective ..........................................................................................................6  
4.0 The Study ........................................................................................................6  
4.1 Scope of Work ....................................................................................................7  
4.2 Schedule of Work ..............................................................................................7  
4.2.1 Calibration and Testing.................................................................................7  
4.2.2 Runway 33L ...................................................................................................8  
4.2.3 Runway 28 .....................................................................................................8  
4.2.4 Taxiway Uniform ..........................................................................................8  
4.3 Quality Control and Data Collection .................................................................10  
4.4 Initial Results ....................................................................................................11  
4.2 Survey Results ..................................................................................................14
EXECUTIVE SUMMARY

The Pilot Visibility Study (Study) was undertaken to determine the relative conspicuity of low index (Type I) and high index (Type III) glass beads from an aircraft. Sightline, LC, an independent airfield-marking consultant, conducted the study at the request of glass bead manufacturers.

Glass beads are designed to return light to its source, and all government agencies responsible for airport safety, including the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO), recommend the inclusion of glass beads in airfield pavement markings to increase their conspicuity for operations during darkness.

Federal Specification TT-B-1325D, Type III (Type III) glass beads have a higher index of refraction (IOR) compared to TT-B-1325D, Type I (Type I) glass beads. That means that a greater proportion of light is returned directly to the source with Type III beads versus Type I beads. Prior tests conducted by the FAA and the U.S. Army Corps of Engineers (USACE) conclude “Type III glass beads are brighter initially and over time.”

The Study included quality control standards used during the marking installation of the paint and glass beads so that the markings would perform properly during the research period. Often, airfield-marking installations lack quality control measures, inspection, and the oversight necessary to ensure they are installed correctly. Markings installed poorly are less reflective and lead to premature degradation and failure. It was important that the markings installed during the Study performed well.

Commercial pilots from Southwest Airlines were surveyed at Baltimore-Washington International Airport to determine if they could see a visible difference in the markings at designated areas on the airfield during taxi, during departure, and during approach. The survey results conclude that pilots could see a visible difference with markings using Type III versus Type I, predominantly upon approach.
1.0 Introduction

The airport industry is often challenged by the quality and effectiveness of airfield markings, an integral part of the visual guidance system. The FAA conducted research in March 2003 focused on developing objective criteria for determining marking effectiveness. The report recommended practical performance standards on marking color, presence, and retro-reflectivity (the measurement of pavement marking brightness).

Further, the FAA commissioned research in 2006 through the Innovative Pavement Research Foundation (IPRF) to produce the Airfield Marking Handbook. The handbook identifies challenges that are common to airfield markings and prescribes solutions and best practices for the installation of markings on airfields. Within the handbook, recommendations for higher reflectivity values are made both to increase visibility during darkness and to extend the life cycle of airfield markings.

In spite of the information available to the industry, airfield markings continue to lag the advancements and performance standards found in most highway markings. State Departments of Transportation regularly monitor highway markings for visibility, particularly during darkness. A reflectometer is a device used in the highway industry that measures retro-reflectivity: the amount of light that is returned to the driver based on angles derived from the headlights, to the marking, and back to the driver, illustrated in Figure 1. In an automobile, the angle of the light source to the pavement is generally 30-meters, and thus the reflectometer was designed to measure retro-reflectivity based on 30-meter geometry.

![30m Geometry Measurement for Retro-Reflectivity](image_url)

Figure 1. Illustration of 30-meter geometry measurement for retro-reflectivity.
Aircraft differ considerably from automobiles in the position of the lights relative to the pilots (observers), and it has been argued that the highway marking retro-reflectivity research does not correlate to airport markings. The evidence from this Study concludes that the same equipment used to measure highway markings is relevant to airfield markings.

Airfield markings have been the subject of several FAA calls to action to enhance conspicuity in order to increase pilot situational awareness. Some of those enhancements (a) increased the size and/or dimensions of markings (holding position markings), (b) added enhancements to the taxiway centerline prior to a runway, and (c) mandated other surface markings, all to improve the visibility of markings for pilots and reduce the incidence of runway incursions. Increasing the retro-reflectivity of markings can contribute to improved safety during darkness and under low visibility conditions when other visual cues are impaired.

The following illustration demonstrates comparative levels of retro-reflectivity. The higher the number associated with a marking, the brighter that marking appears. “Mcd” refers to millicandels, a measurement of

<table>
<thead>
<tr>
<th>Mcd</th>
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<td>600</td>
<td>300</td>
<td>200</td>
<td>150</td>
<td>100</td>
<td>50</td>
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</tr>
</tbody>
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light. The actual retro-reflective measurement is expressed in millicandelas per square meter per lux or mcd/m²/lux.

2.0 Background

Over the last 10 years, the USACE, the FAA Airport Safety Technology Research and Development Sub-Team, and IPRF have conducted studies\textsuperscript{4,5} to measure the retro-reflective performance of markings with various glass beads, to determine the effects of using different paint types and application thickness, and to learn the effect of adding protective coatings over markings. These studies have concluded similar retro-reflective results indicating Type III glass beads are brighter than Type I beads in a variety of applications.

Over the years, the practice of using glass beads in airfield markings has changed from the exclusive use of Type III glass beads, to using no beads, to now having a menu of glass beads that are acceptable by the FAA, listed in AC 150/5370-10, Item P620. The multiple choices of coating and glass bead types results in different performance levels of airfield markings. There are materials that perform optimally, both in terms of visibility and durability.

3.0 Objective

The Study was conducted to determine if pilots could identify a difference in the conspicuity of airfield markings using Type III (high index glass beads with a 1.9 IOR) compared to markings using Type I (low index glass beads with a 1.5 IOR).

4.0 The Study

The study began in 2010 and continued into 2011 at Baltimore-Washington International Airport. Airport personnel accommodated the needs of the Study and facilitated the installation of the markings; and cooperation on the part of the Chief Pilots for Southwest Airlines who administered the survey to its pilots was crucial.
4.1 Scope of Work

1. A professional, qualified airfield-marking contractor with prior FAA marking test experience and BWI marking experience was hired to install the airfield markings.
2. Different airfield surfaces were chosen for the study to include taxiway centerline and an enhanced taxiway centerline (for taxiing), a departure runway (used for take off), and an arrival runway (used for approach). Markings were applied using Type I glass beads on half of the markings, and using Type III glass beads on the other half of the markings, so that the markings were compared side-by-side.
3. Safety, airport operations and practicality were the basis for the areas selected for the tests.
4. Standard waterborne paint (TT-P-1952E, Type II) manufactured by a leading manufacturer of highway and aviation paint was used.
5. Type I and Type III glass beads were used, manufactured by a leading manufacturer of highway and aviation glass beads.
6. The striping equipment was calibrated to apply the correct amounts of paint and glass beads.
7. Quality control measures were taken periodically to ensure proper material coverage rates, and that best practices were employed.
8. Pilots from Southwest Airlines were asked to complete surveys based on their observations during taxi, take off, and landing operations. The pilots were unaware of which glass bead type was applied to which markings.

4.2 Schedule of Work

When equipment and materials arrived at BWI, materials were loaded into the equipment, quantities of material were verified, test lines were applied and equipment was calibrated. BWI had scheduled runway closures for Runway 33L; and for Runway 28 and Taxiway U on two separate closures.

4.2.1 Calibration and Testing

Contractor’s personnel staged the equipment and material in the maintenance yard at BWI. The crew loaded paint manufactured by a leading US paint supplier into the airless paint truck, along with Type III glass beads
manufactured by a leading US glass bead supplier. Calibration tests were conducted on each of the five paint guns and glass bead guns, and adjustments were made until the paint film was uniformly 14-16 mils wet film thickness, and considered acceptable for evenness and uniformity. Each of the five glass bead guns was then calibrated the recommended application rate.

4.2.2 Runway 33L

Runway 33L was selected as the approach runway for the Study. Certain markings on runway 33L were applied using Type III glass beads. The threshold marking, the runway landing designator markings (#3 of 33), touchdown zone markings, and aiming point markings left of center were painted using Type III glass beads. The markings on the right side of Runway 33L had been applied two weeks earlier using type I glass beads. Those markings were inspected for proper coverage of both paint and glass beads, and were determined to be have been applied well and were performing well. In the interest of not adding another coat of paint to the pavement, those markings were deemed suitable for comparison purposes.

4.2.3 Runway 28

Runway 28 was selected as the departure runway for the Study. Since most of the Southwest pilots who would participate in the study taxied onto the runway from Taxiway Uniform, west of the threshold markings, only the touchdown zone markings and aiming point markings were painted, using Type III glass beads on those left of center. The same markings right of center were painted using Type I glass beads. After the markings left of center were complete, the equipment was re-calibrated to dispense 7 pounds of Type I glass beads per gallon of paint for the markings right of center.

4.2.4 Taxiway Uniform

4.2.4.1 Taxiway U Centerline

While the runway painting operation was proceeding, the contractor set up two Graco airless paint machines to paint the markings on Taxiway
Uniform. Both machines were calibrated for uniform wet film thickness of 14-16 mils, and the machine that would apply the Type I beads was calibrated for an application rate of 7 pounds per gallon. A 12-inch bead dispenser was used on both machines. Type III beads on the other machine were calibrated for an application rate of 10 pounds per gallon. The application rates were based on FAA standards.\(^6\)

The taxiway centerline from the east side of Runway 4-22 down to the enhanced taxiway centerline at the intersection with Runway 28 was selected for the Study. The first section from the enhanced centerline at Runway 4-22 for approximately 1000 feet (Section A on the diagram) was applied using Type I glass beads. From that point to the enhanced taxiway centerline at Runway 28 (Section B on the diagram – Appendix B), the markings were applied using Type III glass beads. (See Figure 2).

4.2.4.2 Enhanced Taxiway Centerline at Taxiway U and Runway 28

The dashes on the enhanced taxiway centerline at Taxiway U and Runway 28 were included to provide a side-by-side evaluation of yellow markings. The dashes on the left side (westward heading) were applied using Type I beads, and the dashes on the right side were applied using Type III beads. (Figure 3 below) Both airless paint machines were calibrated to apply the correct coverage rate.
4.3 Quality Control and Data Collection

Initial calibration of all equipment was conducted prior to moving onto the airfield surfaces. Once the work began, regular monitoring of paint and glass bead application and usage was performed. On one occasion, quality assurance technicians noticed too much paint and glass bead overlap, causing an uneven appearance. Painting operations were interrupted to change the position of the material guns to minimize the overlap, and work progressed.

Generally, the painting operation was excellent, and work was completed within two to three hours on both nights.

Attached as Appendix A are Daily Reports for the work shifts on both June 9 and June 16, 2011. Included in the daily reports are the total square footage painted, the amount of material used, the resulting coverage rates, information about the material used, and quality control measures taken throughout the work periods. Additionally, weather conditions, which can affect marking quality, were monitored and recorded. Retro-reflectivity
readings were taken two weeks after the markings were installed on Runway 33L and one week after the markings were installed on Runway 28 and Taxiway Uniform.

4.4 Initial Results

On June 23rd, quality assurance technicians returned to BWI to acquire retro-reflectivity data. The readings collected on markings populated by Type III glass beads were found to be 2-3 times higher than those markings populated by the Type I glass beads. According to the studies performed for highways\(^7\), the brighter the markings are, the higher the margin of safety provided for drivers. Brighter markings can be attained with Type III glass beads when applied well. The retro-reflectivity values for the three areas are shown in Tables 1, 2 and 3.

<table>
<thead>
<tr>
<th>Retro-Reflectivity Values - RWY 33L</th>
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<tbody>
<tr>
<td><strong>Marking Name</strong></td>
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<tr>
<td>Threshold Marking</td>
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<td>Runway Landing Desig.</td>
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<td>500 ft Touchdown Zone</td>
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<tr>
<td>Aiming Point Marking</td>
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</tr>
<tr>
<td>2500 ft Touchdown Zone</td>
</tr>
<tr>
<td>3000 ft Touchdown Zone</td>
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<tr>
<td><strong>Reflectivity Average:</strong></td>
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</tbody>
</table>

Table 1 – Runway 33L

<table>
<thead>
<tr>
<th>Retro-Reflectivity Values - RWY 28</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Marking Name</strong></td>
</tr>
<tr>
<td>500 ft Touchdown Zone</td>
</tr>
<tr>
<td>Aiming Point Marking</td>
</tr>
<tr>
<td>1500 ft Touchdown Zone</td>
</tr>
<tr>
<td>2000 ft Touchdown Zone</td>
</tr>
<tr>
<td>2500 ft Touchdown Zone</td>
</tr>
<tr>
<td><strong>Reflectivity Average:</strong></td>
</tr>
</tbody>
</table>

Table 2 – Runway 28
The taxiway centerline markings on Taxiway Uniform were not side-by-side. Approximately 1000 linear feet of centerline had been painted using Type I beads, and then the next 1000 linear feet had been painted using Type III beads. Figure 4 illustrates the enhanced brightness of Type III glass beads at the interface of the two types.

The difference between the low and high index beads, seen in both Figure 3 and Figure 4 demonstrates that brighter markings are visible from further away.

The markings on Runway 33L included threshold markings and the runway landing designator markings (33), both side-by-side comparisons; and the visible difference was noticeable from the ground, as seen in Figures 5 and 6.
Figure 5. Threshold markings on left were installed using Type III beads. At the top of the picture, the Runway Landing Designator, “3” on the left of “33” is visible, whereas the “3” on the right is not.

Figure 6. Runway Landing Designator Markings.
4.2 Survey Results

The Chief Pilots at southwest Airlines at BWI administered the surveys that were created by the consultants for the study. Copies of the three different surveys provided to the pilots are attached as Appendix B. The surveys received from Southwest are attached as Appendix C.

Runway 33L

The majority of the surveys received were from pilots on approach to Runway 33L. Eighty-three percent (83%) of pilots that completed a survey for Runway 33L identified the left side of the runway (the side marked using Type III beads, as having “enhanced visibility”.)

Runway 28

Thirty-three percent (33%) of reporting pilots noticed a visible difference upon takeoff, and identified the left side of the runway markings (Type III beads) as having “enhanced visibility”.

Taxiway Uniform Centerline

Thirty-three percent (33%) of pilots that turned in the survey identified Section B (markings applied with Type III beads) as being more visible.

Taxiway Uniform Enhanced Taxiway Centerline at Runway 28

Thirty-three percent (33%) of the surveys submitted for the Enhanced Taxiway Centerline at Runway 28 identified the side that had been installed using Type III beads as being more visible.

5.0 CONCLUSIONS

The purpose of this study was to determine if pilots could see a visible difference between markings applied using Type III versus Type I glass beads. Based on the surveys submitted by the Southwest pilots, it is evident that pilots can and did detect a difference. Of the twelve surveys turned in for the four different subject surfaces, seven (58%) indicated there was a visible difference in the marking with the Type III beads.
The pilots were objective subjects during the study, without any prior knowledge of which markings had been applied with either type of glass bead. All of the surveys submitted noted the time of the observations as occurring during darkness. No other questions were asked of the pilots to determine what they focus on during taxi, departure, or approach; they were simply asked to comment if they did or did not see a difference in visibility.

Markings are often overlooked and taken for granted, both on highways and on airports. They are peripheral to the main focus of either the driver or the pilot. The only time when they are actually noticed is when they are difficult to see at all, or when they have failed. To be effective “peripherally”, the surface markings must be of high quality and highly visible. State Departments of Transportation invest millions of dollars each year to remark roads and highways, and then they monitor the effectiveness of those markings. Performance standards for the brightness of markings are enforced in many states for highways; airports have not adopted any such standards, except on a limited basis.

It is commonly recognized that markings provide critical guidance during darkness and under low visibility conditions, both on highways and on airports. The relative brightness of those markings is most important at high speeds, providing the observer with greater distance recognition and longer reaction times. A study conducted by the Transportation Research Board concluded that, “minimum retro-reflectivity values are speed dependent. Preview or visibility distance is the distance that the delineation provides the driver to see changes in roadway alignment. Preview distance is important, especially at higher speeds [that occur during landings and take-offs of aircraft]. When drivers [or pilots] are provided with higher reflectivity values, longer preview distances are achieved, which is desirable from an information acquisition, information processing, and safety point of view”.  

The data collection from the Visibility Study provides sufficient evidence to conclude that some pilots can see a difference when markings are applied using Type III glass beads, and that the markings did provide enhanced visibility. The results of this Study also confirm that the 30-meter geometry engineered for highway marking evaluations does have relative value to the airport industry in evaluating airfield markings.
The pilot population worldwide has become inured to poor markings on airfields, and has adjusted to the lower standard. When enlightened about what constitutes a quality marking, members of the Airline Pilots’ Association (ALPA) have unanimously agreed that they would prefer markings that are more visible. It is imperative that the standard be raised, that better-performing materials are specified, that close attention to the details of application be carefully monitored, and that performance standards and maintenance standards be put into place to create a safer environment for pilots, their passengers, and others driving on airfield surfaces. The United States Air Force has established minimum retro-reflectivity standards for new markings at installation. Although the minimum values are relatively low, the precedence for enforcing reflectivity levels and monitoring markings for minimum levels of visibility has been established.

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1 DOT/FAA/AR-02/128, “Paint and Bead Durability Study”, March 2003, Holly M. Cyrus
4 ERDC/GSL/TR-07-20, A Comparative Field Study of Permastripe™ Polymer Concrete and Waterborne Airfield Markings, April 2007, John K. Newman, Ph.D.
6 FAA AC 150/5370-10, Item P-620, Table 1, “Application Rates for Paint and Glass Beads”, dated September 30, 2011.
8 Ibid.