technical note technical note

# Elevated Runway Edge Light Fixture Intensity Measurement

Donald W. Gallagher

September 2017

DOT/FAA/TC-TN17/51



U.S. Department of Transportation
**Federal Aviation Administration**

## NOTICE

**Technical Report Documentation Page**

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| DOT/FAA/TC-TN17/51 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| ELEVATED RUNWAY EDGE LIGHT FIXTURE INTENSITY MEASUREMENT | September 2017 |
| | 6. Performing Organization Code |

| 7. Author(s) | 8. Performing Organization Report No. |
|---|---|
| Donald W. Gallagher | |

| 9. Performing Organization Name and Address | 10. Work Unit No. (TRAIS) |
|---|---|
| U.S. Department of Transportation<br>Federal Aviation Administration<br>William J. Hughes Technical Center<br>Airport and Aircraft Safety Research and Development Division<br>Airport Technology Research and Development Branch<br>Atlantic City Intl Airport, NJ 08405 | |
| | 11. Contract or Grant No. |

| 12. Sponsoring Agency Name and Address | 13. Type of Report and Period Covered |
|---|---|
| U.S. Department of Transportation<br>Federal Aviation Administration<br>Office of Airport Safety and Standards<br>800 Independence Ave SW<br>Orville Wright Bldg. (FOB10A)<br>Washington, DC 20591 | Technical Note |
| | 14. Sponsoring Agency Code<br>AAS-100 |

15. Supplementary Notes

16. Abstract

The Airport Technology Research and Development Branch was tasked to measure the luminous intensity output of incandescent, elevated, omnidirectional, medium-intensity runway edge lights and directional high-intensity runway edge lights (L-861 and L-862, respectively) in vertical areas between 15-90 degrees.

Luminous intensity measurements were conducted of each fixture in vertical areas between 15-90 degrees at 5-degree increments for vertical scan and 10-degree increments for horizontal scan. These measurements at nadir (0°, 0°) position were taken at the following current levels: three levels for L-861 type (6.6 amperes (A), 5.5 A, and 4.8 A), which is how the intensity steps 3, 2 and 1 were obtained, and five levels for L-862 type (6.6 A, 5.2 A, 4.1 A, 3.4 A, and 2.8 A), which is how the intensity steps 5, 4, 3, 2, and 1 were obtained. Resulting data was compiled and presented for the sponsors' use.

| 17. Key Words | 18. Distribution Statement |
|---|---|
| Aviation lighting, Edge delineation, Visual acquisition, Human factors, Runway edge lights | This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov. |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price |
|---|---|---|---|
| Unclassified | Unclassified | 95 | |

ACKNOWLEDGEMENTS

The measurements referenced in this technical note was taken and supported under agreement 16-G-019 with Rensselaer Polytechnic Institute's Lighting Research Center. Special thanks to Jean Paul Freyssinier, Andrew Bierman, Yiting Zhu, Yi-Wei Liu, and Martin Overington.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

# LIST OF ACRONYMS

| | |
|---|---|
| A | Ampere |
| AC | Advisory Circular |
| ATRD | Airport Technology Research and Development Branch |
| FAA | Federal Aviation Administration |
| FY | Fiscal year |
| IFR | Instrument Flight Rules |
| LED | Light-emitting diode |
| LOB/SO | Line of business/safety oversight |
| LRC | Lighting Research Center |
| RBDM | Risk-Based Decision Making |
| SMS | Safety Management System |
| SSI | Significant Safety Issues |
| VFR | Visual Flight Rules |

# EXECUTIVE SUMMARY

In 2015, the Federal Aviation Administration (FAA) established formal, repeatable processes to identify Significant Safety Issues (SSI) as part of Activity 2b within the Risk-Based Decision Making (RBDM) Strategic Initiative.

As a result, an FAA SSI team was formed to develop a process to collect and prioritize the line of business/safety oversight (LOB/SO) lists. By the end of fiscal year (FY) 2015, the SSI team identified a prioritized list of 10 FAA-level, cross-organizational SSIs.

The FAA Safety Management System Executive Council agreed to apply cross-organizational resources to conduct comprehensive safety risk assessments for the top two SSIs, one of which was "Light Emitting Diode (LED), Lighting of Airfields, Obstacles, and Aircraft."

The Office of Airports, as an Office of Primary Responsibility, is responsible for developing mitigation strategy and risk control for the hazard.

The hazard description in "FY15-SSI-LED 06: Loss of Sight of LED Airport Lighting" states "LED directionality is more focused than incandescent lighting. During night VFR (e.g., VFR traffic pattern, circling approach), flight crew loses sight of segments of LED airport lights."

Given a standard approach pattern of 1000 feet altitude within 1 to 1/2 mile from runway, the resulting angle is 13-20 degrees. This could result in losing the runway edge lights momentarily at a given point during the pattern at angles above 15-degree angle specified for an L-861 fixture. At that same point, runway lights further away, such as 1 1/2 to 2 miles, would be at angles 10-8 degrees, respectively, which is within the specified 15-degree beam pattern.

The Airport Technology Research and Development Branch (ATRD) was tasked to measure the luminous intensity output of incandescent elevated omnidirectional medium-intensity runway edge lights and directional high-intensity runway edge lights (L-861 and L-862, respectively) in vertical areas between 15-90 degrees.

Luminous intensity measurements were conducted of each fixture in vertical areas between 15-90 degrees at 5-degree increments for vertical scan and 10-degree increments for horizontal scan. These measurements at nadir (0°, 0°) position were taken at the following current levels: three levels for L-861 type (6.6 ampere (A), 5.5 A, and 4.8 A), which is how the intensity steps 3, 2, and 1 were obtained, and five levels for L-862 type (6.6 A, 5.2 A, 4.1 A, 3.4 A, and 2.8 A), which is how the intensity steps 5, 4, 3, 2, and 1 were obtained. Resulting data was compiled and presented for the sponsors' use.

## INTRODUCTION

In 2015, the Federal Aviation Administration (FAA) established formal, repeatable processes to identify Significant Safety Issues (SSI) as part of Activity 2b within the Risk-Based Decision Making (RBDM) Strategic Initiative.

As a result, an FAA SSI team was formed to develop a process to collect and prioritize the line of business/safety oversight (LOB/SO) lists. By the end of fiscal year (FY) 2015, the SSI team identified a prioritized list of 10 FAA-level, cross-organizational SSIs.

The FAA Safety Management System (SMS) Executive Council agreed to apply cross-organizational resources to conduct comprehensive safety risk assessments for the top two SSIs, one of which was "Light Emitting Diode (LED), Lighting of Airfields, Obstacles, and Aircraft," or "FAA LED SSI" for short.

## BACKGROUND

The Office of Airports, as an Office of Primary Responsibility, is responsible for developing mitigation strategy and risk control for the hazard.

The hazard description in "FY15-SSI-LED_06: Loss of Sight of LED Airport Lighting" states "LED directionality is more focused than incandescent lighting. During night Visual Flight Rules (VFR) (e.g., VFR traffic pattern, circling approach), flight crew loses sight of segments of LED airport lights."

During discussions about this issue in a June 2016 FAA SSI meeting, it was stated that the specific issue was a perceived lack of omnidirectional light from LED L-862 (L)* and L-861 (L) fixtures from 15-90 degrees.

Currently, there are no FAA or International Civil Aviation Organization photometric requirements for either incandescent or LED fixtures in these vertical beam areas.

Examples of certified incandescent L-861 and L-862 are shown in figures 1 and 2. Preventing "spillage" light while meeting the specifications for required light output using incandescent light source is a design challenge. With LED technology, the specifications are easier to achieve.

* To differentiate from incandescent fixtures, LED fixtures are designated with an (L).

Figure 1. The L-861 Sample

Figure 2. The L-862 Sample

Manufacturers by design do not allow for light output from 15-90 degrees, as shown in the LED versions, figures 3 and 4. Among manufacturers, the general consensus is that light emission is coincidental.

The objective of this project was to measure the light output produced by incandescent fixtures. To accomplish this, two fixtures were obtained from each manufacturer. Once obtained, measurements were taken on all but one of the manufacturers' current incandescent fixtures. Light output measurements of one manufacturer's LED fixtures were taken only for comparison to the incandescent versions.

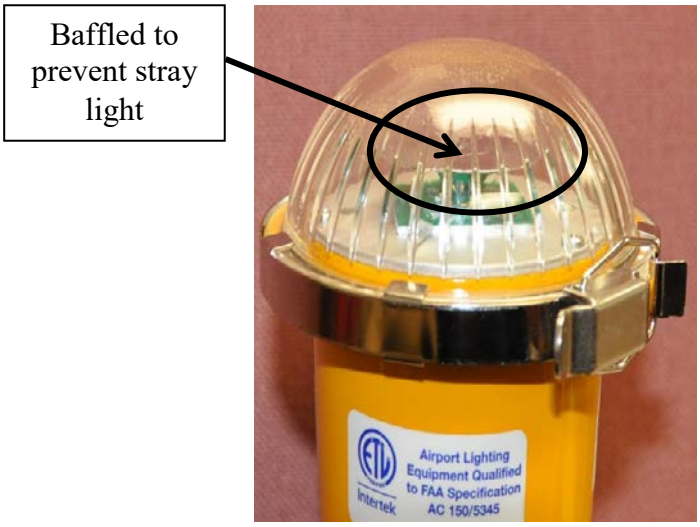


Figure 3. The LED Version L-861 (L)

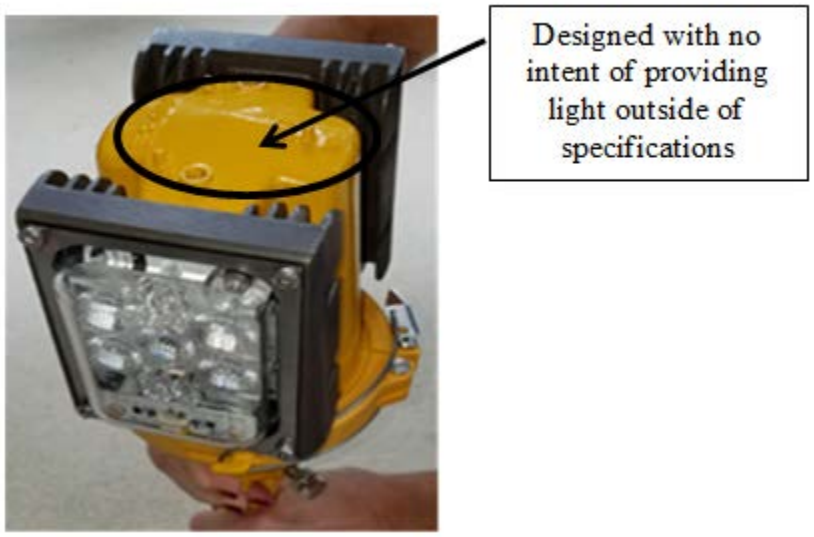


Figure 4. The LED Version L-862 (L)

Current specification for vertical light output of an L-861 is up to 15 degrees, according to the Advisory Circular (AC) AC 150/5345-46E [1]. (See table 1).

Table 1. Photometric Requirements for Omnidirectional Elevated Lights [1]

| Type | Color | Intensity (Candelas) | | |
|---|---|---|---|---|
| | | 2 to 10 Degrees | | 10 to 15 Degrees |
| | | Minimum | Minimum Average Intensity | Minimum |
| L-861 | White | 75 | 125 | 40 |

Current specification for vertical light output of an L-862 is up to 15 degrees, according to AC 150/5345-46E [1]. (See table 2.)

Table 2. Photometric Requirements for Directional Elevated Lights [1]

| Type | Minimum Beam Coverage (Degrees) | | | | Intensity (Candelas) | | | |
|---|---|---|---|---|---|---|---|---|
| | Main Beam | | 10 Percent | | | | | |
| | Horizontal | Vertical | Horizontal | Vertical | White | Yellow | Green | Red |
| L-862 | -2 to 9 | 0 to 7 | -4 to 11 | -2.5 to 9.5 | 10,000 | 5,000 | 2,500 | 2,000 |

STANDARD AIRPORT TRAFFIC PATTERNS.

Since the specified light output requirement is from 15-90 degrees vertical, a field of reference is needed to determine the pilot's angle on approach to an airport.

According to the Airplane Flying Handbook [2], the standard airport traffic pattern is as follows:

- Traffic pattern altitude is usually 1000 feet above the elevation of the airport surface.
- When approaching an airport for landing, the traffic pattern is normally entered at a 45° angle to the downwind leg, headed toward a point abeam the midpoint of the runway to be used for landing.
- The downwind leg is flown approximately 1⁄2 to 1 mile out from the landing runway and at the specified traffic pattern altitude. [2] (See figure 5.)

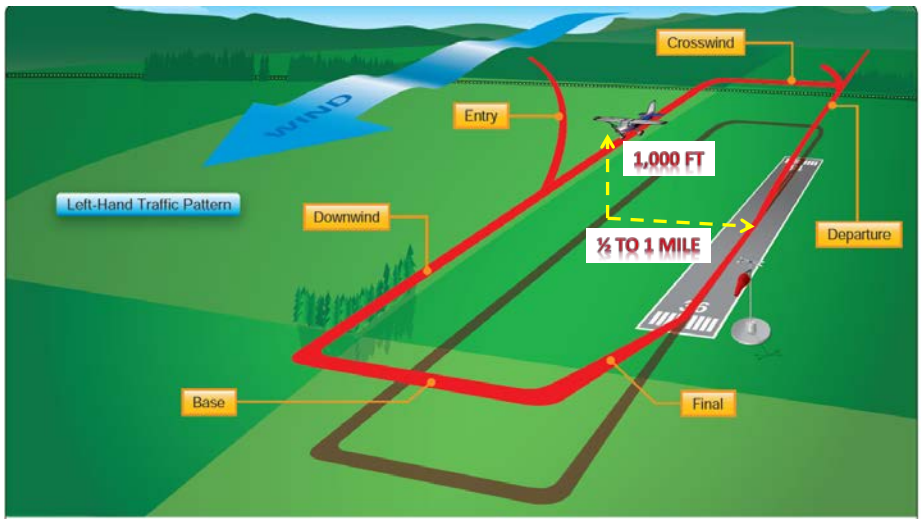


Figure 5. Standard Airport Traffic Patterns [2]

Using this data, the angles from the aircraft to the runway edge lights can be calculated. (See table 3.)

Table 3. Angles From Aircraft to Runway Edge Lights

| Altitude | Lateral Distance From Runway (nm) | | | |
|---|---|---|---|---|
| | 0.50 | 1.00 | 1.50 | 2.00 |
| | Angle in Degrees | | | |
| 1000 | 20 | 13 | 10 | 8 |
| 1100 | 21 | 13 | 10 | 8 |
| 1200 | 22 | 14 | 10 | 8 |
| 1300 | 23 | 15 | 11 | 9 |
| 1400 | 24 | 15 | 11 | 9 |
| 1500 | 25 | 16 | 12 | 10 |
| 1600 | 26 | 17 | 12 | 10 |
| 1700 | 27 | 17 | 13 | 10 |
| 1800 | 28 | 18 | 13 | 11 |
| 1900 | 30 | 19 | 14 | 11 |
| 2000 | 31 | 20 | 14 | 11 |

nm–nautical mile

Given a standard approach pattern of 1000 feet altitude at within 1 to 1/2 mile from runway, the angle is 13-20 degrees. For an L-861 fixture, this could result in losing the runway edge lights momentarily at a given point during the pattern at angles above 15 degrees. At that same point, runway lights further down the runway, such as 1 1/2 to 2 miles, would be at angles 10-8 degrees, respectively, which is within the specified 15-degree beam pattern.

## PURPOSE

The Airport Technology Research and Development Branch (ATRD) was tasked to measure the luminous intensity output of incandescent, elevated, omnidirectional, medium-intensity runway edge lights and directional high-intensity runway edge lights (L-861 and L-862, respectively) in the vertical areas between 15-90 degrees.

## PROJECT APPROACH

This project consisted of two tasks: (1) obtaining samples from certified manufacturers, and (2) measuring luminosity intensities of each sample.

TASK 1—SAMPLES FROM CERTIFIED MANUFACTURERS.

The ATRD obtained samples of the incandescent L-861 and L-862 from certified manufacturers as per AC 150/5345-53D [3].

This AC indicates there are currently seven certified manufacturers of the L-861 and five certified manufacturers of the L-862. S ome manufacturers offer different versions of these fixtures, as indicated in table 4. All but one manufacturer's fixtures were acquired and tested, as indicated in table 5.

Table 4. The L-861 and L-862 Certified Fixture Combinations

| | Tungsten Halogen (Quartz) | | Incandescent | Different Combos | Two Samples Each |
|---|---|---|---|---|---|
| L-861 Number of Manufacturers | 30 Watt | 45 Watt | 45 Watt | | |
| | 3 | 5 | 5 | 13 | 26 |
| L-862 Number of Manufacturers | 120 Watt | 150 Watt | - | 7 | 14 |
| | 3 | 4 | Maximum Tested | | 40 |

Table 5. The L-861 and L-862 Fixtures Tested

| | Tungsten Halogen (Quartz) | | Incandescent | Different Combos | Two Samples Each |
|---|---|---|---|---|---|
| L-861 Number of Manufacturers | 30 Watt | 45 Watt | 45 Watt | | |
| | 3 | 4 | 4 | 11 | 22 |
| L-862 Number of Manufacturers | 120 Watt | 150 Watt | | 6 | 12 |
| | 3 | 3 | Maximum Tested | | 34 |

TASK 2—LUMINOUS INTENSITY MEASUREMENTS.

Luminous intensity measurements were conducted of each fixture in vertical areas between 15-90 degrees at 5-degree increments for vertical scan and 10-degree increments for horizontal scan. These measurements at nadir (0°, 0°) position were taken at the following current levels: three levels for L-861 type (6.6 amperes (A), 5.5 A, and 4.8 A), which is how the intensity steps 3, 2, and 1 were obtained, and five levels for L-862 type (6.6 A, 5.2 A, 4.1 A, 3.4 A, and 2.8 A), which is how the intensity steps 5, 4, 3, 2, and 1 were obtained.

## RESULTS

Photometric measurements were performed by Rensselaer Polytechnic Institute's Lighting Research Center (LRC). The data were collected on two separate dates due to delivery times of candidate fixtures. The LRC's full reports are included in appendices A and B.

A summary of the omnidirectional L-861 fixture measurements are shown in figures 6-11.

THE L-861 SAMPLE.

The L-861 fixture, which is used on nonprecision Instrument Flight Rules (IFR) runways, was manufactured in 30-watt and 45-watt versions. Data on all manufacturers are presented separately for each version in figures 6 through 11.

The 30-Watt Version. The data for the 30-watt version at intensity steps 1, 2, and 3 are presented in figures 6, 7, and 8, respectively. Different colors were used for each manufacturer. The data show the light output follows a similar pattern for all manufacturers. An L-861 LED version RE036A was plotted on all the figures for comparison purposes.

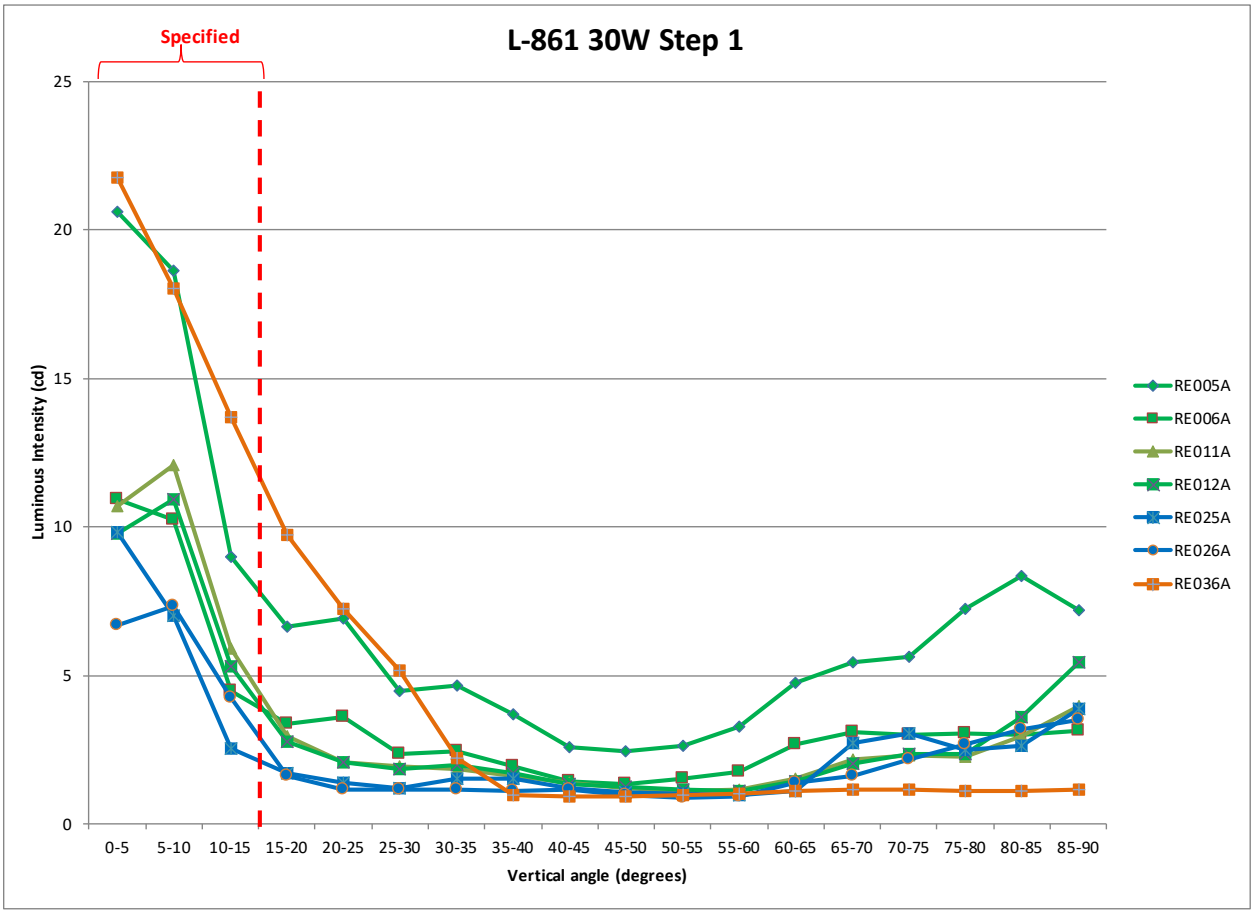


Figure 6. The 30-Watt L-861 Sample at Intensity Step 1

For the 30-watt L-861 sample at intensity step 1, the average candela (cd) for the range of angles up to the specified 15 degrees equals 9.2 cd, from 15-35 degrees equals 3.1 cd, from 35-60 degrees equals 1.5 cd and from 60-90 degrees equals 3.0 cd. The LED version average candela for the range of angles up to the specified 15 degrees equals 17.8 cd, from 15-35 degrees equals 6.1 cd, from 35-60 degrees equals 1.0 cd, and from 60-90 degrees equals 1.1 cd.

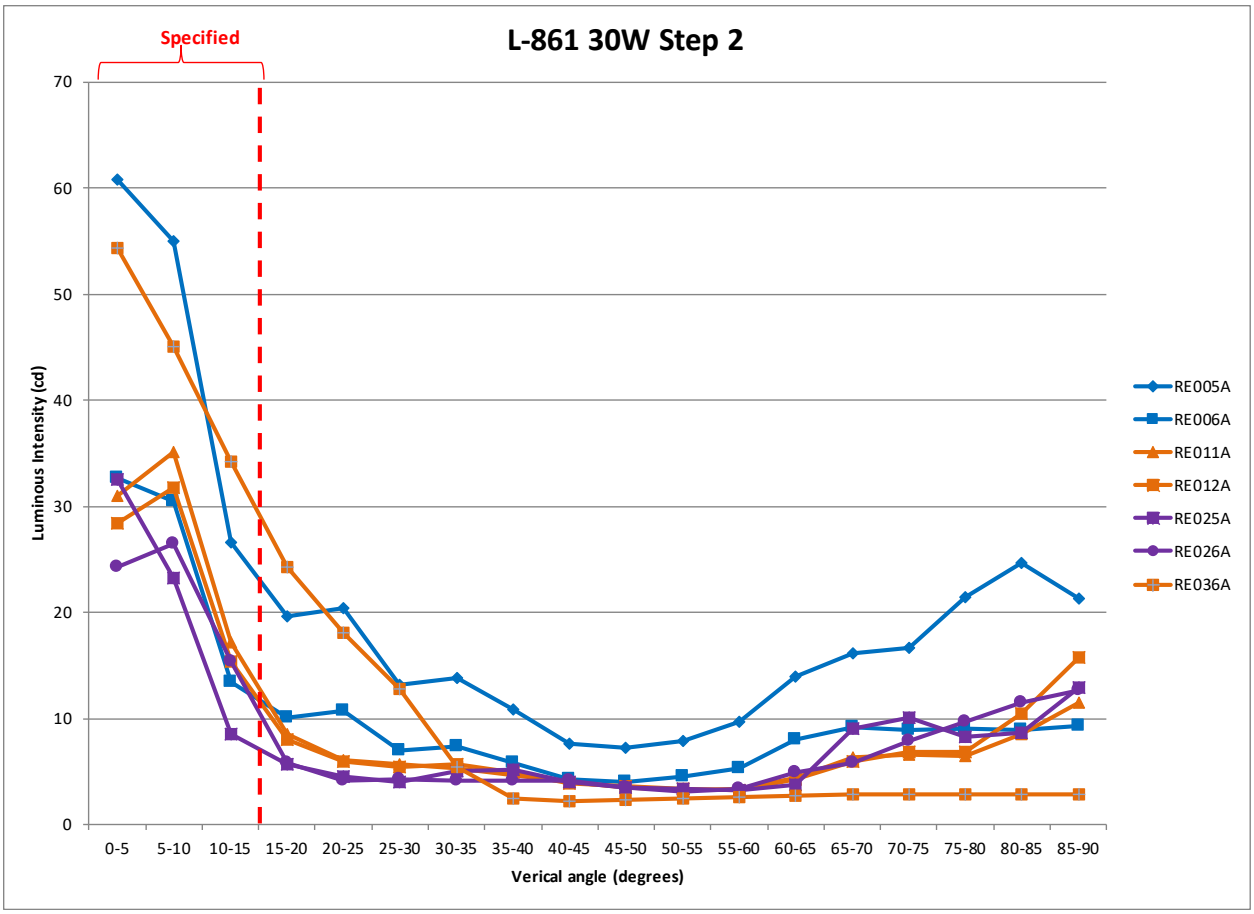


Figure 7. The 30-Watt L-861 Sample at Intensity Step 2

For the 30-watt L-861 sample at intensity step 2, the average candela for the range of angles up to the specified 15 degrees equals 28.2 cd, from 15-35 degrees equals 9.0 cd, from 35-60 degrees equals 4.7 cd, and from 60-90 degrees equals 9.1 cd. The LED version average candela for the range of angles up to the specified 15 degrees equals 44.5 cd, from 15-35 degrees equals 15.2 cd, from 35-60 degrees equals 2.4 cd, and from 60-90 degrees equals 2.8 cd.

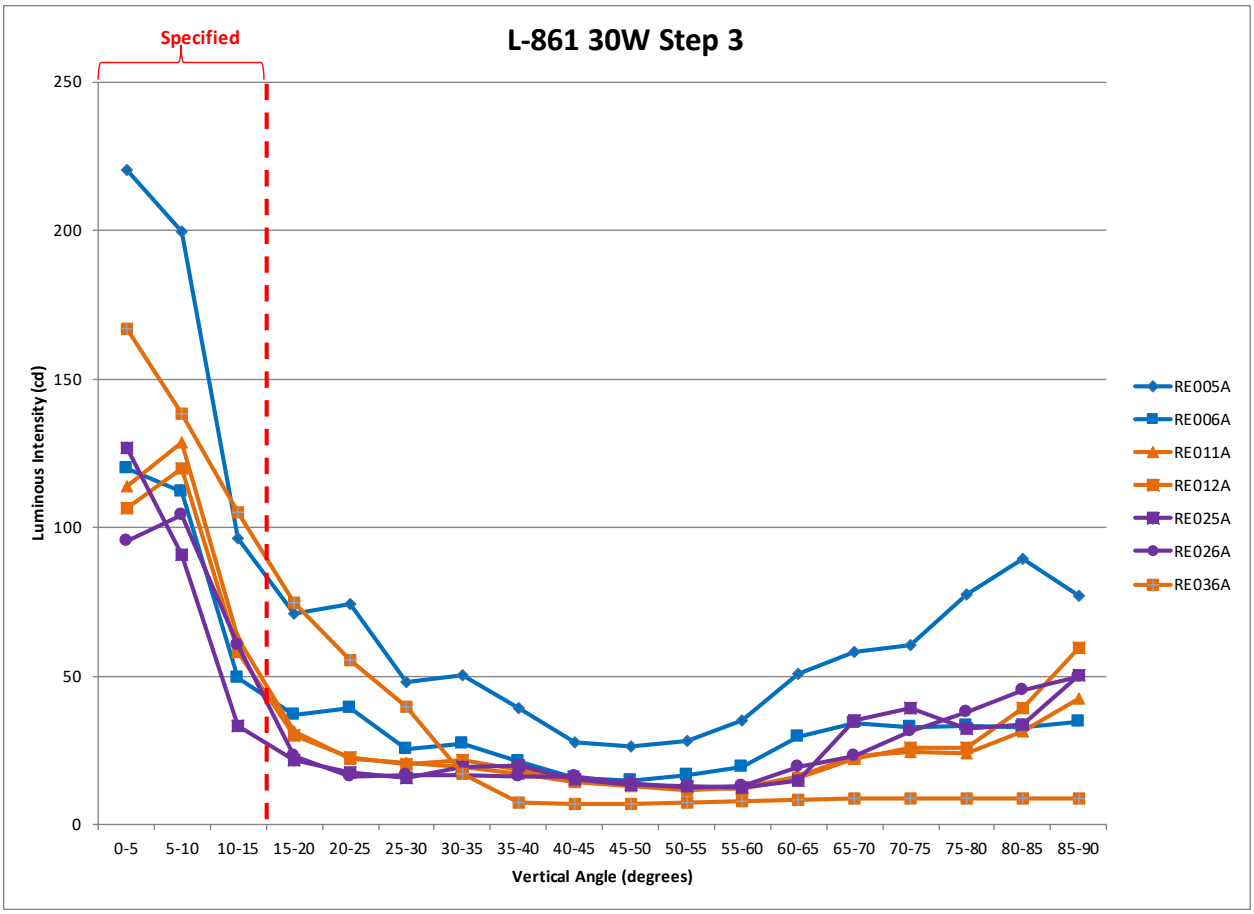


Figure 8. The 30-Watt L-861 Sample at Intensity Step 3

For the 30-watt L-861 sample at intensity step 3, the average candela for the range of angles up to the specified 15 degrees equals 105.4 cd, from 15-35 degrees equals 31.9 cd, from 35-60 degrees equals 17.6 cd, and from 60-90 degrees equals 33.9 cd. The LED version average candela for the range of angles up to the specified 15 degrees equals 136.8 cd, from 15-35 degrees equals 46.6 cd, from 35-60 degrees equals 7.4 cd, and from 60-90 degrees equals 8.6 cd.

The 45-Watt Version. The data for the 45-watt version at intensity steps 1, 2, and 3 are presented in figures 9, 10, and 11, respectively. LED version RE036A was plotted on all the figures for comparison purposes. The data show the light output follows a similar pattern for all manufacturers.

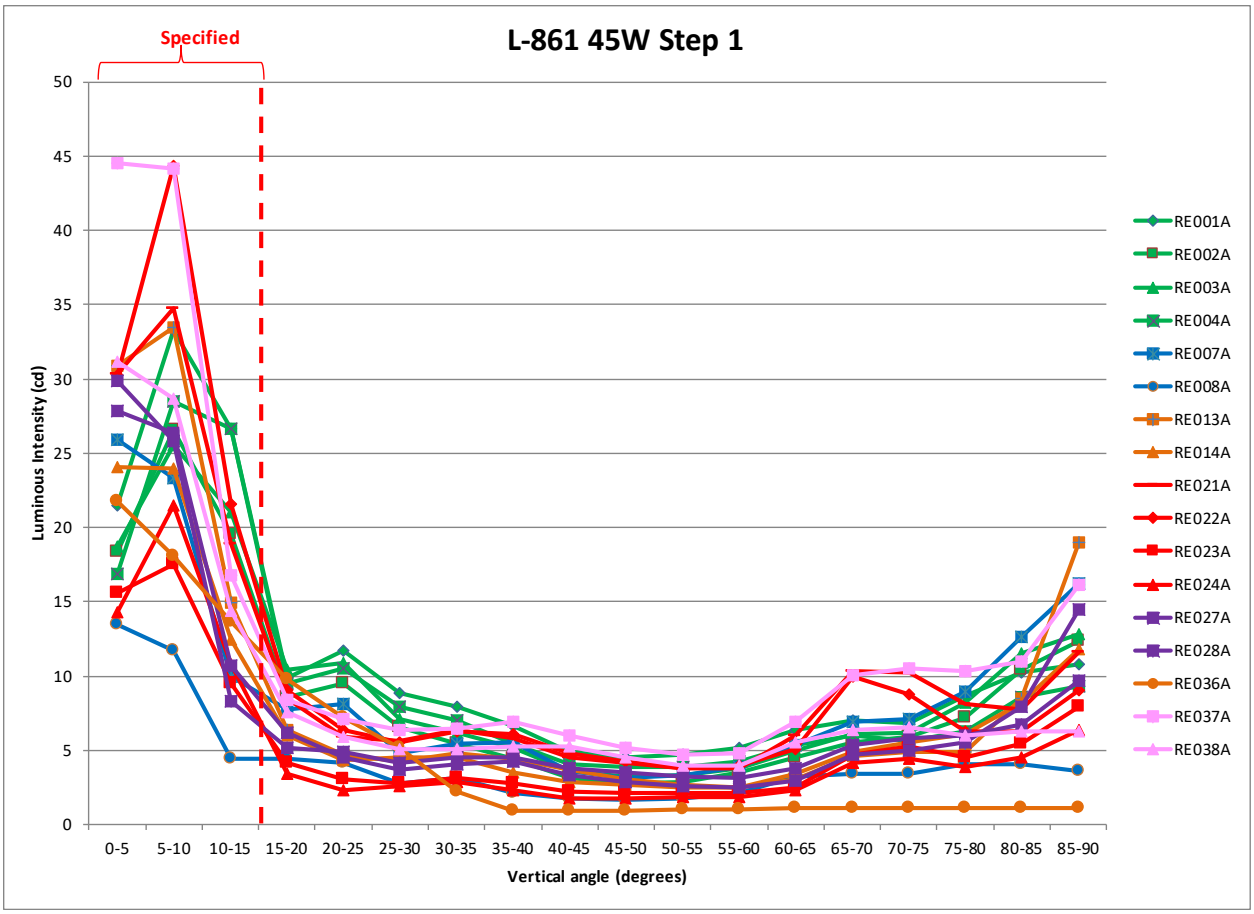


Figure 9. The 45-Watt L-861 Sample at Intensity Step 1

For the 45-watt L-861 sample at intensity step 1, the average candela for the range of angles up to the specified 15 degrees equals 22.7 cd, from 15-35 degrees equals 6.0 cd, from 35-60 degrees equals 3.7 cd, and from 60-90 degrees equals 7.1 cd. The LED version average candela for the range of angles up to the specified 15 degrees equals 17.8 cd, from 15-35 degrees equals 6.1 cd, from 35-60 degrees equals 1.0 cd, and from 60-90 degrees equals 1.1 cd.

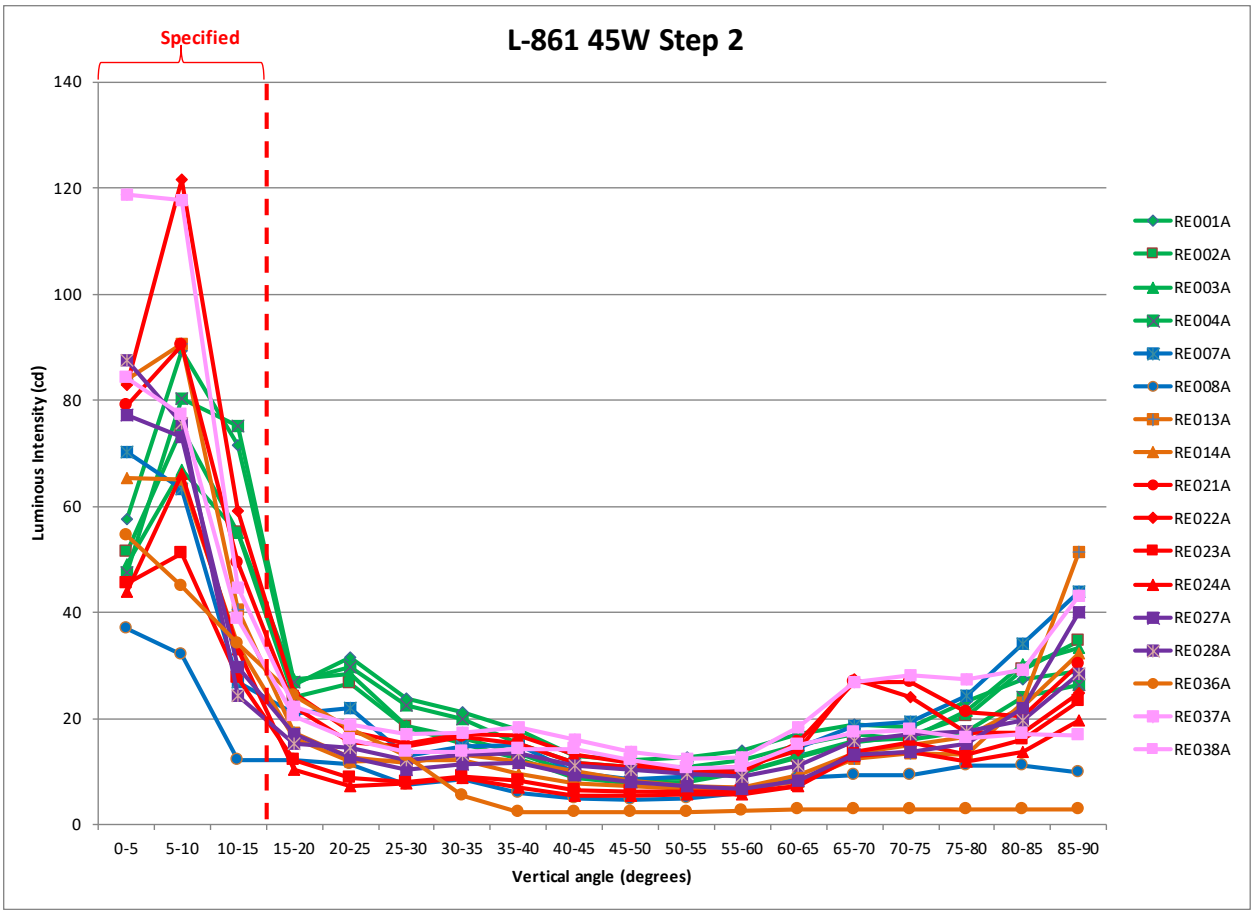


Figure 10. The 45-Watt L-861 Sample at Intensity Step 2

For the 45-watt L-861 sample at intensity step 2, the average candela for the range of angles up to the specified 15 degrees equals 62.3 cd, from 15-35 degrees equals 16.5 cd, from 35-60 degrees equals 10.0 cd, and from 60-90 degrees equals 19.6 cd. The LED version average candela for the range of angles up to the specified 15 degrees equals 44.5 cd, from 15-35 degrees equals 15.2 cd, from 35-60 degrees equals 2.4 cd, and from 60-90 degrees equals 2.8 cd.

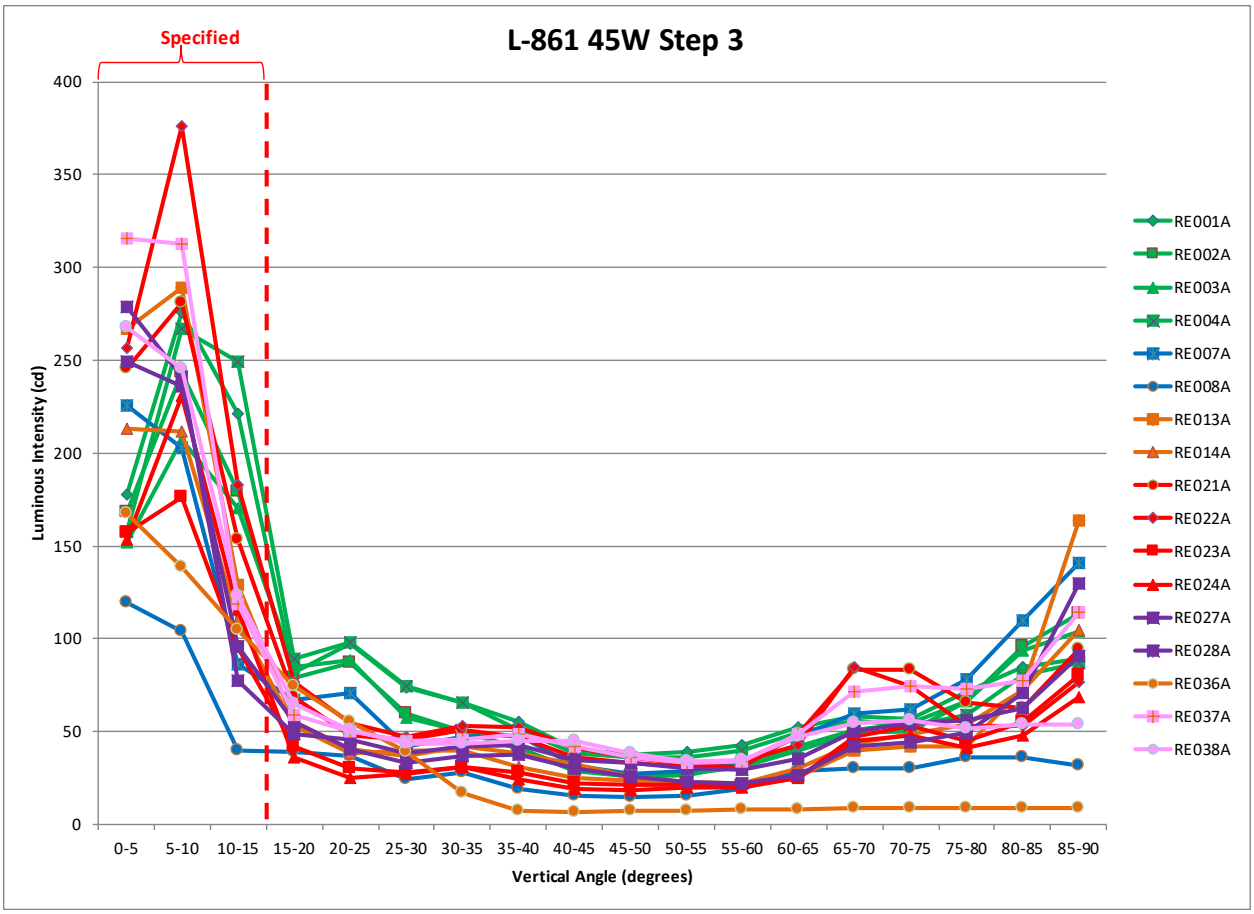


Figure 11. The 45-Watt L-861 Sample at Intensity Step 3

For the 45-watt L-861 sample at intensity step 3, the average candela for the range of angles up to the specified 15 degrees equals 196.9 cd, from 15-35 degrees equals 52.2 cd, from 35-60 degrees equals 31.7 cd, and from 60-90 degrees equals 62.0 cd. The LED version average candela for the range of angles up to the specified 15 degrees equals 136.8 cd, from 15-35 degrees equals 46.6 cd, from 35-60 degrees equals 7.4 cd, and from 60-90 degrees equals 8.6 cd.

THE L-862 SAMPLE.

The directional L-862 fixture, which is used on precision IFR runways, was manufactured in 120- and 150-watt versions. Data on all manufacturers are presented separately for each version in figures 12 through 21.

The 120-Watt Version. The data for the 120-watt version at intensity steps 1, 2, 3, 4, and 5 are presented in figures 12, 13, 14, 15, a nd 16, respectively. The data show that the light output follows a similar pattern for all but one manufacturer. The difference in distribution is due to the lack of additional optics in this manufacturer's fixture compared to the other manufacturers.

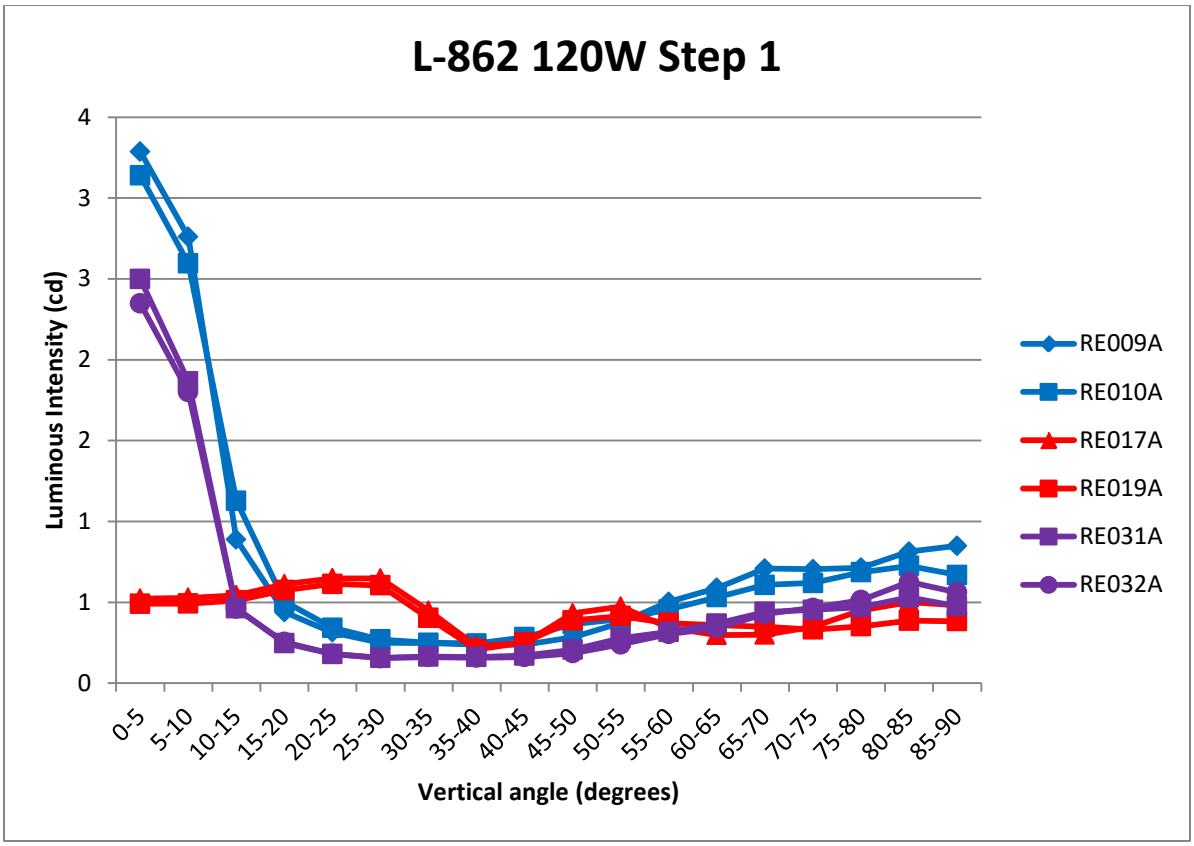


Figure 12. The 120-Watt L-862 Sample at Intensity Step 1

For the 120-watt L-862 sample at intensity step 1, the average candela for the range of angles up to the specified 15 degrees equals 1.5 cd, from 15-35 degrees equals 0.4 cd, from 35-60 degrees equals 0.3 cd, and from 60-90 degrees equals 0.5 cd.

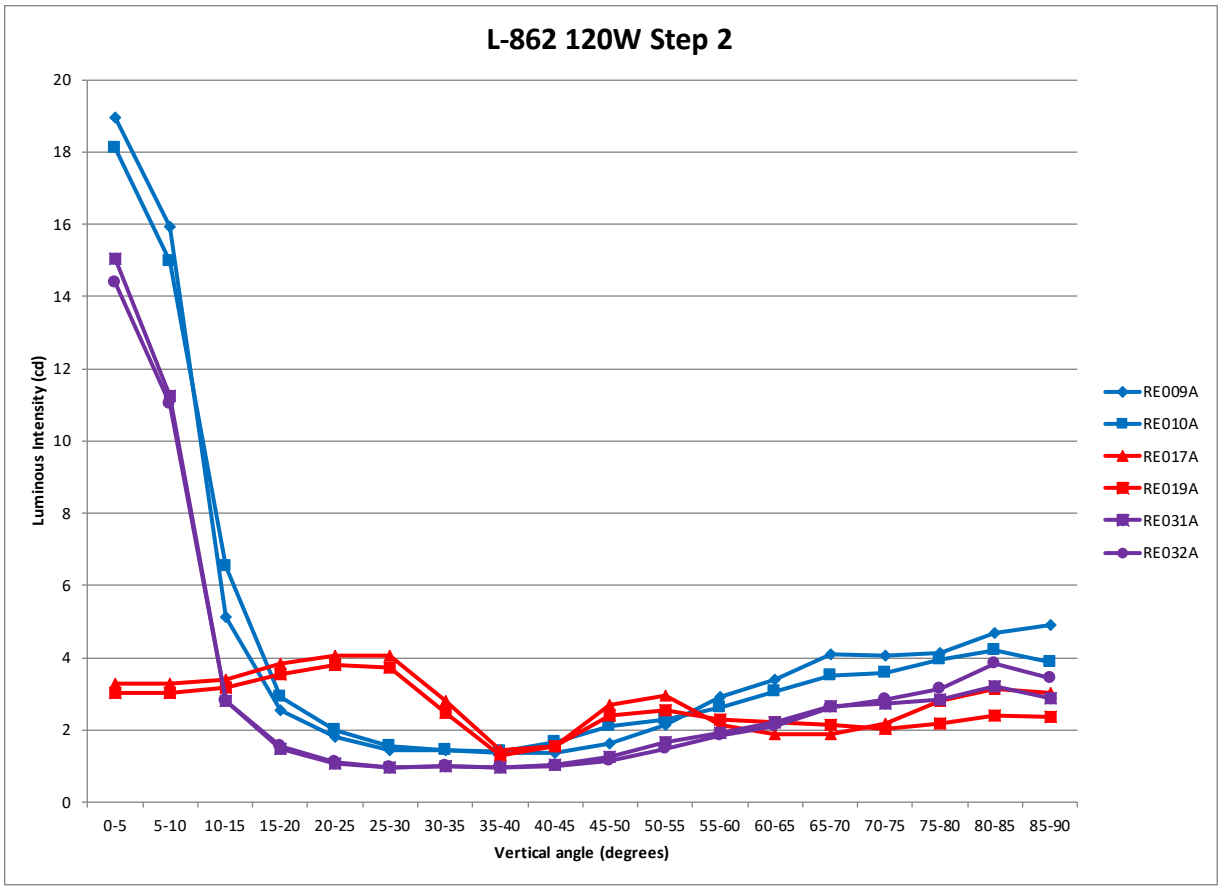


Figure 13. The 120-Watt L-862 Sample at Intensity Step 2

For the 120-watt L-862 sample at intensity step 2, the average candela for the range of angles up to the specified 15 degrees equals 8.7 cd, from 15-35 degrees equals 2.2 cd, from 35-60 degrees equals 1.8 cd, and from 60-90 degrees equals 3.1 cd.

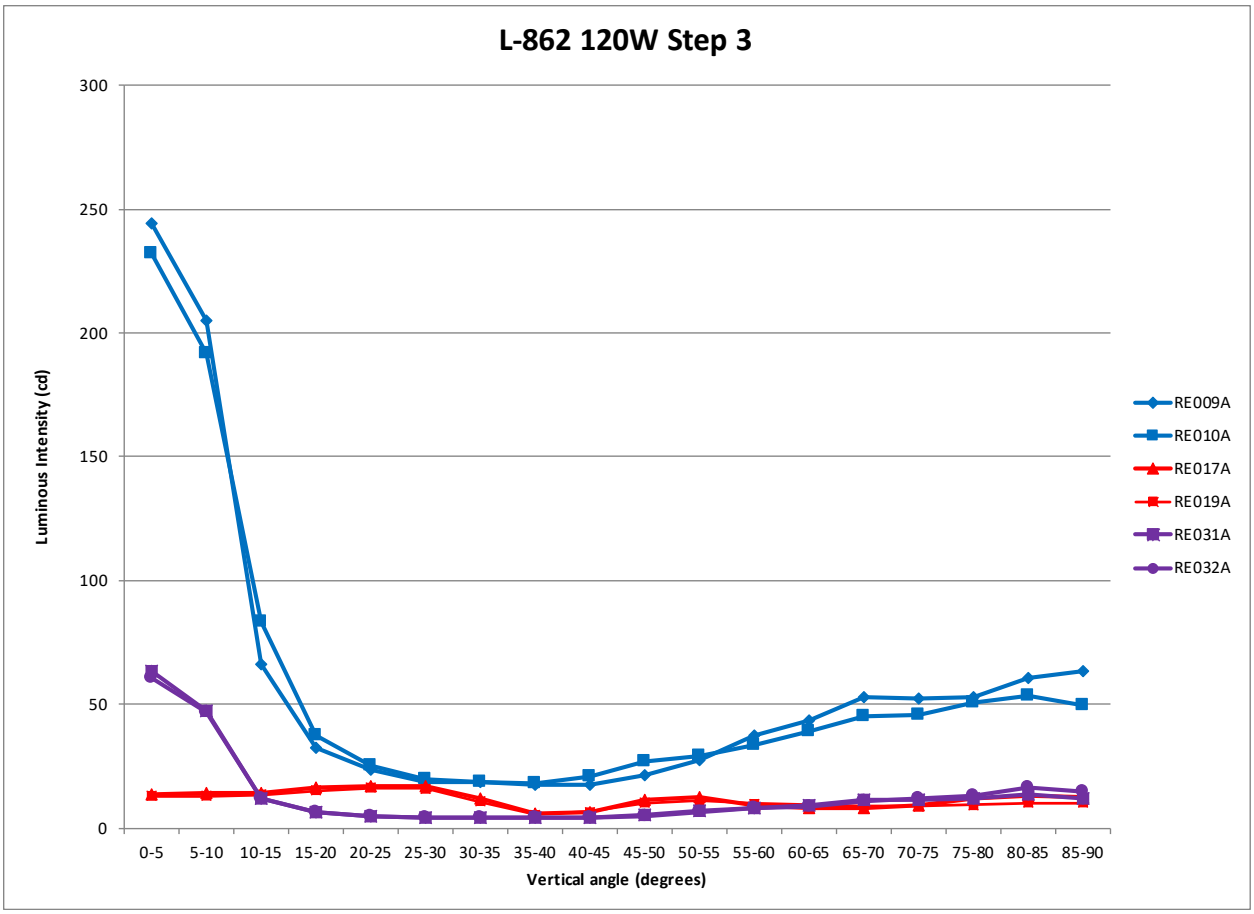


Figure 14. The 120-Watt L-862 Sample at Intensity Step 3

For the 120-watt L-862 sample at intensity step 3, the average candela for the range of angles up to the specified 15 degrees equals 74.8 cd, from 15-35 degrees equals 14.7 cd, from 35-60 degrees equals 13.2 cd, and from 60-90 degrees equals 24.3 cd.

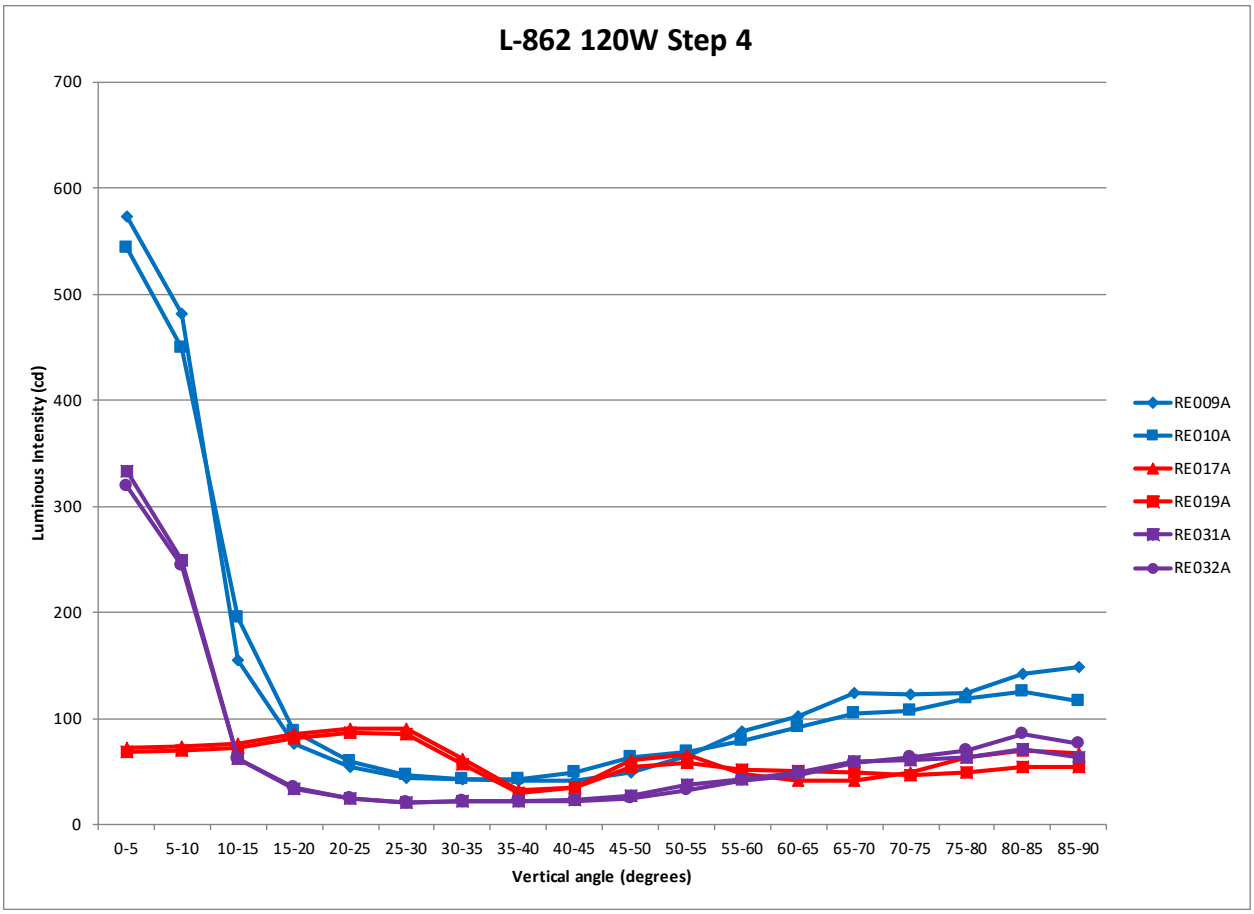


Figure 15. The 120-Watt L-862 Sample at Intensity Step 4

For the 120-watt L-862 sample at intensity step 4, the average candela for the range of angles up to the specified 15 degrees equals 227.7 cd, from 15-35 degrees equals 53.9 cd, from 35-60 degrees equals 45.0 cd, and from 60-90 degrees equals 78.5 cd.

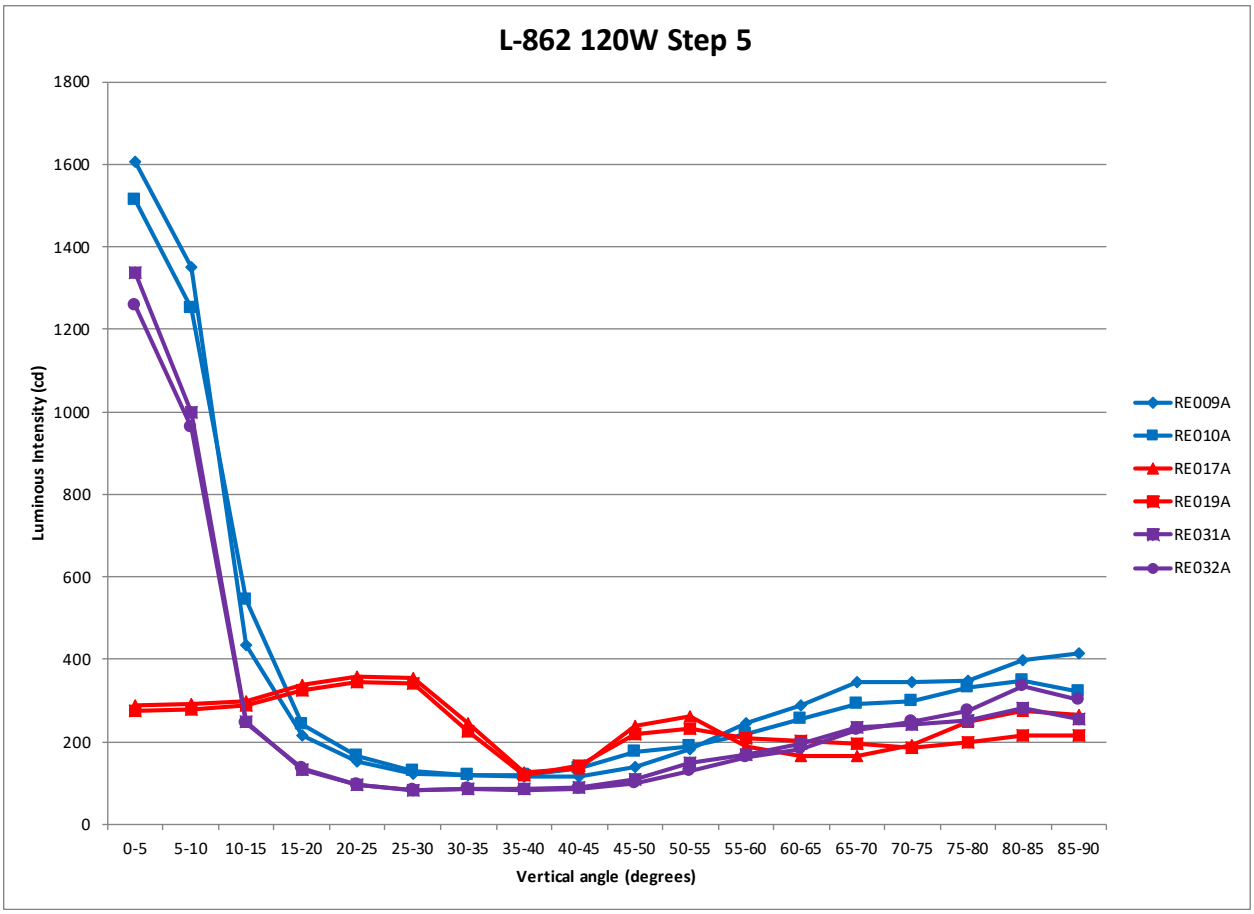


Figure 16. The 120-Watt L-862 Sample at Intensity Step 5

For the 120-watt L-862 sample at intensity step 5, the average candela for the range of angles up to the specified 15 degrees equals 748.1 cd, from 15-35 degrees equals 192.0 cd, from 35-60 degrees equals 155.9 cd, and from 60-90 degrees equals 265.4 cd.

The 150-Watt Version. The data for the 150-watt version at intensity steps 1, 2, 3, 4, and 5 are presented in figures 17, 18, 19, 20, and 21, respectively. The data show the light output follows a similar pattern for all but one manufacturer. The difference in distribution is due to the lack of additional optics in this manufacturers' fixture as compared to the other manufacturers.

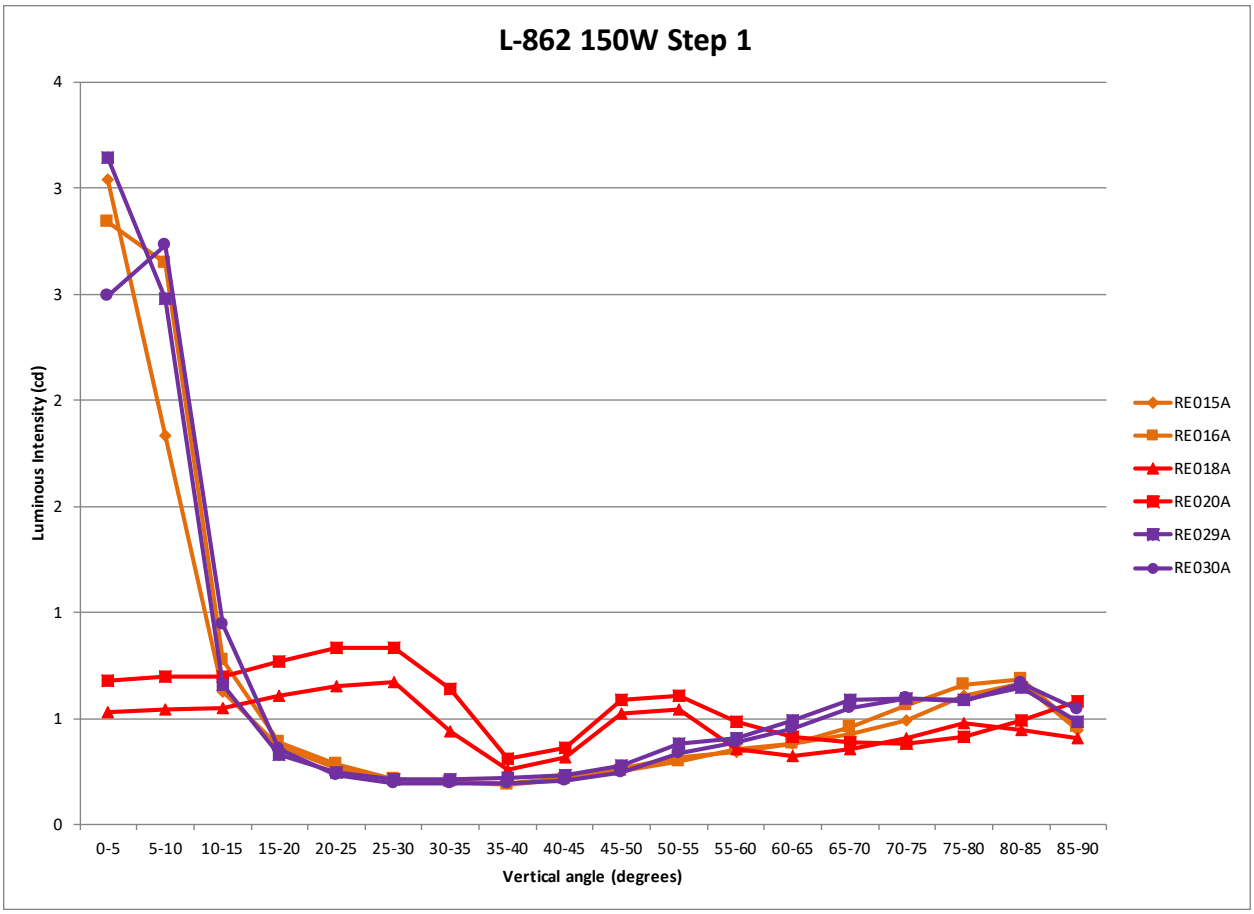


Figure 17. The 150-Watt L-862 Sample at Intensity Step 1

For the 150-watt L-862 sample at intensity step 1, the average candela for the range of angles up to the specified 15 degrees equals 1.5 cd, from 15-35 degrees equals 0.4 cd, from 35-60 degrees equals 0.3 cd, and from 60-90 degrees equals 0.5 cd.

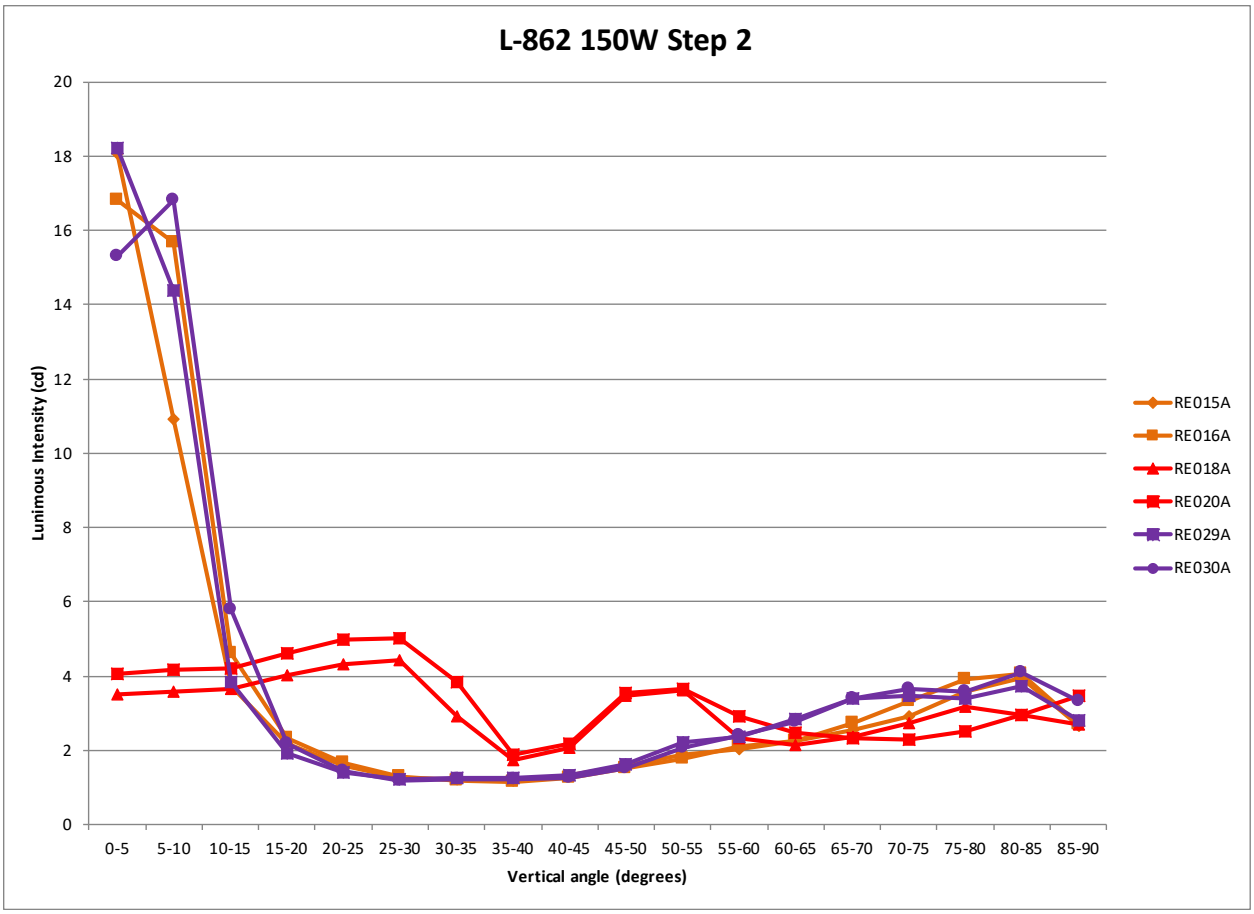


Figure 18. The 150-Watt L-862 Sample at Intensity Step 2

For the 150-watt L-862 sample at intensity step 2, the average candela for the range of angles up to the specified 15 degrees equals 9.3 cd, from 15-35 degrees equals 2.4 cd, from 35-60 degrees equals 2.0 cd, and from 60-90 degrees equals 3.0 cd.

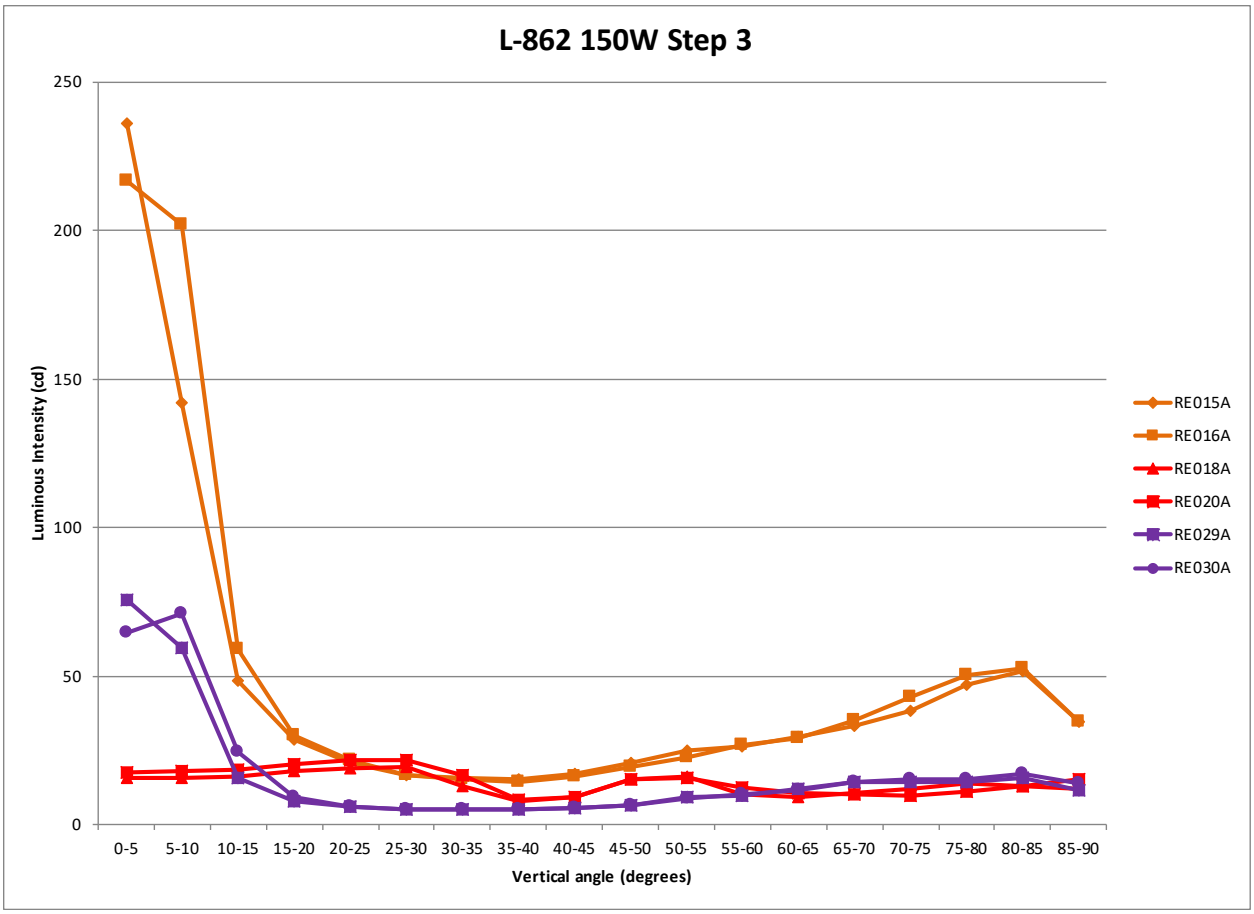


Figure 19. The 150-Watt L-862 Sample at Intensity Step 3

For the 150-watt L-862 sample at intensity step 3, the average candela for the range of angles up to the specified 15 degrees equals 73.2 cd, from 15-35 degrees equals 15.1 cd, from 35-60 degrees equals 13.2 cd, and from 60-90 degrees equals 21.9 cd.

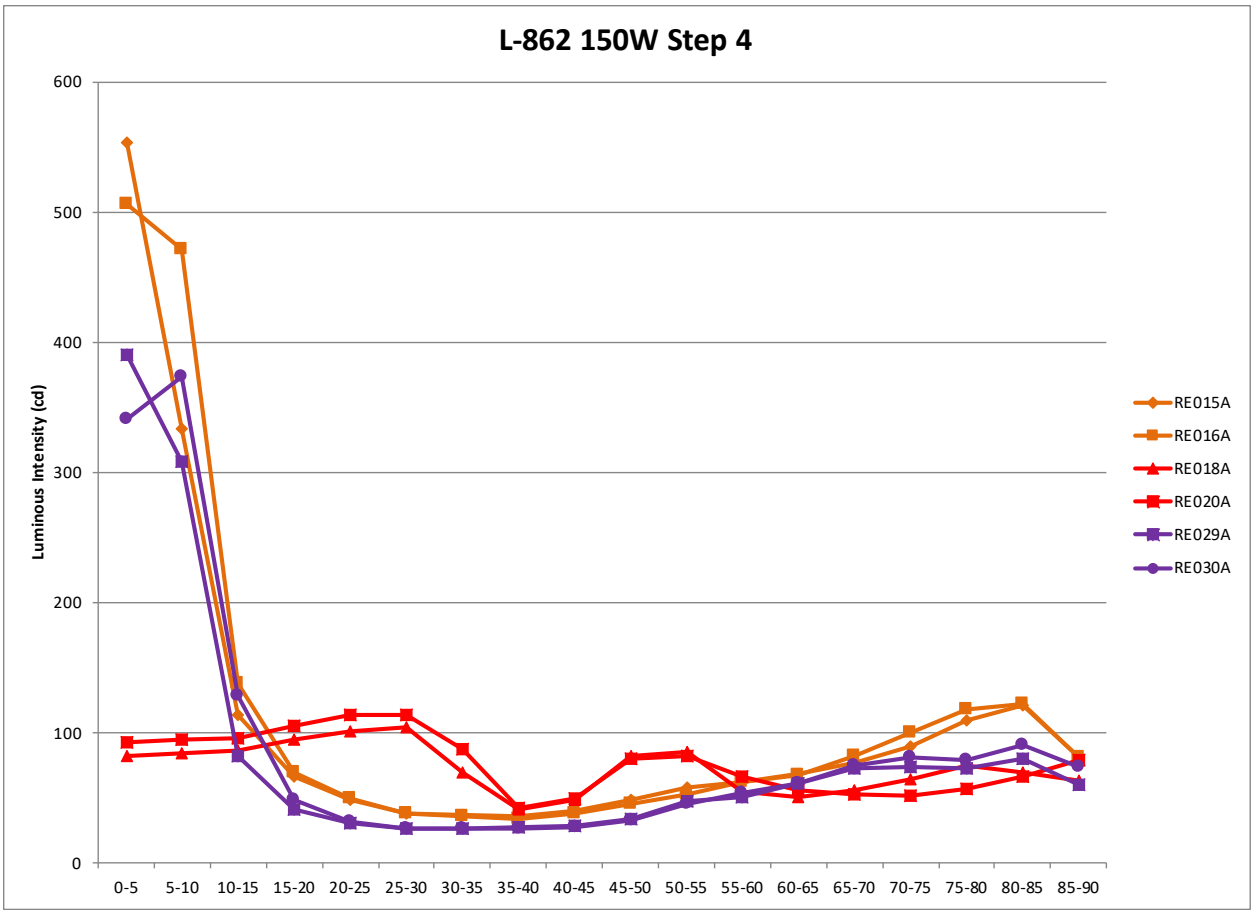


Figure 20. The 150-Watt L-862 Sample at Intensity Step 4

For the 150-watt L-862 sample at intensity step 4, the average candela for the range of angles up to the specified 15 degrees equals 237.6 cd, from 15-35 degrees equals 59.7 cd, from 35-60 degrees equals 49.6 cd, and from 60-90 degrees equals 76.2 cd.

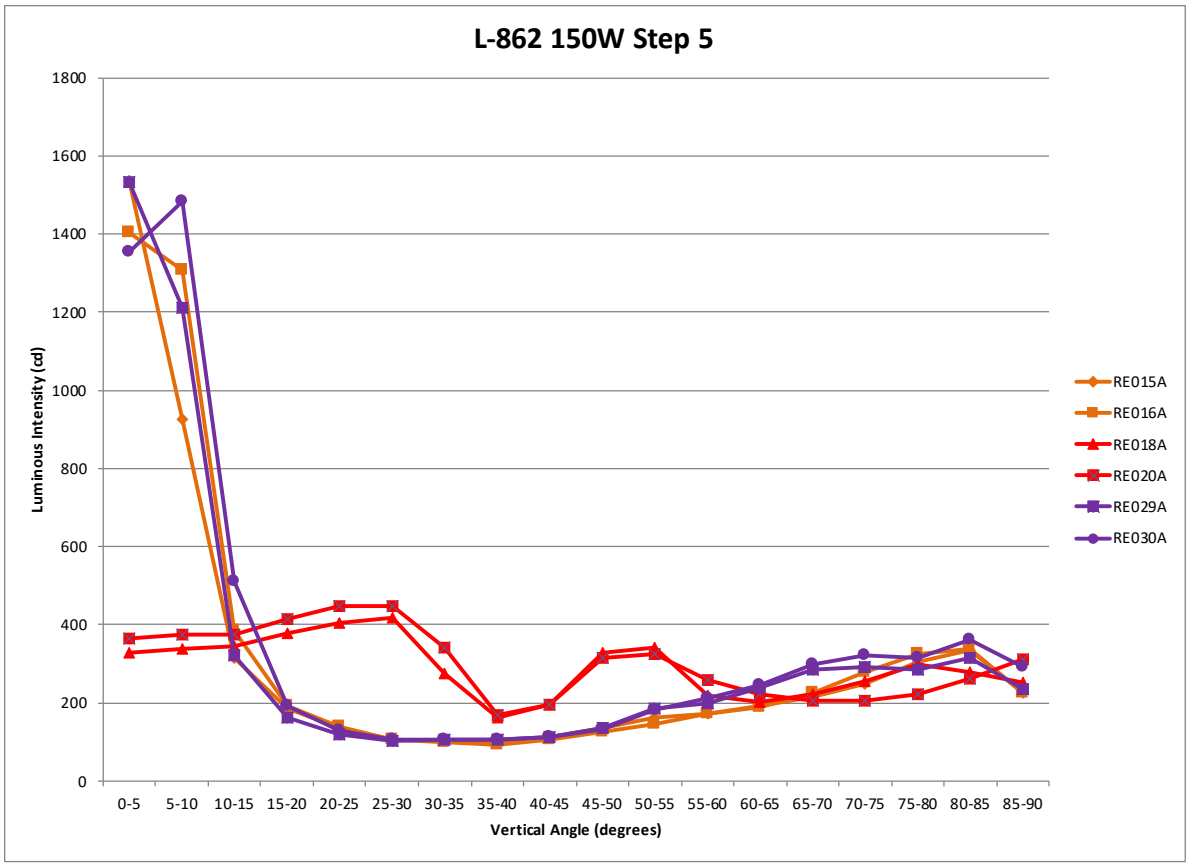


Figure 21. The 150-Watt L-862 Sample at Intensity Step 5

For the 150-watt L-862 sample at intensity step 5, the average candela for the range of angles up to the specified 15 degrees equals 800.8 cd, from 15-35 degrees equals 217.4 cd, from 35-60 degrees equals 177.3 cd, and from 60-90 degrees equals 264.8 cd.

## SUMMARY

Luminous intensity measurements were conducted of each fixture in vertical areas between 15-90 degrees on l-861 and l-862 runway edge light fixtures. Resulting data was compiled and presented for the sponsors use.

## REFERENCES

1. Federal Aviation Administration (FAA), "Specification for Runway and Taxiway Light Fixtures," Advisory Circular (AC) 150/5345-46E, March 2, 2016.

2. FAA, *Airplane Flying Handbook*, FAA-H-8083-3B, Chapter 7, "Airport Traffic Patterns," FAA Handbook Series, Aviation Supplies and Academics, Inc., Newcastle, Washington, November 28, 2016.

3. FAA, "Airport Lighting Equipment Certification Program, Appendix 1—Third Party Certification Bodies, Addendum," AC 150/5345-53D, March 24, 2016.

APPENDIX A—RESEARCH STUDY ON HIGH- AND MEDIUM-INTENSITY RUNWAY EDGE LIGHT OUTPUT, ROUND 1

Note: The following research study was prepared by the Rensselaer Polytechnic Institute. The study is presented unedited and in its entirety.

**Report: Research Study on High and Medium Intensity Runway Edge Light Output**

Prepared by: Lighting Research Center,[2] Rensselaer Polytechnic Institute

for the Federal Aviation Administration, Cooperative Agreement 16-G-019

*Revised May 9, 2017*

---

## Introduction

As part of Task 6 of Cooperative Agreement 16-G-016, incandescent-based high (L-862) and medium (L-861) intensity runway edge lights were measured in two separate rounds of testing at the Lighting Research Center (LRC) for angular luminous intensity distribution to understand the light emission between 15 and 90 degree vertical angles. The rounds were based on availability of fixtures and resulted in two reports based on the same test procedures

## Test procedure

### Overview

The intensity distribution of each luminaire was tested with a goniophotometer per IES LM-35-1989, *IES Approved Method for Photometric Testing of Floodlights Using Incandescent Filament or Discharge Lamps*. Two goniophotometers at the LRC were being used to perform intensity distribution measurements: a commercial type-C moving-mirror goniophotometer (model Sensing GMS-1900), shown in Figure 1, and a custom-built moving source goniophotometer set up for type-C coordinate system (referred to as "bar-photometer"), shown in Figure 2. All L-861 type luminaires were tested on the type-C moving-mirror goniophotometer; all L-862 type luminaires were tested on the bar-photometer due to the high light output of the L-862 type luminaires for which the bar-photometer has a larger light signal dynamic range. The distance between the optical center of each tested luminaire and the photometer is 4.348 m and 6.248 m for the type-C moving-mirror goniophotometer and bar-photometer, respectively.

Before testing, each luminaire was seasoned at its rated current of 6.6 A a.c. for 0.5% of the rated lifetime of each incandescent lamp per IES LM-54-12, *IES Guide to Lamp Seasoning*. Each luminaire was then mounted in the goniophotometer and stabilized at

---

[2] LRC testing team: M. Overington, Y. Zhu, and A. Bierman. Principal Investigator: N. Narendran.

6.6 A dc for at least 15 minutes before measurements were taken following the requirement in AC 150/5345-46E, *Specification for Runway and Taxiway Light Fixtures.*

For both luminaire types, intensity measurements were then taken over elevation angles (gamma) ranging from 0 to 100 degrees, and azimuthal angles (C) ranging from 0 to 360 degrees. The angular increments were 1 degree for the L-861 and 2 degrees for the L-862 luminaires. Luminous intensity measurements at nadir (0°, 0°) position were taken at the following current levels: 3 levels for L-861 type (6.6 A, 5.5 A, and 4.8 A) and 5 levels for L-862 type (6.6 A, 5.2 A, 4.1 A, 3.4 A, and 2.8 A). Previous luminous intensity distribution measurements of one of the L-862 luminaires showed no significant difference in the relative intensity distribution when operated at different current levels. Therefore, the intensity distributions for operating currents other than 6.6 A can be obtained by scaling measurement for 6.6 A operation by the ratios of nadir intensities.

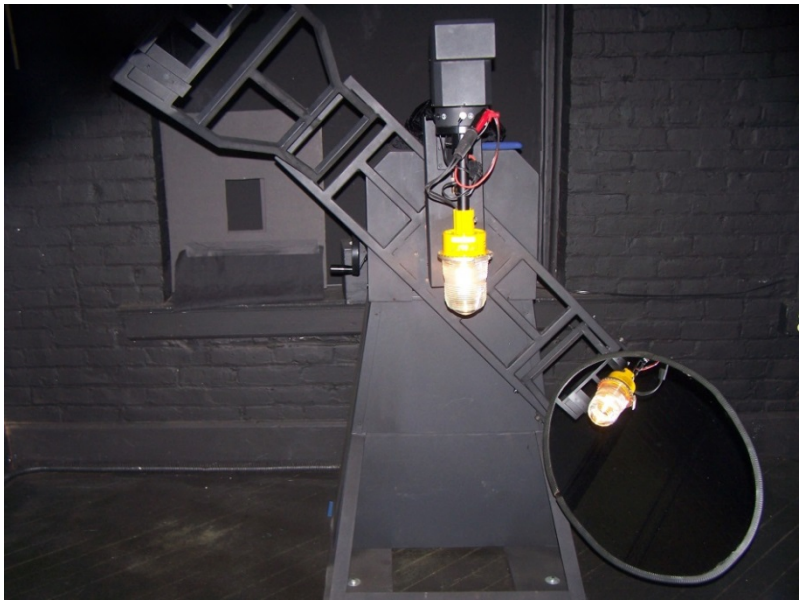

***Figure 1.*** *View of a luminaire under test mounted on the type-C mirror goniophotometer. The geometric center of the luminaire was used as reference for alignment.*

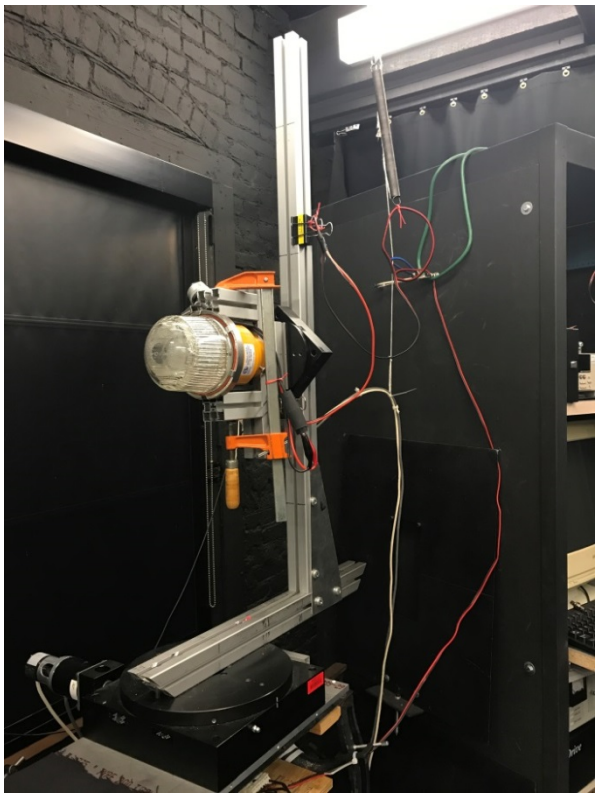

***Figure 2.*** *View of a luminaire under test mounted on the bar-photometer. The geometric center of the luminaire was used as reference for alignment.*

**Round 1**

This report summarizes the procedures and the results of the tests for products in the second round of testing. Table 1 lists the products tested in Round 1.

**Table 1.** Information of luminaires tested, including luminaire manufacturer, type, part number, lamp type and lamp model number.

| FAA ID | LRC ID | Luminaire and lamp information | | | | |
|---|---|---|---|---|---|---|
| | | Manufacturer | Luminaire type | Luminaire P/N | Incandescent lamp type | Lamp model No. |
| RE001-A | 110116 | Manufacturer A | L-861 | N/A | Halogen; 6.6A, 45W | NARVA 7654H |
| RE002-A | 110117 | Manufacturer A | L-861 | N/A | Halogen; 6.6A, 45W | GE EXM |
| RE003-A | 110119 | Manufacturer A | L-861 | N/A | Halogen; 6.6A, 45W | NARVA 7654H |
| RE004-A | 110118 | Manufacturer A | L-861 | N/A | Halogen; 6.6A, 45W | GE EXM |
| RE005-A | 110127 | Manufacturer B | L-861 | 6170-H-WW-14 | Halogen; 6.6A, 30W | GE EXL |
| RE006-A | 110126 | Manufacturer B | L-861 | 6170-H-WW-14 | Halogen; 6.6A, 30W | GE EXL |
| RE007-A | 110128 | Manufacturer B | L-861 | 6170-H-WW-14 | Halogen; 6.6A, 45W | GE EXM |
| RE008-A | 110129 | Manufacturer B | L-861 | 6170-H-WW-14 | Halogen; 6.6A, 45W | GE EXM |
| RE009A | 110131 | Manufacturer B | L-862 | 6370-R-WW-14 | Halogen; 6.6A, 120W | Philips 6128 |
| RE010A | 110130 | Manufacturer B | L-862 | 6370-R-WW-14 | Halogen; 6.6A, 120W | Philips 6128 |
| RE011A | 110121 | Manufacturer C | L-861 | L861-066-W-30-14M | Halogen; 6.6A, 30W | GE EXL |
| RE012A | 110123 | Manufacturer C | L-861 | L861-066-W-30-14M | Halogen; 6.6A, 30W | GE EXL |
| RE013A | 110122 | Manufacturer C | L-861 | L861-066-W-45-14M | Halogen; 6.6A, 45W | GE EXM |
| RE014A | 110120 | Manufacturer C | L-861 | L861-066-W-45-14M | Halogen; 6.6A, 45W | GE EXM |
| RE015A | 110124 | Manufacturer C | L-862 | L-862-150-WW-14 | Halogen; 6.6A, 150W | GE EWR |
| RE016A | 110125 | Manufacturer C | L-862 | L-862-150-WW-14 | Halogen; 6.6A, 150W | GE EWR |

**Test results**

The intensity distribution for each luminaire was plotted in several ways to help compare and analyze the results. For an overall visualization of the output in all directions, 3D renderings of the intensity distribution are shown using false color to indicate the intensity values. Because the L-862 luminaires have bi-directional outputs with very high intensities along the runway (10,000 cd) and relatively much lower level elsewhere, an additional 3D rendering is shown for these luminaires using logarithmic axis-scaling to better visualize the lower intensity outputs in the 15 to 90 degree vertical angle range of interest.

To facilitate comparisons of the intensity in the 15 to 90 degree range, the three-dimensional intensity distribution for each luminaire was averaged across the azimuthal angle (C) and this average intensity is plotted as a function of elevation angle (gamma) in both Cartesian coordinates and polar coordinates.

Individual plots for every luminaire tested are shown in the sections A1 to A16. Figures 3 and 4 depict in Cartesian coordinates the range of intensities measured for all 45 W and 30 W L-861 type luminaires tested at 6.6 A d.c. Figure 5 shows the same for all L-862 type luminaires tested at 6.6 A d.c.

Tables 2 and 3 list the azimuthal average intensity (in cd) over the range of elevation angles from 0 to 90 degrees in 5-degree increments for the L-861 and L-862 luminaires tested at 6.6 A d.c., respectively. Table 4 lists the calculated scaling factors when operated at different step dim levels (three levels for L-861 type: 6.6 A, 5.5 A, and 4.8 A; five levels for L-862 type: 6.6 A, 5.2 A, 4.1 A, 3.4 A, and 2.8 A) based on luminous intensity measured at nadir (0°, 0°). Section B lists individual tables of the azimuthal average intensity (in cd) over the range of elevation angles from 0 to 90 degrees in 5-degree increments for the L-861 and L-862 luminaires at different step dim levels after multiplying the corresponding scaling factors from Table 4.

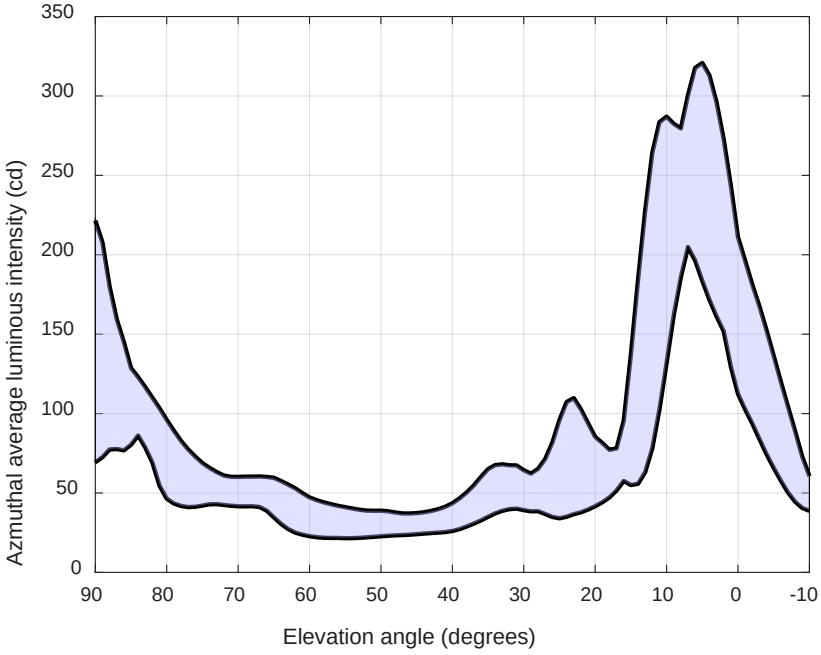


***Figure 3.*** *Range of intensity distributions of all 45 W L-861 type luminaires tested at 6.6 A d.c. in Cartesian coordinates*

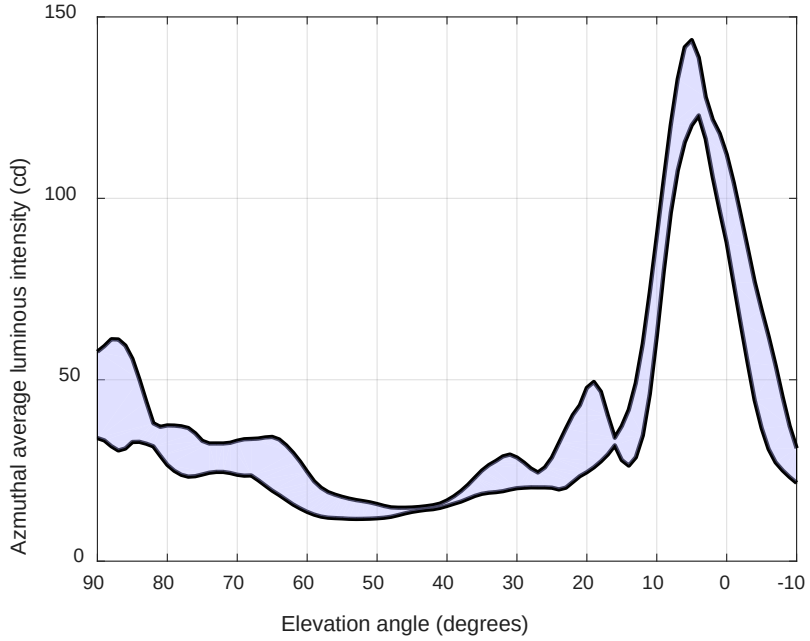


***Figure 4.*** *Range of intensity distributions of all 30 W L-861 type luminaires tested at 6.6 A d.c. in Cartesian coordinates*

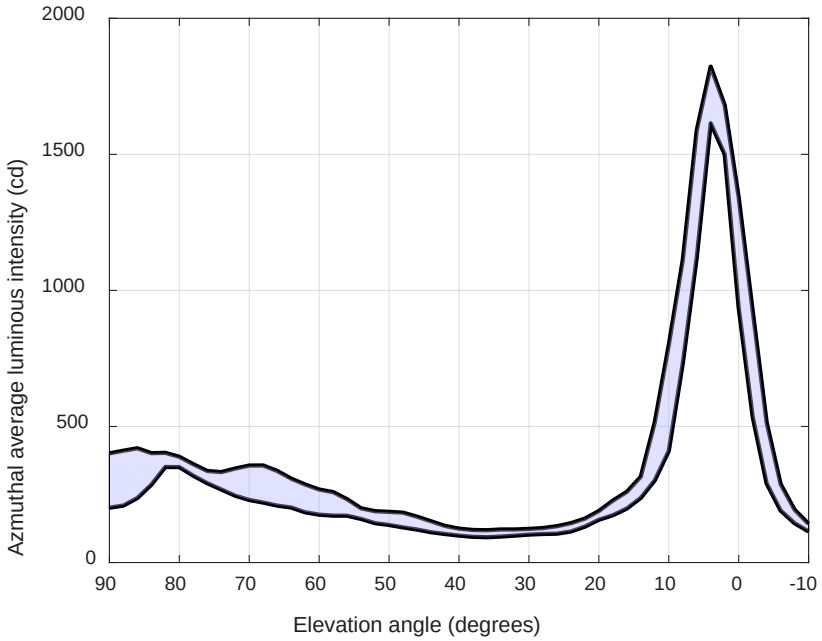


***Figure 5.*** *Range of intensity distributions of all L-862 type luminaires tested at 6.6 A d.c. in Cartesian coordinates*

**Table 2.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested L-861 luminaires tested at 6.6 A d.c.

| FAA ID | RE001-A | RE002-A | RE003-A | RE004-A | RE005-A | RE006-A | RE007-A | RE008-A | RE011-A | RE012-A | RE013-A | RE014-A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LRC ID | 110116 | 110117 | 110119 | 110118 | 110127 | 110126 | 110128 | 110129 | 110121 | 110123 | 110122 | 110120 |
| Elevation angle range (degrees) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 177.8 | 168.2 | 151.9 | 157.9 | 220.4 | 119.9 | 225.5 | 119.6 | 113.9 | 106.6 | 267.2 | 212.9 |
| 5-10 | 275.9 | 243.5 | 207.0 | 266.7 | 199.4 | 112.1 | 203.0 | 103.9 | 128.7 | 119.6 | 288.8 | 211.9 |
| 10-15 | 221.0 | 179.5 | 170.5 | 249.3 | 96.1 | 49.2 | 86.3 | 39.6 | 62.8 | 57.9 | 129.0 | 109.9 |
| 15-20 | 81.5 | 78.7 | 84.6 | 89.3 | 70.9 | 37.0 | 67.3 | 39.4 | 31.4 | 30.0 | 55.2 | 53.2 |
| 20-25 | 97.1 | 87.3 | 88.5 | 98.3 | 74.0 | 39.3 | 70.6 | 36.9 | 22.1 | 22.5 | 40.5 | 38.4 |
| 25-30 | 73.7 | 60.1 | 57.8 | 74.6 | 47.9 | 25.6 | 41.7 | 24.6 | 20.6 | 20.4 | 36.7 | 39.7 |
| 30-35 | 65.6 | 49.8 | 50.1 | 65.9 | 50.0 | 27.0 | 47.5 | 27.8 | 19.4 | 21.6 | 41.7 | 39.7 |
| 35-40 | 55.3 | 40.5 | 41.6 | 50.9 | 39.4 | 21.2 | 48.0 | 19.1 | 17.2 | 18.4 | 38.2 | 30.9 |
| 40-45 | 40.2 | 29.1 | 29.3 | 38.4 | 27.7 | 15.5 | 31.4 | 15.5 | 14.5 | 14.5 | 32.2 | 25.1 |
| 45-50 | 37.5 | 25.7 | 25.8 | 36.4 | 26.2 | 14.7 | 27.5 | 14.8 | 12.7 | 13.4 | 25.9 | 23.5 |
| 50-55 | 39.2 | 26.3 | 27.1 | 36.0 | 28.3 | 16.5 | 29.0 | 15.5 | 11.7 | 12.4 | 23.0 | 22.1 |
| 55-60 | 43.1 | 32.4 | 30.8 | 40.2 | 35.2 | 19.4 | 33.6 | 19.1 | 12.5 | 12.2 | 21.9 | 22.3 |
| 60-65 | 52.6 | 41.7 | 40.0 | 49.7 | 50.6 | 29.5 | 46.8 | 28.5 | 16.0 | 15.8 | 25.9 | 30.3 |
| 65-70 | 58.2 | 50.6 | 49.1 | 56.4 | 58.3 | 33.9 | 59.9 | 30.3 | 23.1 | 22.2 | 39.6 | 43.5 |
| 70-75 | 56.5 | 54.4 | 50.1 | 53.0 | 60.2 | 32.6 | 62.0 | 29.9 | 24.3 | 25.6 | 42.4 | 48.8 |
| 75-80 | 71.6 | 66.3 | 66.5 | 58.7 | 77.5 | 33.2 | 78.1 | 35.9 | 23.9 | 25.8 | 41.9 | 53.6 |
| 80-85 | 84.7 | 95.5 | 93.8 | 80.1 | 89.5 | 32.9 | 109.8 | 36.3 | 31.5 | 39.1 | 72.9 | 72.3 |
| 85-90 | 89.3 | 113.4 | 103.7 | 87.2 | 77.0 | 34.4 | 140.9 | 31.9 | 42.2 | 59.3 | 163.8 | 104.6 |

**Table 3.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested L-862 luminaires tested at 6.6 A d.c.

| FAA ID | RE009-A | RE010-A | RE015-A | RE016-A |
|---|---|---|---|---|
| LRC ID | 110131 | 110130 | 110124 | 110125 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 1607.6 | 1512 | 1536.2 | 1403.3 |
| 5-10 | 1349.8 | 1250 | 926.1 | 1306.1 |
| 10-15 | 434.6 | 543.4 | 316.7 | 383.3 |
| 15-20 | 214.7 | 243.6 | 186.1 | 192.5 |
| 20-25 | 153.7 | 165.1 | 134.4 | 138.9 |
| 25-30 | 122.3 | 130.1 | 106.9 | 106.4 |
| 30-35 | 120.8 | 120.1 | 102.1 | 99 |
| 35-40 | 116 | 118.2 | 98.9 | 93.8 |
| 40-45 | 116 | 136.9 | 111.8 | 105.1 |
| 45-50 | 138.9 | 175.9 | 134.5 | 125.1 |
| 50-55 | 181.9 | 190.5 | 161.3 | 147.6 |
| 55-60 | 245.7 | 219.2 | 172.4 | 173.8 |
| 60-65 | 287.8 | 256 | 191.8 | 187.6 |
| 65-70 | 346.6 | 292.5 | 214.8 | 227 |
| 70-75 | 344.7 | 298.4 | 248 | 277.6 |
| 75-80 | 348.9 | 330.4 | 305.3 | 326 |
| 80-85 | 397.9 | 349.5 | 335.2 | 338.9 |
| 85-90 | 415.5 | 322.4 | 224.9 | 225 |

**Table 4.** Calculated scaling factors when operated at different step dim levels (three levels for L-861 type: 6.6A, 5.5A and 4.8A; five levels for L-862 type: 6.6A, 5.2A, 4.1A, 3.4A and 2.8A) based on luminous intensity measured at nadir (0°, 0°)

| FAA ID | LRC ID | Manufacturer | Luminaire Type | Luminaire P/N | Scaling factor | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 6.6 A | 5.2 A | 4.1 A | 3.4 A | 2.8 A |
| | | | | | 6.6 A | 5.5 A | 4.8 A | | |
| RE001-A | 110116 | Manufacturer A | L-861 | N/A | 100% | 32% | 12% | n/a | n/a |
| RE002-A | 110117 | Manufacturer A | L-861 | N/A | 100% | 31% | 11% | n/a | n/a |
| RE003-A | 110119 | Manufacturer A | L-861 | N/A | 100% | 32% | 12% | n/a | n/a |
| RE004-A | 110118 | Manufacturer A | L-861 | N/A | 100% | 30% | 11% | n/a | n/a |
| RE005-A | 110127 | Manufacturer B | L-861 | 6170-H-WW-14 | 100% | 28% | 9% | n/a | n/a |
| RE006-A | 110126 | Manufacturer B | L-861 | 6170-H-WW-14 | 100% | 27% | 9% | n/a | n/a |
| RE007-A | 110128 | Manufacturer B | L-861 | 6170-H-WW-14 | 100% | 31% | 11% | n/a | n/a |
| RE008-A | 110129 | Manufacturer B | L-861 | 6170-H-WW-14 | 100% | 31% | 11% | n/a | n/a |
| RE009A | 110131 | Manufacturer B | L-862 | 6370-R-WW-14 | 100% | 36% | 15% | 1.2% | 0.2% |
| RE010A | 110130 | Manufacturer B | L-862 | 6370-R-WW-14 | 100% | 36% | 15% | 1.2% | 0.2% |
| RE011A | 110121 | Manufacturer C | L-861 | L861-066-W-30-14M | 100% | 27% | 9% | n/a | n/a |
| RE012A | 110123 | Manufacturer C | L-861 | L861-066-W-30-14M | 100% | 27% | 9% | n/a | n/a |
| RE013A | 110122 | Manufacturer C | L-861 | L861-066-W-45-14M | 100% | 31% | 12% | n/a | n/a |
| RE014A | 110120 | Manufacturer C | L-861 | L861-066-W-45-14M | 100% | 31% | 11% | n/a | n/a |
| RE015A | 110124 | Manufacturer C | L-862 | L-862-150-WW-14 | 100% | 36% | 15% | 1.2% | 0.2% |
| RE016A | 110125 | Manufacturer C | L-862 | L-862-150-WW-14 | 100% | 36% | 15% | 1.2% | 0.2% |

# Section A1 – Detailed testing results for sample RE001-A

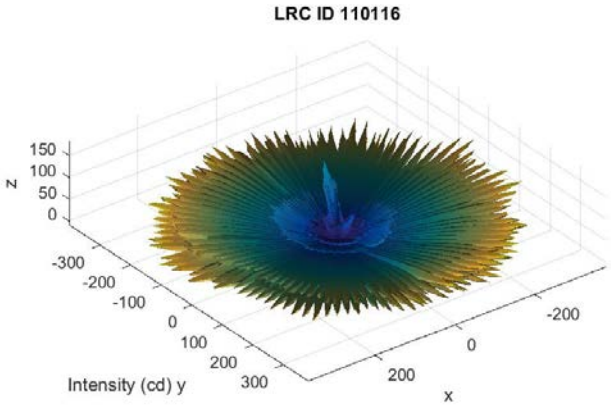


***Figure A1-1.*** *3D rendering of the intensity distribution of RE001-A (L-861 type) luminaire tested at 6.6 A d.c.*

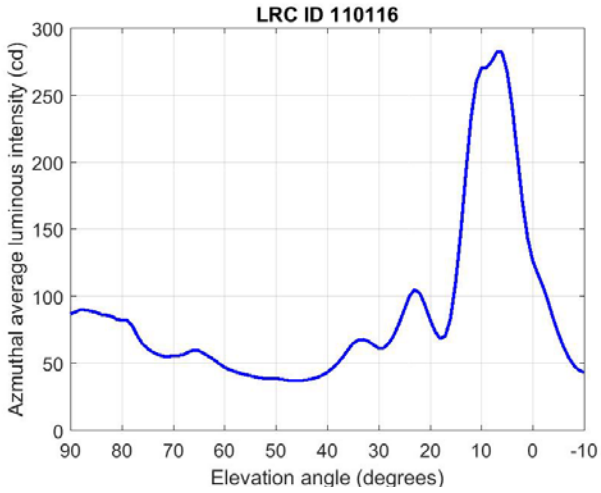


***Figure A1-2.*** *Azimuthal average intensity distribution of RE001-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

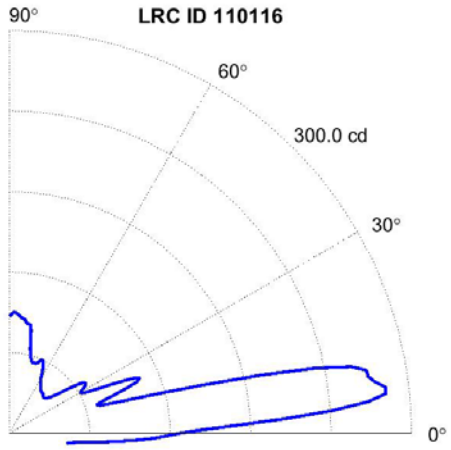


***Figure A1-3.*** *Azimuthal average intensity distribution of RE001-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A2 – Detailed testing results for sample RE002-A

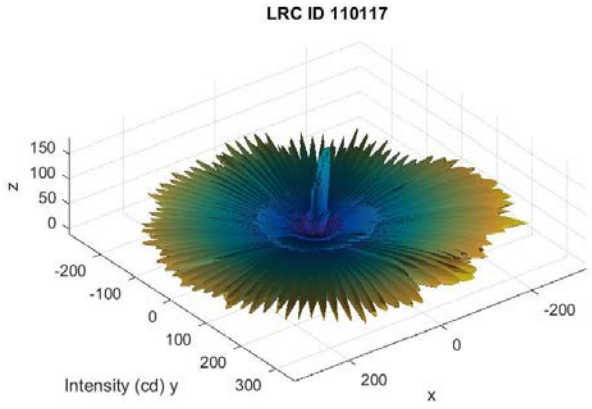


***Figure A2-1.*** *3D rendering of the intensity distribution of RE002-A (L-861 type) luminaire tested at 6.6 A d.c.*

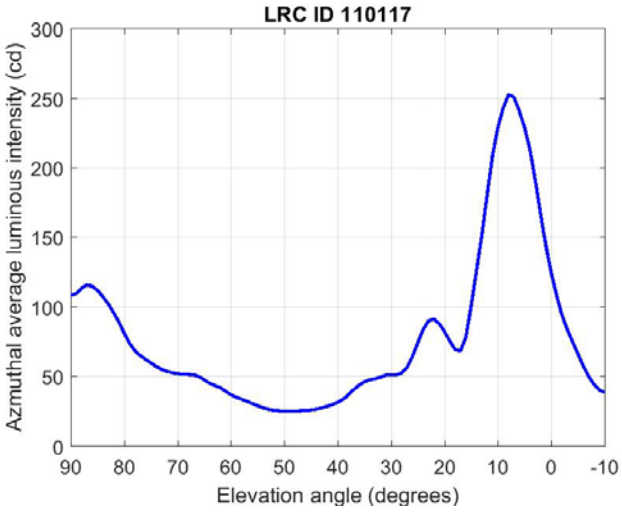


***Figure A2-2.*** *Azimuthal average intensity distribution of RE002-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

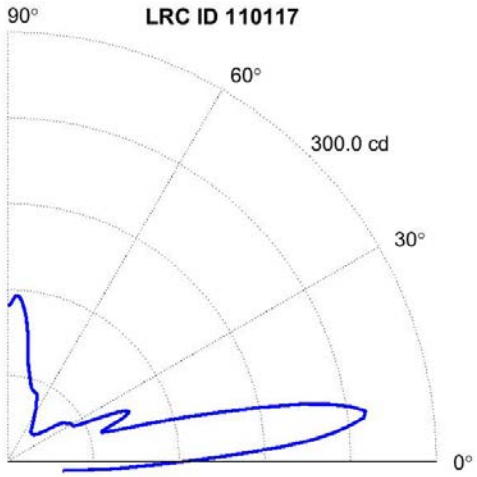


***Figure A2-3.*** *Azimuthal average intensity distribution of RE002-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A3 – Detailed testing results for sample RE003-A

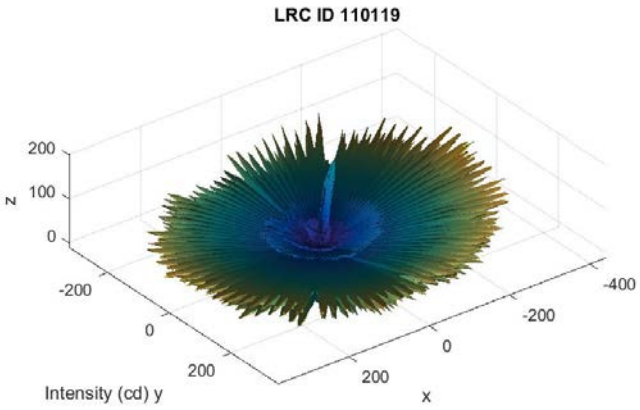


***Figure A3-1.*** *3D rendering of the intensity distribution of RE003-A (L-861 type) luminaire tested at 6.6 A d.c.*

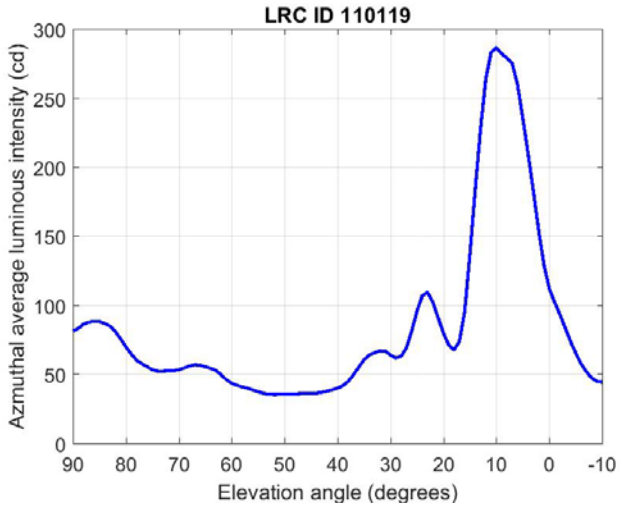


***Figure A3-2.*** *Azimuthal average intensity distribution of RE003-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

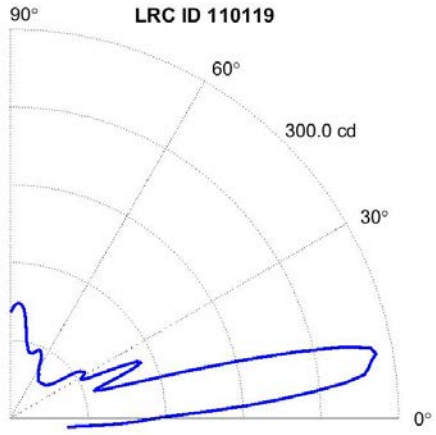


***Figure A3-3.*** *Azimuthal average intensity distribution of RE003-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A4 – Detailed testing results for sample RE004-A

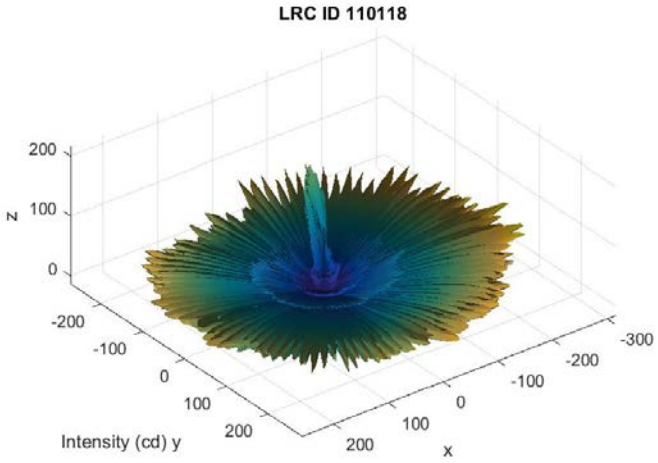


***Figure A4-1.*** *3D rendering of the intensity distribution of RE004-A (L-861 type) luminaire tested at 6.6 A d.c.*

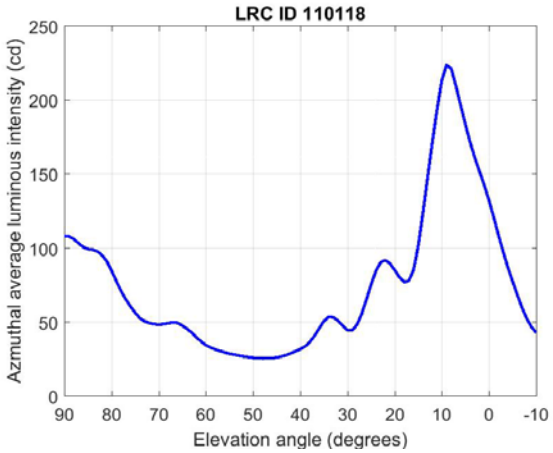


***Figure A4-2.*** *Azimuthal average intensity distribution of RE004-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

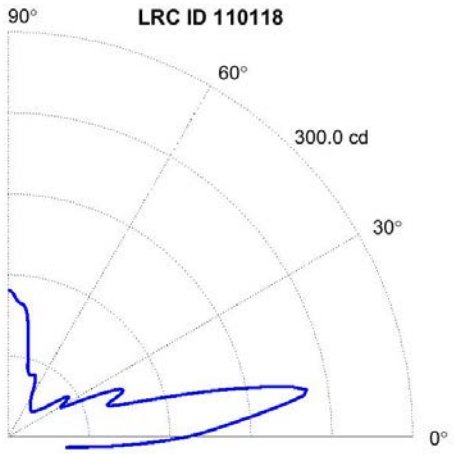


***Figure A4-3.*** *Azimuthal average intensity distribution of RE004-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A5 – Detailed testing results for sample RE005-A

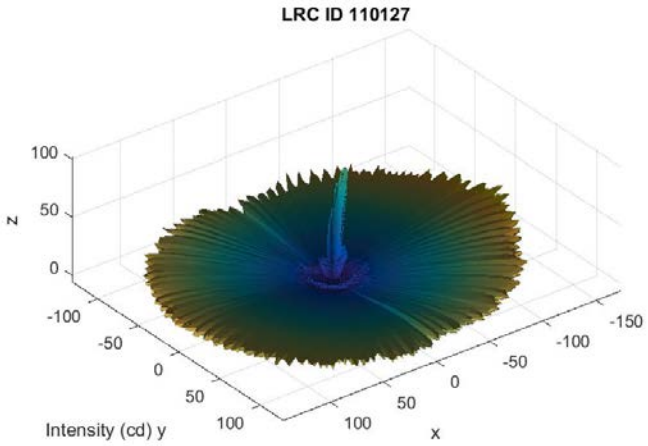


***Figure A5-1.*** *3D rendering of the intensity distribution of RE005-A (L-861 type) luminaire tested at 6.6 A d.c.*

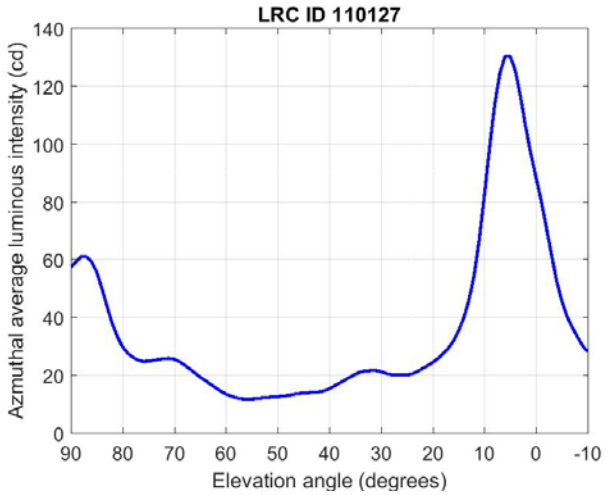


***Figure A5-2.*** *Azimuthal average intensity distribution of RE005-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

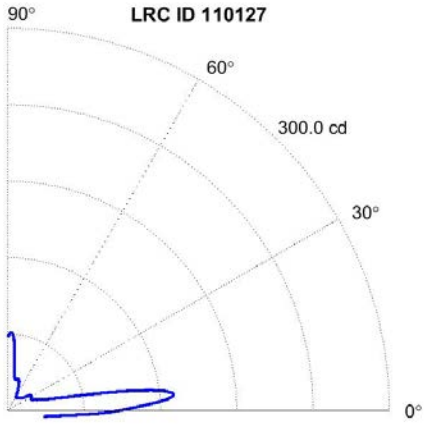


***Figure A5-3.*** *Azimuthal average intensity distribution of RE005-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A6 – Detailed testing results for sample RE006-A

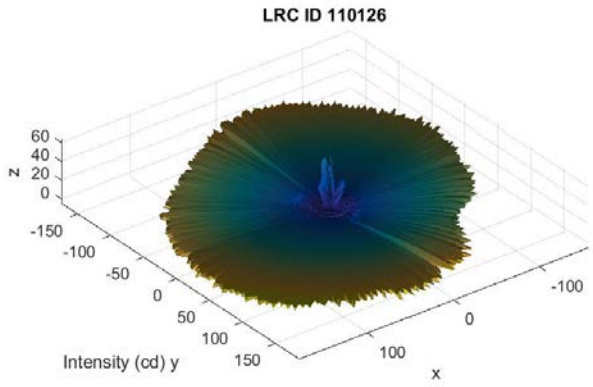


***Figure A6-1.*** *3D rendering of the intensity distribution of RE006-A (L-861 type) luminaire tested at 6.6 A d.c.*

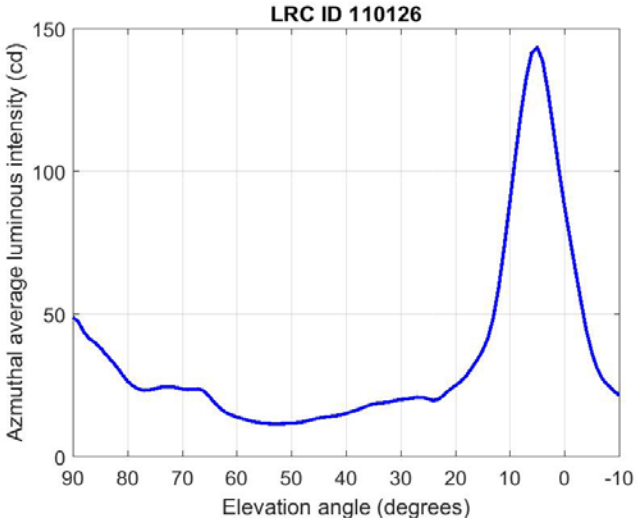


***Figure A6-2.*** *Azimuthal average intensity distribution of RE006-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

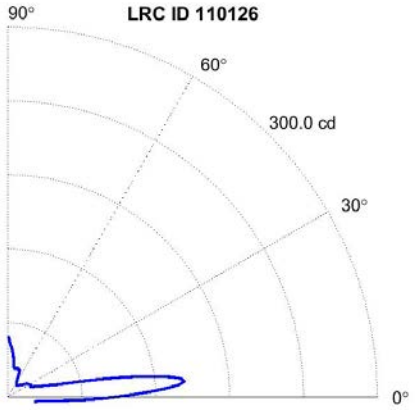


***Figure A6-3.*** *Azimuthal average intensity distribution of RE006-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A7 – Detailed testing results for sample RE007-A

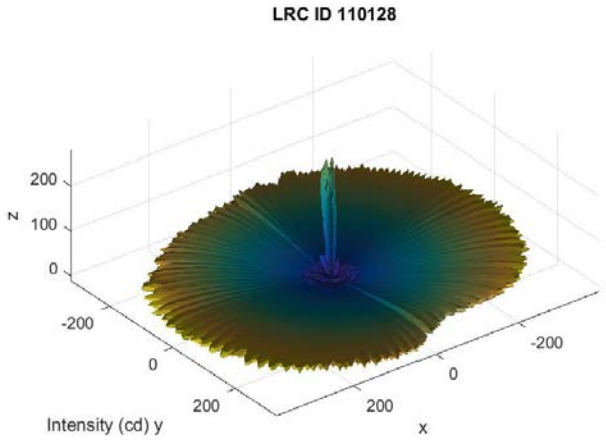


***Figure A7-1.*** *3D rendering of the intensity distribution of RE007-A (L-861 type) luminaire tested at 6.6 A d.c.*

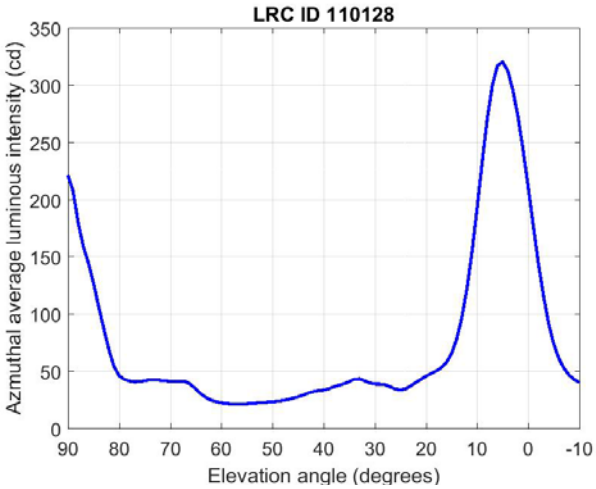


***Figure A7-2.*** *Azimuthal average intensity distribution of RE007-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

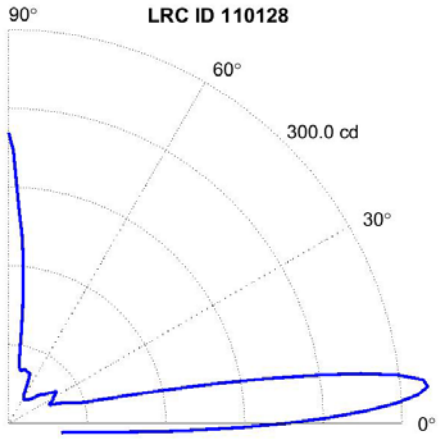


***Figure A7-3.*** *Azimuthal average intensity distribution of RE007-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A8 – Detailed testing results for sample RE008-A

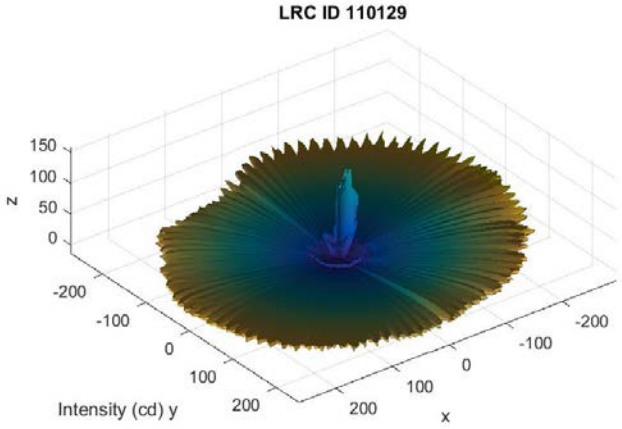


***Figure A8-1.*** *3D rendering of the intensity distribution of RE008-A (L-861 type) luminaire tested at 6.6 A d.c.*

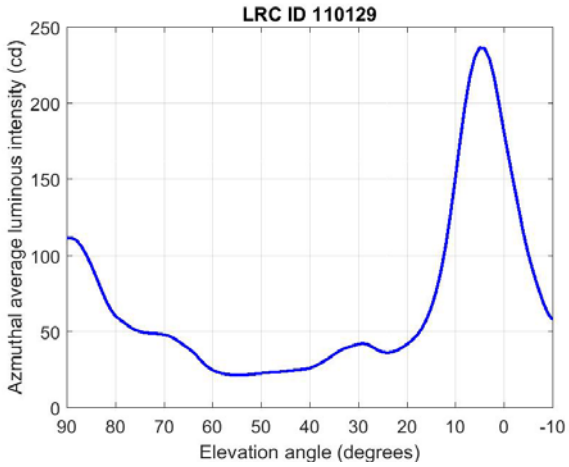


***Figure A8-2.*** *Azimuthal average intensity distribution of RE008-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

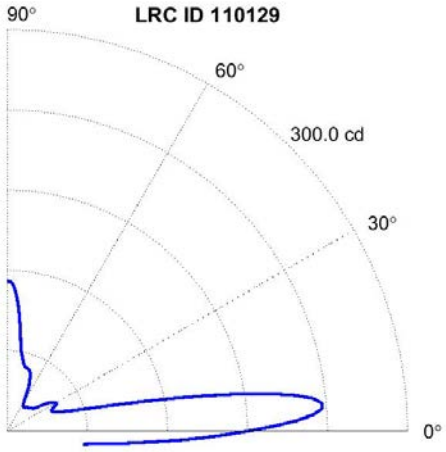


***Figure A8-3.*** *Azimuthal average intensity distribution of RE008-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A9 – Detailed testing results for sample RE009-A

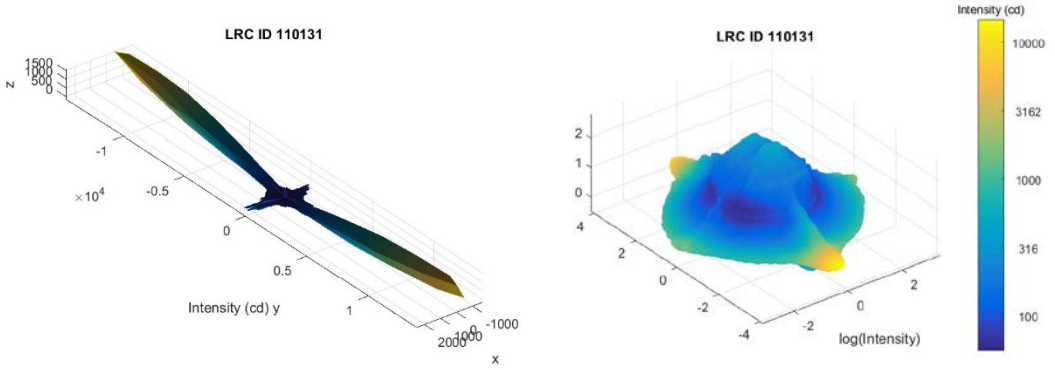


***Figure A9-1.*** *3D rendering of the intensity distribution of RE009-A (L-862 type) luminaire tested at 6.6 A d.c. in linear scale (left) and in logarithmic scale (right)*

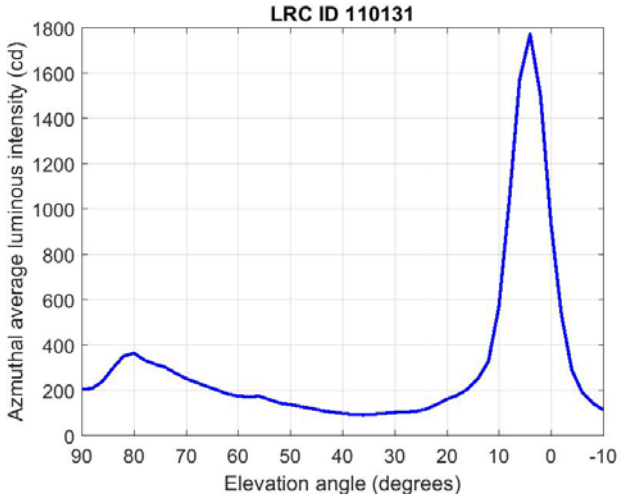


***Figure A9-2.*** *Azimuthal average intensity distribution of RE009-A (L-862 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

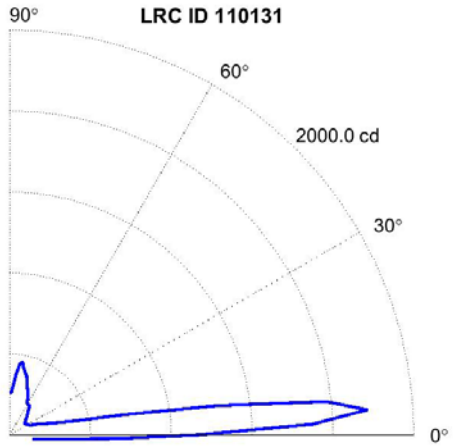


***Figure A8-3.*** *Azimuthal average intensity distribution of RE009-A (L-862 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A10 – Detailed testing results for sample RE010-A

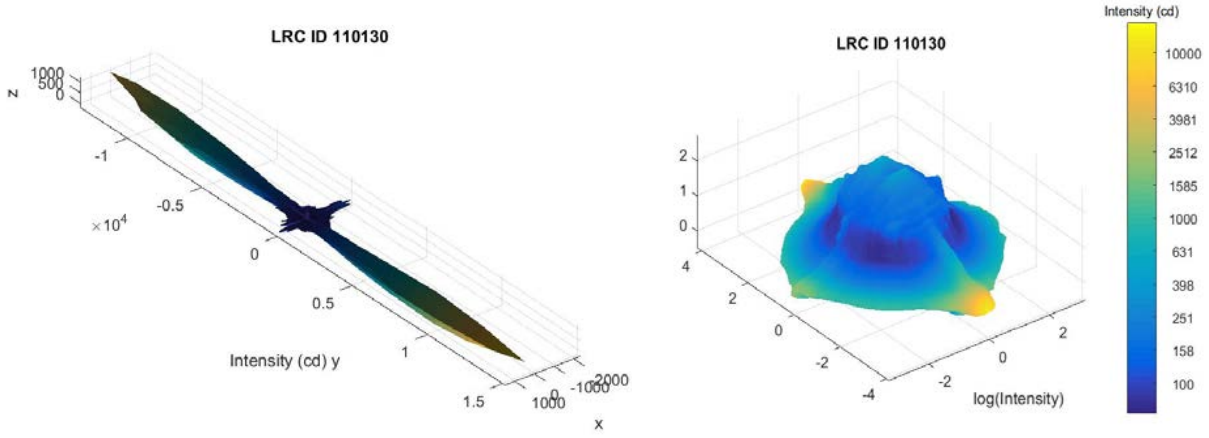


***Figure A10-1.*** *3D rendering of the intensity distribution of RE010-A (L-862 type) luminaire tested at 6.6 A d.c. in linear scale (left) and in logarithmic scale (right)*

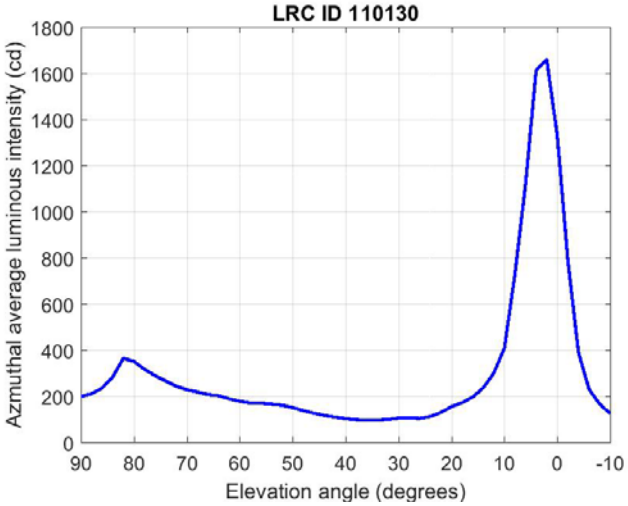


***Figure A10-2.*** *Azimuthal average intensity distribution of RE010-A (L-862 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

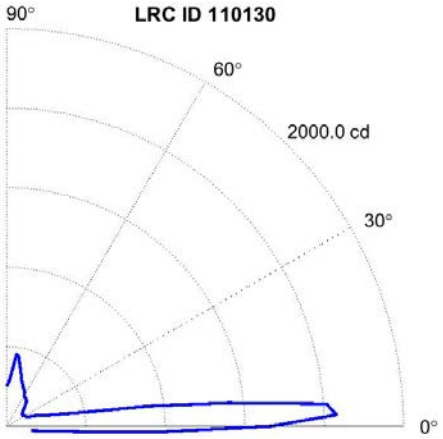


***Figure A10-3.*** *Azimuthal average intensity distribution of RE010-A (L-862 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A11 – Detailed testing results for sample RE011-A

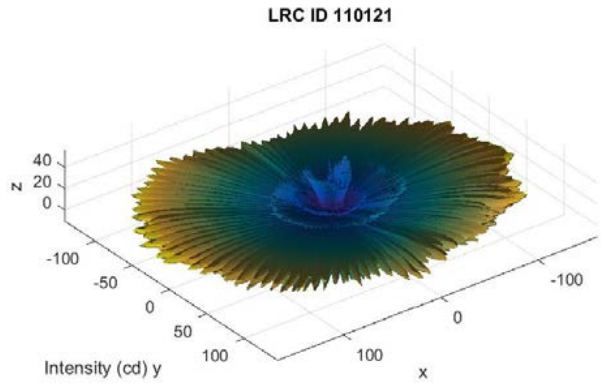


***Figure A11-1.*** *3D rendering of the intensity distribution of RE011-A (L-861 type) luminaire tested at 6.6 A d.c.*

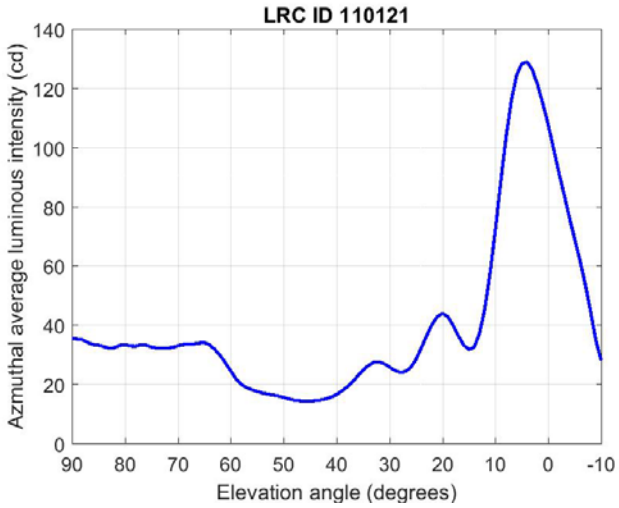


***Figure A11-2.*** *Azimuthal average intensity distribution of RE011-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

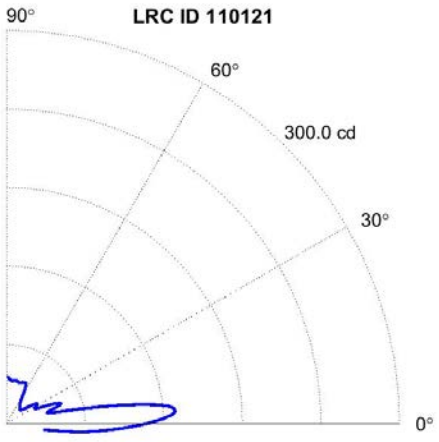


***Figure A11-3.*** *Azimuthal average intensity distribution of RE011-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A12 – Detailed testing results for sample RE012-A

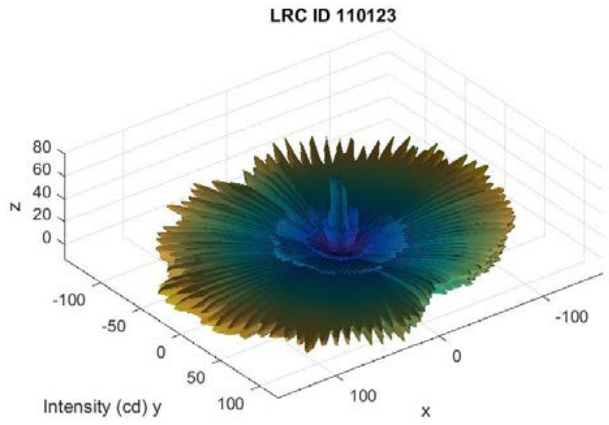


***Figure A12-1.*** *3D rendering of the intensity distribution of RE012-A (L-861 type) luminaire tested at 6.6 A d.c.*

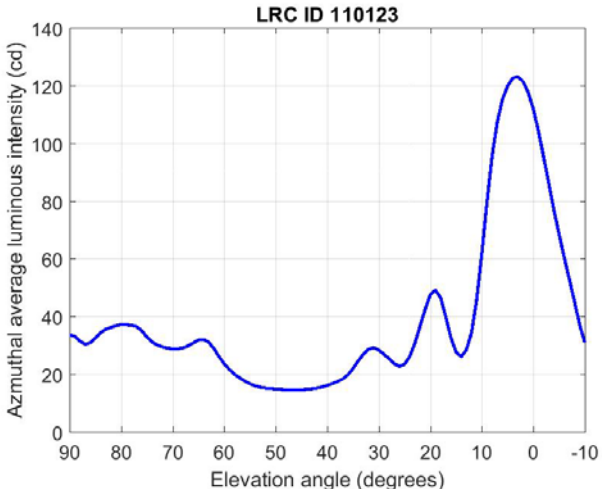


***Figure A12-2.*** *Azimuthal average intensity distribution of RE012-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

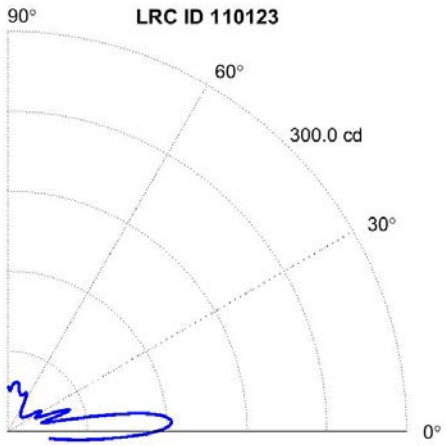


***Figure A12-3.*** *Azimuthal average intensity distribution of RE012-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A13 – Detailed testing results for sample RE013-A

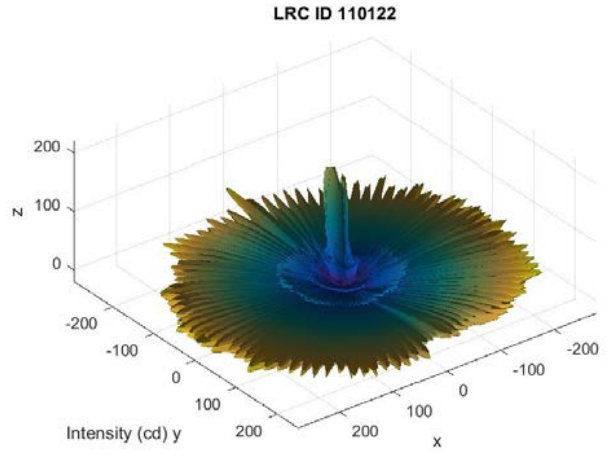


***Figure A13-1.*** *3D rendering of the intensity distribution of RE013-A (L-861 type) luminaire tested at 6.6 A d.c.*

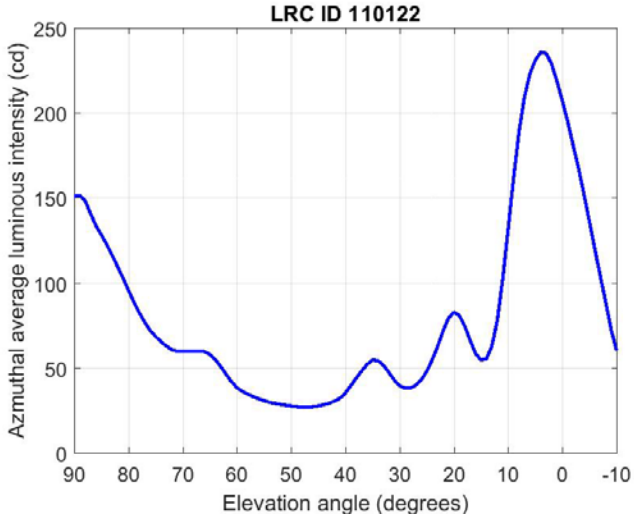


***Figure A13-2.*** *Azimuthal average intensity distribution of RE013-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

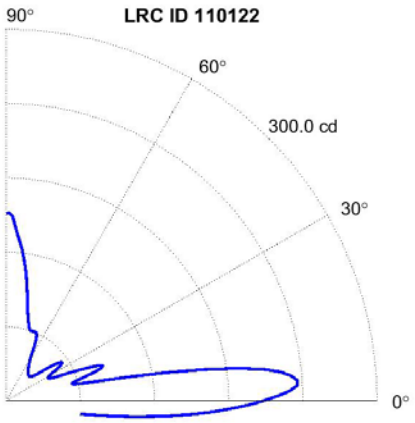


***Figure A13-3.*** *Azimuthal average intensity distribution of RE013-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A14 – Detailed testing results for sample RE014-A

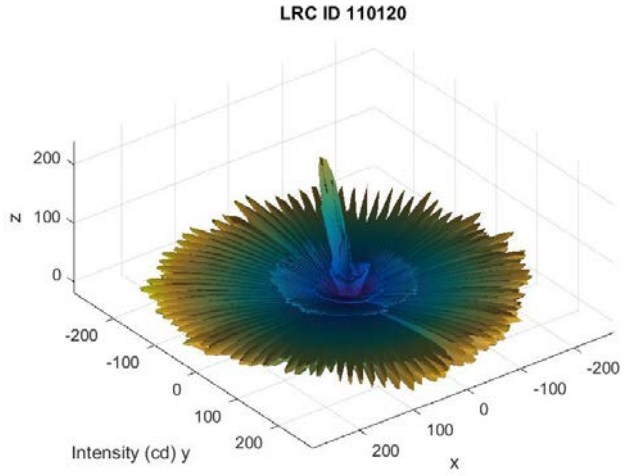


***Figure A14-1.*** *3D rendering of the intensity distribution of RE014-A (L-861 type) luminaire tested at 6.6 A d.c.*

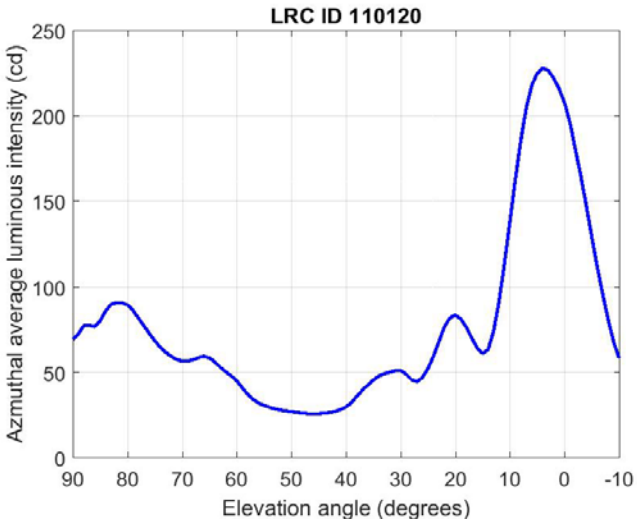


***Figure A14-2.*** *Azimuthal average intensity distribution of RE014-A (L-861 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

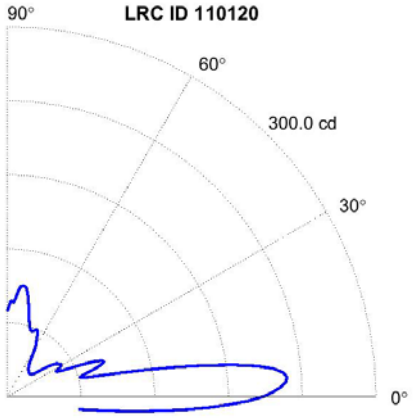


***Figure A14-3.*** *Azimuthal average intensity distribution of RE014-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A15 – Detailed testing results for sample RE015-A

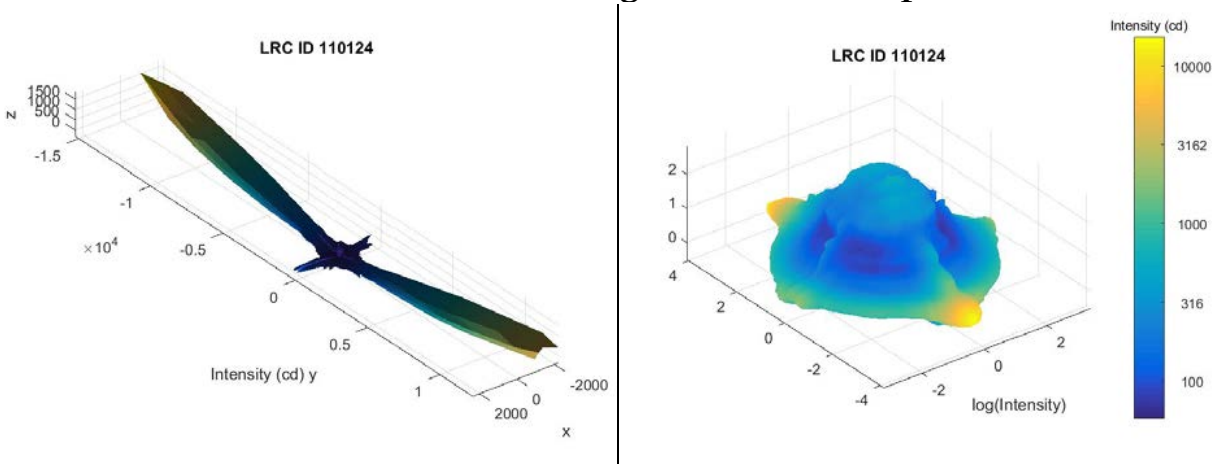


***Figure A15-1.*** *3D rendering of the intensity distribution of RE015-A (L-862 type) luminaire tested at 6.6 A d.c. in linear scale (left) and in logarithmic scale (right)*

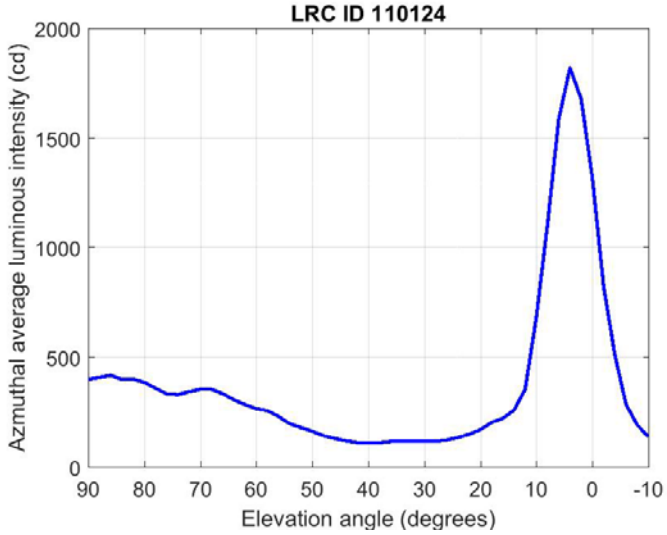


***Figure A15-2.*** *Azimuthal average intensity distribution of RE015-A (L-862 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

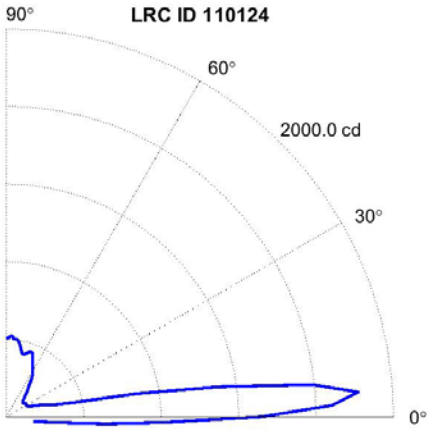


***Figure A15-3.*** *Azimuthal average intensity distribution of RE015-A (L-862 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section A16 – Detailed testing results for sample RE016-A

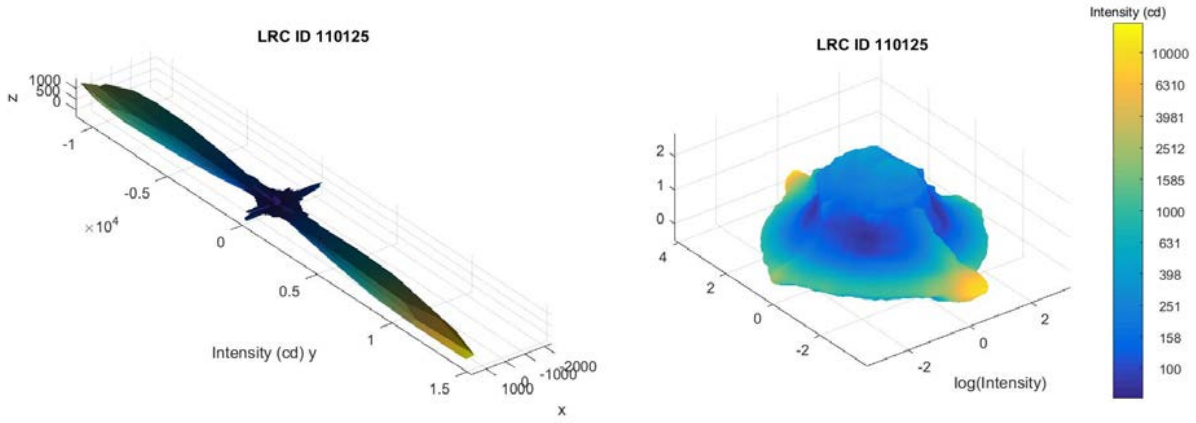


***Figure A16-1.*** *3D rendering of the intensity distribution of RE016-A (L-862 type) luminaire tested at 6.6 A d.c. in linear scale (left) and in logarithmic scale (right)*

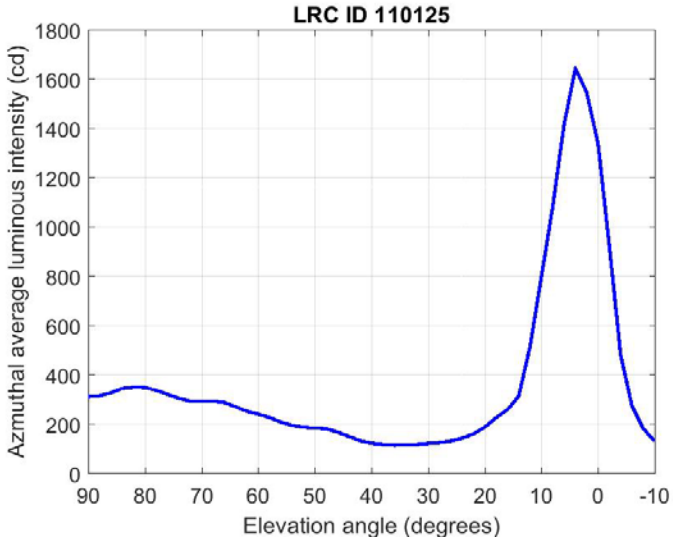


***Figure A16-2.*** *Azimuthal average intensity distribution of RE016-A (L-862 type) luminaire tested at 6.6 A d.c. in Cartesian coordinates*

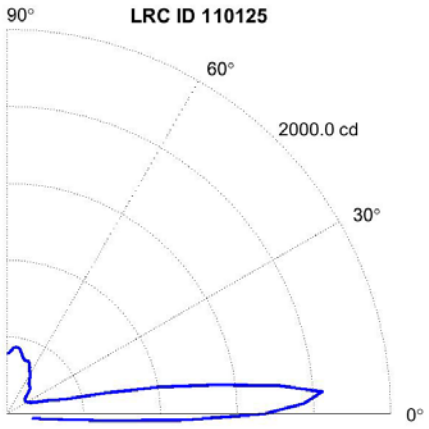


***Figure A16-3.*** *Azimuthal average intensity distribution of RE016-A (L-861 type) luminaire tested at 6.6 A d.c. in polar coordinates*

# Section B– Calculated luminous intensity at different step dim levels

**Table B1.** Summary of the calculated azimuthal average luminous intensity (cd) for every 5-degree zone from 0 to 90 degree elevation angle for all tested **L-861** luminaires operated at **5.5 A d.c.**

| FAA ID | RE001 -A | RE002 -A | RE003 -A | RE004 -A | RE005 -A | RE006 -A | RE007 -A | RE008 -A | RE011 -A | RE012- A | RE013- A | RE014 -A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LRC ID | 110116 | 110117 | 110119 | 110118 | 110127 | 110126 | 110128 | 110129 | 110121 | 110123 | 110122 | 110120 |
| Elevation angle range (degrees) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 57.6 | 51.5 | 49.0 | 47.5 | 60.8 | 32.6 | 70.2 | 36.8 | 31.0 | 28.4 | 83.8 | 65.4 |
| 5-10 | 89.3 | 74.5 | 66.7 | 80.2 | 55.0 | 30.5 | 63.2 | 32.0 | 35.1 | 31.8 | 90.6 | 65.1 |
| 10-15 | 71.5 | 54.9 | 55.0 | 75.0 | 26.5 | 13.4 | 26.9 | 12.2 | 17.1 | 15.4 | 40.5 | 33.8 |
| 15-20 | 26.4 | 24.1 | 27.3 | 26.9 | 19.6 | 10.1 | 20.9 | 12.1 | 8.6 | 8.0 | 17.3 | 16.4 |
| 20-25 | 31.4 | 26.7 | 28.5 | 29.6 | 20.4 | 10.7 | 22.0 | 11.4 | 6.0 | 6.0 | 12.7 | 11.8 |
| 25-30 | 23.9 | 18.4 | 18.6 | 22.4 | 13.2 | 7.0 | 13.0 | 7.6 | 5.6 | 5.4 | 11.5 | 12.2 |
| 30-35 | 21.2 | 15.2 | 16.2 | 19.8 | 13.8 | 7.3 | 14.8 | 8.6 | 5.3 | 5.7 | 13.1 | 12.2 |
| 35-40 | 17.9 | 12.4 | 13.4 | 15.3 | 10.9 | 5.8 | 14.9 | 5.9 | 4.7 | 4.9 | 12.0 | 9.5 |
| 40-45 | 13.0 | 8.9 | 9.4 | 11.5 | 7.6 | 4.2 | 9.8 | 4.8 | 3.9 | 3.9 | 10.1 | 7.7 |
| 45-50 | 12.2 | 7.9 | 8.3 | 10.9 | 7.2 | 4.0 | 8.6 | 4.6 | 3.5 | 3.6 | 8.1 | 7.2 |
| 50-55 | 12.7 | 8.1 | 8.7 | 10.8 | 7.8 | 4.5 | 9.0 | 4.8 | 3.2 | 3.3 | 7.2 | 6.8 |
| 55-60 | 13.9 | 9.9 | 9.9 | 12.1 | 9.7 | 5.3 | 10.5 | 5.9 | 3.4 | 3.2 | 6.9 | 6.8 |
| 60-65 | 17.0 | 12.7 | 12.9 | 15.0 | 14.0 | 8.0 | 14.6 | 8.8 | 4.4 | 4.2 | 8.1 | 9.3 |
| 65-70 | 18.8 | 15.5 | 15.8 | 17.0 | 16.1 | 9.2 | 18.6 | 9.3 | 6.3 | 5.9 | 12.4 | 13.4 |
| 70-75 | 18.3 | 16.6 | 16.1 | 16.0 | 16.6 | 8.9 | 19.3 | 9.2 | 6.6 | 6.8 | 13.3 | 15.0 |
| 75-80 | 23.2 | 20.3 | 21.4 | 17.7 | 21.4 | 9.0 | 24.3 | 11.1 | 6.5 | 6.9 | 13.2 | 16.5 |
| 80-85 | 27.4 | 29.2 | 30.2 | 24.1 | 24.7 | 9.0 | 34.2 | 11.2 | 8.6 | 10.4 | 22.9 | 22.2 |
| 85-90 | 28.9 | 34.7 | 33.4 | 26.2 | 21.2 | 9.4 | 43.9 | 9.8 | 11.5 | 15.8 | 51.4 | 32.1 |

**Table B2.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested **L-861** luminaires operated at **4.8 A d.c.**

| FAA ID | RE001-A | RE002-A | RE003-A | RE004-A | RE005-A | RE006-A | RE007-A | RE008-A | RE011-A | RE012-A | RE013-A | RE014-A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LRC ID | 110116 | 110117 | 110119 | 110118 | 110127 | 110126 | 110128 | 110129 | 110121 | 110123 | 110122 | 110120 |
| Elevation angle range (degrees) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 21.5 | 18.4 | 18.7 | 16.8 | 20.6 | 10.9 | 25.9 | 13.5 | 10.7 | 9.8 | 30.9 | 24.1 |
| 5-10 | 33.3 | 26.6 | 25.5 | 28.5 | 18.6 | 10.2 | 23.3 | 11.7 | 12.1 | 10.9 | 33.4 | 24.0 |
| 10-15 | 26.7 | 19.6 | 21.0 | 26.6 | 9.0 | 4.5 | 9.9 | 4.5 | 5.9 | 5.3 | 14.9 | 12.4 |
| 15-20 | 9.8 | 8.6 | 10.4 | 9.5 | 6.6 | 3.4 | 7.7 | 4.4 | 3.0 | 2.7 | 6.4 | 6.0 |
| 20-25 | 11.7 | 9.5 | 10.9 | 10.5 | 6.9 | 3.6 | 8.1 | 4.2 | 2.1 | 2.1 | 4.7 | 4.3 |
| 25-30 | 8.9 | 6.6 | 7.1 | 8.0 | 4.5 | 2.3 | 4.8 | 2.8 | 1.9 | 1.9 | 4.2 | 4.5 |
| 30-35 | 7.9 | 5.4 | 6.2 | 7.0 | 4.7 | 2.5 | 5.5 | 3.1 | 1.8 | 2.0 | 4.8 | 4.5 |
| 35-40 | 6.7 | 4.4 | 5.1 | 5.4 | 3.7 | 1.9 | 5.5 | 2.1 | 1.6 | 1.7 | 4.4 | 3.5 |
| 40-45 | 4.9 | 3.2 | 3.6 | 4.1 | 2.6 | 1.4 | 3.6 | 1.7 | 1.4 | 1.3 | 3.7 | 2.8 |
| 45-50 | 4.5 | 2.8 | 3.2 | 3.9 | 2.4 | 1.3 | 3.2 | 1.7 | 1.2 | 1.2 | 3.0 | 2.7 |
| 50-55 | 4.7 | 2.9 | 3.3 | 3.8 | 2.6 | 1.5 | 3.3 | 1.7 | 1.1 | 1.1 | 2.7 | 2.5 |
| 55-60 | 5.2 | 3.5 | 3.8 | 4.3 | 3.3 | 1.8 | 3.9 | 2.2 | 1.2 | 1.1 | 2.5 | 2.5 |
| 60-65 | 6.3 | 4.5 | 4.9 | 5.3 | 4.7 | 2.7 | 5.4 | 3.2 | 1.5 | 1.4 | 3.0 | 3.4 |
| 65-70 | 7.0 | 5.5 | 6.1 | 6.0 | 5.4 | 3.1 | 6.9 | 3.4 | 2.2 | 2.0 | 4.6 | 4.9 |
| 70-75 | 6.8 | 5.9 | 6.2 | 5.7 | 5.6 | 3.0 | 7.1 | 3.4 | 2.3 | 2.3 | 4.9 | 5.5 |
| 75-80 | 8.6 | 7.2 | 8.2 | 6.3 | 7.2 | 3.0 | 9.0 | 4.1 | 2.2 | 2.4 | 4.9 | 6.1 |
| 80-85 | 10.2 | 10.4 | 11.6 | 8.5 | 8.4 | 3.0 | 12.6 | 4.1 | 3.0 | 3.6 | 8.4 | 8.2 |
| 85-90 | 10.8 | 12.4 | 12.8 | 9.3 | 7.2 | 3.1 | 16.2 | 3.6 | 4.0 | 5.4 | 19.0 | 11.8 |

**Table B3.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested **L-862** luminaires operated at **5.2 A d.c.**

| FAA ID | RE009-A | RE010-A | RE015-A | RE016-A |
|---|---|---|---|---|
| LRC ID | 110131 | 110130 | 110124 | 110125 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 573 | 543 | 553 | 507 |
| 5-10 | 481 | 449 | 333 | 471 |
| 10-15 | 155 | 195 | 114 | 138 |
| 15-20 | 76 | 88 | 67 | 69 |
| 20-25 | 55 | 59 | 48 | 50 |
| 25-30 | 44 | 47 | 38 | 38 |
| 30-35 | 43 | 43 | 37 | 36 |
| 35-40 | 41 | 42 | 36 | 34 |
| 40-45 | 41 | 49 | 40 | 38 |
| 45-50 | 49 | 63 | 48 | 45 |
| 50-55 | 65 | 68 | 58 | 53 |
| 55-60 | 88 | 79 | 62 | 63 |
| 60-65 | 103 | 92 | 69 | 68 |
| 65-70 | 123 | 105 | 77 | 82 |
| 70-75 | 123 | 107 | 89 | 100 |
| 75-80 | 124 | 119 | 110 | 118 |
| 80-85 | 142 | 126 | 121 | 122 |
| 85-90 | 148 | 116 | 81 | 81 |

**Table B4.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested **L-862** luminaires operated at **4.1 A d.c.**

| FAA ID | RE009-A | RE010-A | RE015-A | RE016-A |
|---|---|---|---|---|
| LRC ID | 110131 | 110130 | 110124 | 110125 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 244 | 232 | 236 | 217 |
| 5-10 | 205 | 192 | 142 | 202 |
| 10-15 | 66 | 83 | 49 | 59 |
| 15-20 | 33 | 37 | 29 | 30 |
| 20-25 | 23 | 25 | 21 | 21 |
| 25-30 | 19 | 20 | 16 | 16 |
| 30-35 | 18 | 18 | 16 | 15 |
| 35-40 | 18 | 18 | 15 | 14 |
| 40-45 | 18 | 21 | 17 | 16 |
| 45-50 | 21 | 27 | 21 | 19 |
| 50-55 | 28 | 29 | 25 | 23 |
| 55-60 | 37 | 34 | 26 | 27 |
| 60-65 | 44 | 39 | 29 | 29 |
| 65-70 | 53 | 45 | 33 | 35 |
| 70-75 | 52 | 46 | 38 | 43 |
| 75-80 | 53 | 51 | 47 | 50 |
| 80-85 | 60 | 54 | 51 | 52 |
| 85-90 | 63 | 50 | 35 | 35 |

**Table B5.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested **L-862** luminaires operated at **3.4 A d.c.**

| FAA ID | RE009-A | RE010-A | RE015-A | RE016-A |
|---|---|---|---|---|
| LRC ID | 110131 | 110130 | 110124 | 110125 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 19.0 | 18.1 | 18.1 | 16.8 |
| 5-10 | 15.9 | 15.0 | 10.9 | 15.7 |
| 10-15 | 5.1 | 6.5 | 3.7 | 4.6 |
| 15-20 | 2.5 | 2.9 | 2.2 | 2.3 |
| 20-25 | 1.8 | 2.0 | 1.6 | 1.7 |
| 25-30 | 1.4 | 1.6 | 1.3 | 1.3 |
| 30-35 | 1.4 | 1.4 | 1.2 | 1.2 |
| 35-40 | 1.4 | 1.4 | 1.2 | 1.1 |
| 40-45 | 1.4 | 1.6 | 1.3 | 1.3 |
| 45-50 | 1.6 | 2.1 | 1.6 | 1.5 |
| 50-55 | 2.1 | 2.3 | 1.9 | 1.8 |
| 55-60 | 2.9 | 2.6 | 2.0 | 2.1 |
| 60-65 | 3.4 | 3.1 | 2.3 | 2.2 |
| 65-70 | 4.1 | 3.5 | 2.5 | 2.7 |
| 70-75 | 4.1 | 3.6 | 2.9 | 3.3 |
| 75-80 | 4.1 | 4.0 | 3.6 | 3.9 |
| 80-85 | 4.7 | 4.2 | 3.9 | 4.1 |
| 85-90 | 4.9 | 3.9 | 2.6 | 2.7 |

**Table B6.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested **L-862** luminaires operated at **2.8 A d.c.**

| FAA ID | RE009-A | RE010-A | RE015-A | RE016-A |
|---|---|---|---|---|
| LRC ID | 110131 | 110130 | 110124 | 110125 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 3.3 | 3.1 | 3.0 | 2.8 |
| 5-10 | 2.8 | 2.6 | 1.8 | 2.6 |
| 10-15 | 0.9 | 1.1 | 0.6 | 0.8 |
| 15-20 | 0.4 | 0.5 | 0.4 | 0.4 |
| 20-25 | 0.3 | 0.3 | 0.3 | 0.3 |
| 25-30 | 0.3 | 0.3 | 0.2 | 0.2 |
| 30-35 | 0.2 | 0.2 | 0.2 | 0.2 |
| 35-40 | 0.2 | 0.2 | 0.2 | 0.2 |
| 40-45 | 0.2 | 0.3 | 0.2 | 0.2 |
| 45-50 | 0.3 | 0.4 | 0.3 | 0.3 |
| 50-55 | 0.4 | 0.4 | 0.3 | 0.3 |
| 55-60 | 0.5 | 0.5 | 0.3 | 0.4 |
| 60-65 | 0.6 | 0.5 | 0.4 | 0.4 |
| 65-70 | 0.7 | 0.6 | 0.4 | 0.5 |
| 70-75 | 0.7 | 0.6 | 0.5 | 0.6 |
| 75-80 | 0.7 | 0.7 | 0.6 | 0.7 |
| 80-85 | 0.8 | 0.7 | 0.7 | 0.7 |
| 85-90 | 0.8 | 0.7 | 0.4 | 0.5 |

# APPENDIX B—RESEARCH STUDY ON HIGH- AND MEDIUM-INTENSITY RUNWAY EDGE LIGHT OUTPUT, ROUND 2

Note: The following research study was prepared by the Rensselaer Polytechnic Institute. The study is presented unedited and in its entirety.

Prepared by: Lighting Research Center,[3] Rensselaer Polytechnic Institute
for the Federal Aviation Administration, Cooperative Agreement 16-G-019
*Revised July 13, 2017*

## Round 2

This report summarizes the procedures and the results of the tests for products in the second round of testing. Table 1 lists the products tested in Round 2.

**Table 1.** Information of luminaires tested, including luminaire manufacturer, type, part number, lamp type and lamp model number

| FAA ID | LRC ID | Luminaire and lamp information | | | | |
|---|---|---|---|---|---|---|
| | | Manufacturer | Luminaire Type | Luminaire P/N | Lamp Type | Lamp Model No. |
| RE017A | 110132 | Manufacturer D | L-862 | 44A2071/1011 | Halogen; 6.6A, 120W | GE EVV 6.6A 120W |
| RE018A | 110134 | Manufacturer D | L-862 | 44A2071/2011 | Halogen; 6.6A, 150W | GE EWR 6.6A 150W |
| RE019A | 110133 | Manufacturer D | L-862 | 44A2071/1011 | Halogen; 6.6A, 120W | GE EVV 6.6A 120W |
| RE020A | 110135 | Manufacturer D | L-862 | 44A2071/2011 | Halogen; 6.6A, 150W | GE EWR 6.6A 150W |
| RE021A | 110136 | Manufacturer D | L-861 | 44C1081/6111 | Halogen; 6.6A, 45W | Osram EXM 64320 6.6A 45W |
| RE022A | 110137 | Manufacturer D | L-861 | 44C1081/6111 | Halogen; 6.6A, 45W | Osram EXM 64320 6.6A 45W |
| RE023A | 110138 | Manufacturer D | L-861 | 44C1081/2111 | Incandescent; 6.6A, 45W | Narva 7654C 6.6A 45W |
| RE024A | 110139 | Manufacturer D | L-861 | 44C1081/2111 | Incandescent; 6.6A, 45W | Narva 7654C 6.6A 45W |
| RE025A | 110140 | Manufacturer E | L-861 | 216 | Incandescent; 6.6A, 30W | GE Airport J6C 6.6A 30W |
| RE026A | 110141 | Manufacturer E | L-861 | 216 | Incandescent; 6.6A, 30W | GE Airport J6C 6.6A 30W |
| RE027A | 110142 | Manufacturer E | L-861 | 216Q | Halogen; 6.6A, 45W | GE EXM 6.6A 45W |
| RE028A | 110143 | Manufacturer E | L-861 | 216Q | Halogen; 6.6A, 45W | GE EXM 6.6A 45W |
| RE029A | 110144 | Manufacturer E | L-862 | 213Q | Halogen; 6.6A, 150W | GE EWR 6.6A 150W |
| RE030A | 110145 | Manufacturer E | L-862 | 213Q | Halogen; 6.6A, 150W | GE EWR 6.6A 150W |
| RE031A | 110146 | Manufacturer E | L-862 | 213Q | Halogen; 6.6A, 120W | GE EVV 6.6A 120W |
| RE032A | 110147 | Manufacturer E | L-862 | 213Q | Halogen; 6.6A, 120W | GE EVV 6.6A 120W |
| RE036A | 110151 | Manufacturer C | L-861 | 861-L-W-14 | LED | |
| RE037A | 110152 | Manufacturer F | L-861 | 7000 Series | Halogen; 6.6A, 45W | Osram EXM 64320 6.6A 45W |
| RE038A | 110153 | Manufacturer F | L-861 | 7000 Series | Halogen; 6.6A, 45W | Osram EXM 64320 6.6A 45W |

[3] LRC testing team: M. Overington, Y. Zhu, and A. Bierman. Principal Investigator: N. Narendran.

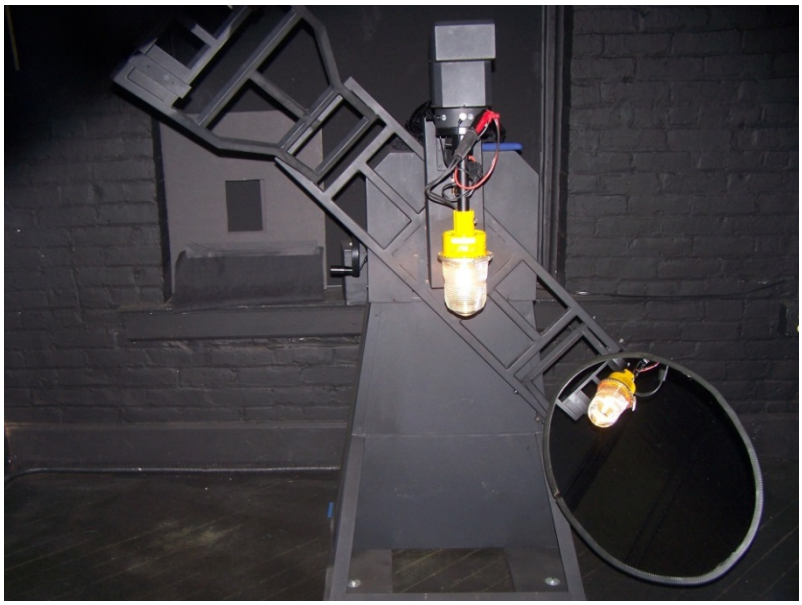

***Figure 1.*** *View of a luminaire under test mounted on the type-C mirror goniophotometer. The geometric center of the luminaire was used as reference for alignment.*

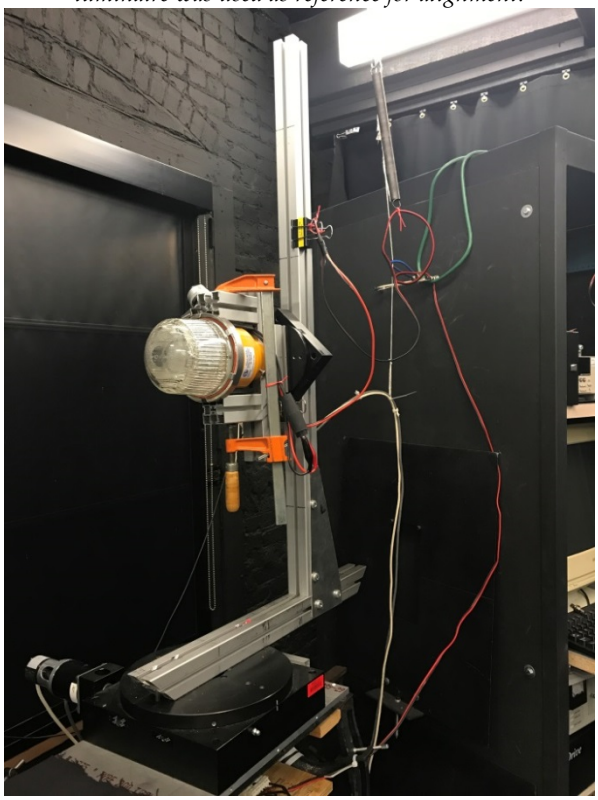

***Figure 2.*** *View of a luminaire under test mounted on the bar-photometer. The geometric center of the glass light-emitting part of the luminaire was used as reference for alignment.*

## Test results

Individual plots for every luminaire tested are shown in the Sections C1 to C19. Figure 3 and Figure 4 depict in Cartesian coordinates the range of intensities measured for all 30

W and 45 W L-861 type luminaires tested at 6.6 A dc, respectively. Figure 5 shows the same for all L-862 type luminaires (including 120 W and 150 W) tested at 6.6 A dc
Tables 2 and 3 list the azimuthal average intensity (in cd) over the range of elevation angles from 0 to 90 degrees in 5-degree increments for the L-861 and L-862 luminaires tested at 6.6 A dc, respectively. Table 4 lists the calculated scaling factors when operated at different step dim levels (three levels for L-861 type: 6.6 A, 5.5 A, and 4.8 A; five levels for L-862 type: 6.6 A, 5.2 A, 4.1 A, 3.4 A, and 2.8 A) based on luminous intensity measured at nadir (0°, 0°). Section D lists individual tables of the azimuthal average intensity (in cd) over the range of elevation angles from 0 to 90 degrees in 5-degree increments for the L-861 and L-862 luminaires at different step dim levels after multiplying the corresponding scaling factors from Table 4.

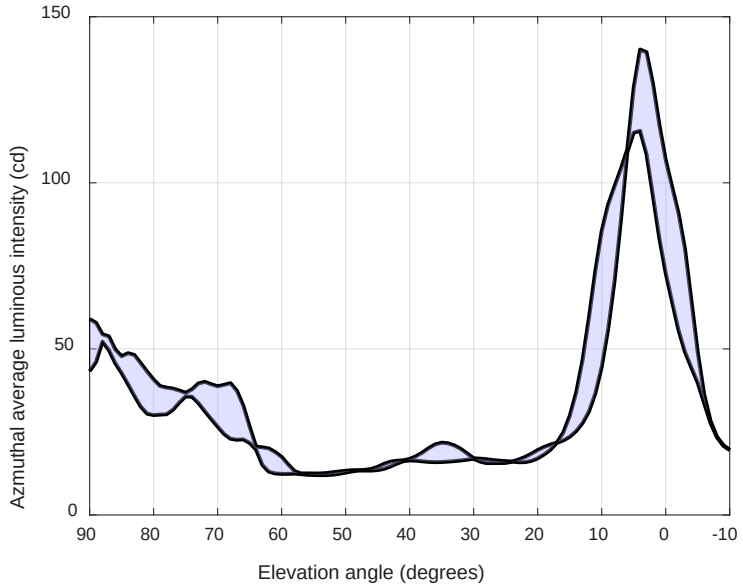


***Figure 3.*** *Range of intensity distributions of all 30-Watt incandescent L-861 type luminaires tested at 6.6 A dc in Cartesian coordinates*

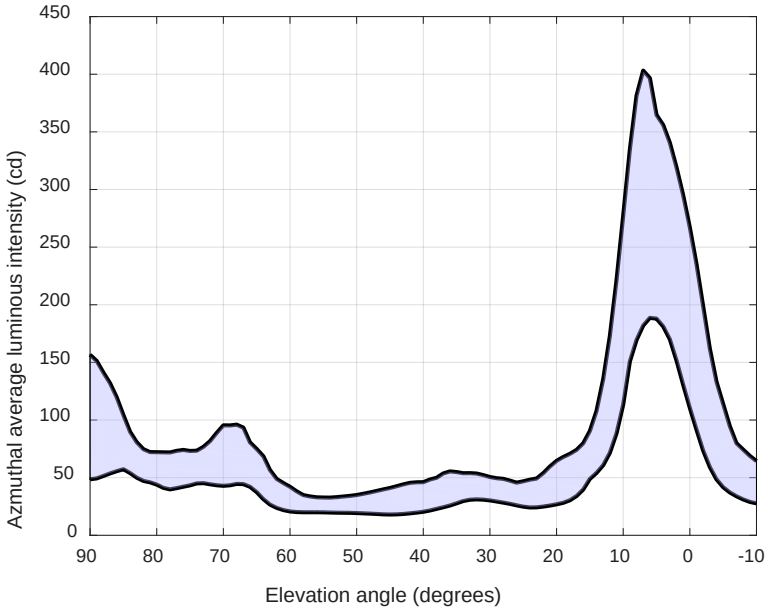


***Figure 4.*** *Range of intensity distributions of all 45-Watt incandescent L-861 type luminaires tested at 6.6 A dc in Cartesian coordinates*

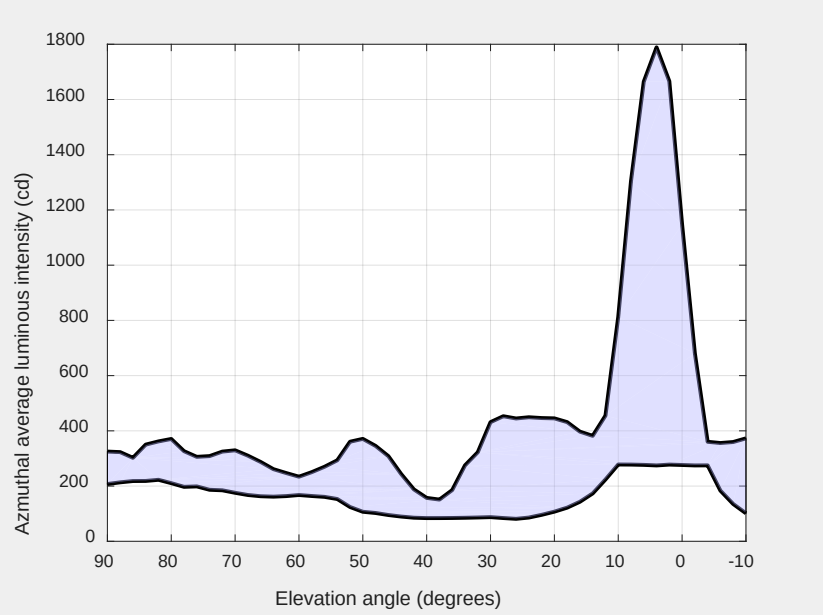


***Figure 5.*** *Range of intensity distributions of all L-862 type luminaires tested at 6.6 A dc in Cartesian coordinates*

**Table 2.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested L-861 luminaires tested at 6.6 A dc

| FAA ID | RE021A | RE022A | RE023A | RE024A | RE025A | RE026A | RE027A | RE028A | RE036A | RE037A | RE038A |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LRC ID | 110136 | 110137 | 110138 | 110139 | 110140 | 110141 | 110142 | 110143 | 110151 | 110152 | 110153 |
| Elevation angle range (degrees) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 245.5 | 256.4 | 156.8 | 153.4 | 126.8 | 95.3 | 249.0 | 278.9 | 167.0 | 315.6 | 267.7 |
| 5-10 | 281.1 | 376.1 | 176.0 | 230.8 | 90.6 | 104.4 | 236.0 | 241.1 | 138.3 | 313.1 | 245.8 |
| 10-15 | 153.4 | 183.0 | 95.1 | 115.4 | 33.0 | 60.3 | 96.1 | 77.7 | 105.0 | 118.8 | 123.3 |
| 15-20 | 68.7 | 76.6 | 41.7 | 36.3 | 21.9 | 22.8 | 55.3 | 48.6 | 74.7 | 59.3 | 64.5 |
| 20-25 | 47.8 | 54.3 | 30.2 | 25.2 | 17.6 | 16.2 | 40.5 | 45.7 | 55.5 | 50.1 | 50.7 |
| 25-30 | 45.6 | 46.9 | 27.7 | 27.3 | 15.7 | 16.6 | 33.1 | 38.5 | 39.4 | 45.1 | 43.5 |
| 30-35 | 51.2 | 52.8 | 31.3 | 30.6 | 19.6 | 16.5 | 36.6 | 42.2 | 16.8 | 46.0 | 43.8 |
| 35-40 | 47.4 | 52.0 | 28.1 | 24.5 | 19.9 | 16.1 | 37.8 | 42.6 | 7.4 | 48.8 | 45.3 |
| 40-45 | 36.5 | 41.1 | 21.8 | 19.2 | 15.4 | 16.1 | 29.9 | 35.0 | 6.9 | 42.3 | 44.8 |
| 45-50 | 33.5 | 36.2 | 21.2 | 18.5 | 13.4 | 13.7 | 25.6 | 32.9 | 7.1 | 36.4 | 38.5 |
| 50-55 | 30.9 | 32.1 | 21.1 | 19.6 | 12.9 | 12.3 | 23.1 | 30.3 | 7.5 | 33.2 | 33.7 |
| 55-60 | 30.7 | 33.9 | 20.9 | 20.0 | 12.5 | 13.0 | 21.9 | 29.1 | 7.9 | 33.8 | 34.4 |
| 60-65 | 48.5 | 43.0 | 25.2 | 25.1 | 14.5 | 19.5 | 26.3 | 35.6 | 8.4 | 49.0 | 47.4 |
| 65-70 | 83.5 | 84.7 | 47.1 | 44.9 | 35.2 | 22.9 | 42.4 | 50.0 | 8.8 | 71.2 | 54.9 |
| 70-75 | 83.2 | 74.5 | 53.1 | 47.6 | 39.1 | 31.2 | 44.4 | 54.2 | 8.7 | 74.7 | 56.4 |
| 75-80 | 65.9 | 53.2 | 45.3 | 41.5 | 32.4 | 37.9 | 49.4 | 56.0 | 8.5 | 72.9 | 51.5 |
| 80-85 | 63.0 | 53.3 | 55.0 | 48.2 | 33.7 | 45.3 | 71.0 | 62.9 | 8.5 | 77.5 | 54.0 |
| 85-90 | 94.1 | 76.5 | 80.1 | 68.5 | 50.1 | 49.9 | 129.6 | 90.7 | 8.7 | 114.3 | 53.5 |

**Table 3.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested L-862 luminaires tested at 6.6 A dc

| FAA ID | RE017A | RE018A | RE019A | RE020A | RE029A | RE030A | RE031A | RE032A |
|---|---|---|---|---|---|---|---|---|
| LRC ID | 110132 | 110134 | 110133 | 110135 | 110144 | 110145 | 110146 | 110147 |
| Elevation angle range (degrees) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 288.1 | 330.0 | 276.3 | 365.2 | 1534.1 | 1352.4 | 1335.9 | 1257.1 |
| 5-10 | 290.9 | 338.0 | 277.3 | 373.6 | 1210.8 | 1484.6 | 997.9 | 963.9 |
| 10-15 | 299.6 | 344.7 | 288.0 | 376.3 | 322.4 | 510.3 | 247.6 | 246.2 |
| 15-20 | 337.3 | 379.2 | 324.0 | 414.3 | 161.9 | 191.7 | 132.5 | 136.3 |
| 20-25 | 357.5 | 405.9 | 345.9 | 446.9 | 119.1 | 127.8 | 96.5 | 97.2 |
| 25-30 | 356.6 | 417.6 | 340.4 | 448.9 | 102.7 | 105.4 | 83.6 | 82.8 |
| 30-35 | 246.7 | 276.1 | 226.9 | 342.9 | 105.1 | 106.6 | 87.9 | 86.4 |
| 35-40 | 126.1 | 163.2 | 117.8 | 168.2 | 106.7 | 106.5 | 86.1 | 84.3 |
| 40-45 | 137.0 | 196.0 | 141.9 | 194.9 | 112.5 | 111.2 | 91.2 | 86.4 |
| 45-50 | 237.7 | 326.9 | 218.7 | 316.6 | 135.1 | 132.0 | 110.8 | 98.9 |
| 50-55 | 260.9 | 340.2 | 233.5 | 326.0 | 187.2 | 181.9 | 148.7 | 128.1 |
| 55-60 | 188.9 | 220.2 | 209.0 | 260.1 | 197.9 | 212.0 | 169.4 | 162.5 |
| 60-65 | 164.4 | 201.2 | 202.2 | 222.1 | 239.3 | 245.3 | 196.8 | 183.0 |
| 65-70 | 165.4 | 223.7 | 196.2 | 207.1 | 285.9 | 298.7 | 235.3 | 228.9 |
| 70-75 | 191.8 | 256.1 | 186.8 | 204.2 | 291.5 | 321.0 | 242.3 | 249.1 |
| 75-80 | 248.5 | 298.2 | 198.0 | 223.6 | 286.4 | 316.1 | 251.5 | 275.2 |
| 80-85 | 276.2 | 278.1 | 217.3 | 263.5 | 313.9 | 360.8 | 283.7 | 334.8 |
| 85-90 | 265.8 | 252.4 | 215.9 | 311.9 | 235.5 | 293.5 | 254.8 | 300.6 |

**Table 4.** Calculated scaling factors when operated at different step dim levels (three levels for L-861 type: 6.6A, 5.5A and 4.8A; five levels for L-862 type: 6.6A, 5.2A, 4.1A, 3.4A and 2.8A) based on luminous intensity measured at nadir (0°, 0°)

| FAA ID | LRC ID | Manufacturer | Luminaire Type | Luminaire P/N | Scaling factor | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | For L-862 type | | | | |
| | | | | | 6.6 A | 5.2 A | 4.1 A | 3.4 A | 2.8 A |
| | | | | | For L-861 type | | | | |
| | | | | | 6.6 A | 5.5 A | 4.8 A | | |
| RE017A | 110132 | Manufacturer D | L-862 | 44A2071/1011 | 100% | 25% | 5% | 1.1% | 0.2% |
| RE018A | 110134 | Manufacturer D | L-862 | 44A2071/1011 | 100% | 25% | 5% | 1.1% | 0.2% |
| RE019A | 110133 | Manufacturer D | L-862 | 44A2071/2011 | 100% | 25% | 5% | 1.1% | 0.2% |
| RE020A | 110135 | Manufacturer D | L-862 | 44A2071/2011 | 100% | 25% | 5% | 1.1% | 0.2% |
| RE021A | 110136 | Manufacturer D | L-861 | 44C1081/6111 | 100% | 32% | 12% | n/a | n/a |
| RE022A | 110137 | Manufacturer D | L-861 | 44C1081/6111 | 100% | 32% | 12% | n/a | n/a |
| RE023A | 110138 | Manufacturer D | L-861 | 44C1081/2111 | 100% | 29% | 10% | n/a | n/a |
| RE024A | 110139 | Manufacturer D | L-861 | 44C1081/2111 | 100% | 29% | 9% | n/a | n/a |
| RE025A | 110140 | Manufacturer E | L-861 | 216 | 100% | 26% | 8% | n/a | n/a |
| RE026A | 110141 | Manufacturer E | L-861 | 216 | 100% | 25% | 7% | n/a | n/a |
| RE027A | 110142 | Manufacturer E | L-861 | 216Q | 100% | 31% | 11% | n/a | n/a |
| RE028A | 110143 | Manufacturer E | L-861 | 216Q | 100% | 31% | 11% | n/a | n/a |
| RE029A | 110144 | Manufacturer E | L-862 | 213Q | 100% | 25% | 5% | 1.2% | 0.2% |
| RE030A | 110145 | Manufacturer E | L-862 | 213Q | 100% | 25% | 5% | 1.1% | 0.2% |
| RE031A | 110146 | Manufacturer E | L-862 | 213Q | 100% | 25% | 5% | 1.1% | 0.2% |
| RE032A | 110147 | Manufacturer E | L-862 | 213Q | 100% | 25% | 5% | 1.1% | 0.2% |
| RE036A | 110151 | Manufacturer C | L-861 | 861-L-W-14 | 100% | 33% | 13% | n/a | n/a |
| RE037A | 110152 | Manufacturer F | L-861 | 7000 Series | 100% | 38% | 14% | n/a | n/a |
| RE038A | 110153 | Manufacturer F | L-861 | 7000 Series | 100% | 31% | 12% | n/a | n/a |

**References**

Illuminating Engineering Society. 2012. IES LM-54-12: *IES Guide to Lamp Seasoning.* New York, NY: Illuminating Engineering Society.

Illuminating Engineering Society. 1989. IES LM-35-89: *IES Approved Method for Photometric Testing of Floodlights Using Incandescent Filament or Discharge Lamps.* New York, NY: Illuminating Engineering Society.

U.S. Department of Transportation, Federal Aviation Administration. 2016. Advisory Circular: Specification for Runway and Taxiway Light Fixtures, AC 150/5345-46E.

U.S. Department of Transportation, Federal Aviation Administration. 2016. Advisory Circular: Airport Lighting Equipment Certification Program, Appendix 1 Third Party Certification Bodies, Addendum dated March 24, 2016, AC 150/5345-46E.

# Section C1 – Detailed testing results for sample RE017-A

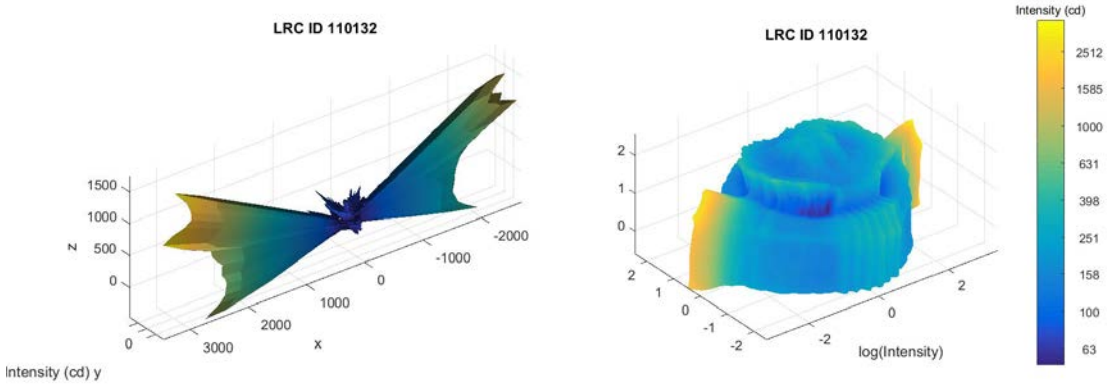


***Figure C1-1.*** *3D rendering of the intensity distribution of RE017-A (L-862 type) luminaire tested at 6.6 A dc in linear scale (left) and in logarithmic scale (right)*

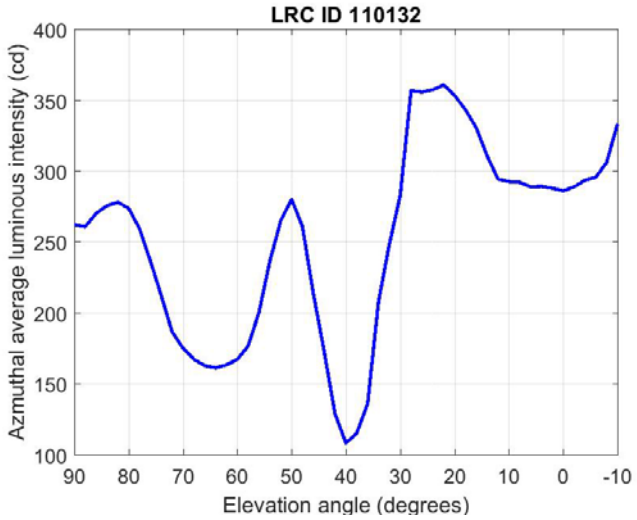


***Figure C1-2.*** *Azimuthal average intensity distribution of RE017-A (L-862 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

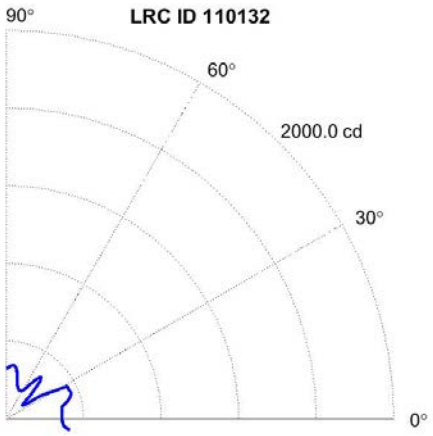


***Figure C1-3.*** *Azimuthal average intensity distribution of RE017-A (L-862 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C2 – Detailed testing results for sample RE018-A

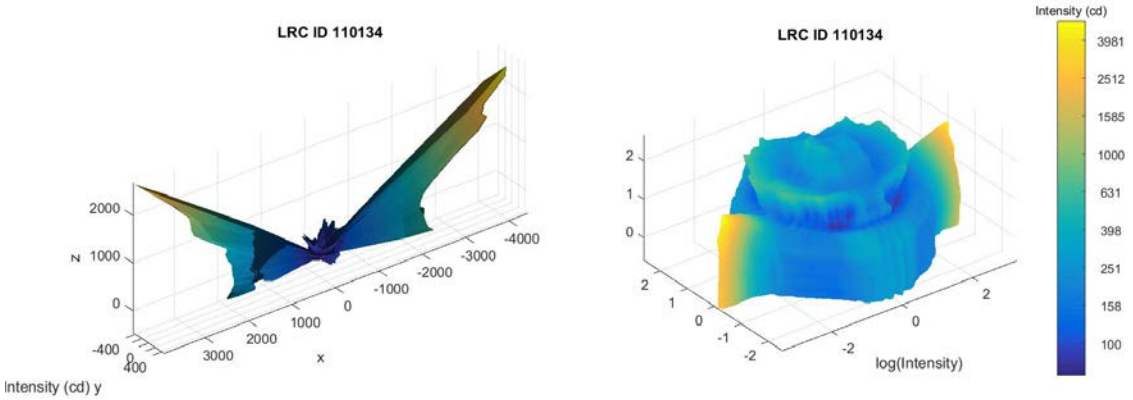


***Figure C2-1.*** *3D rendering of the intensity distribution of RE018-A (L-862 type) luminaire tested at 6.6 A dc in linear scale (left) and in logarithmic scale (right)*

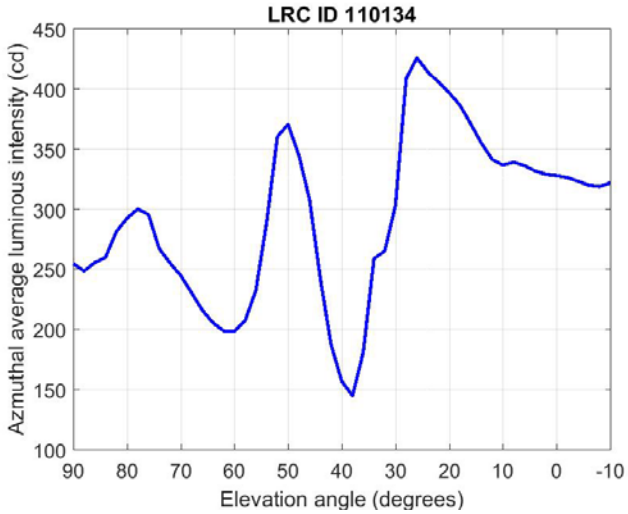


***Figure C2-2.*** *Azimuthal average intensity distribution of RE018-A (L-862 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

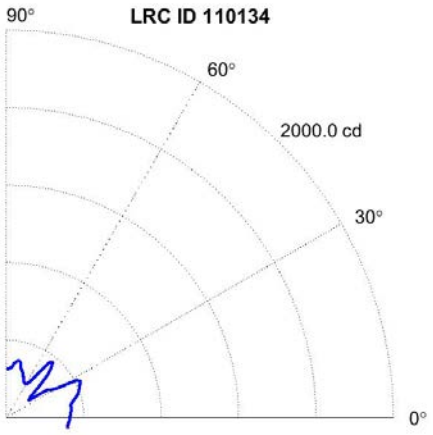


***Figure C2-3.*** *Azimuthal average intensity distribution of RE018-A (L-862 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C3 – Detailed testing results for sample RE019-A

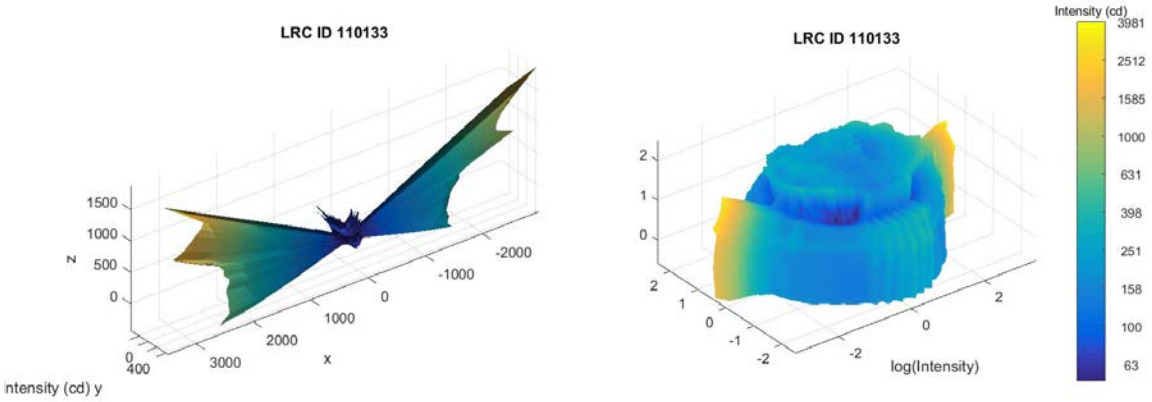


***Figure C3-1.*** *3D rendering of the intensity distribution of RE019-A (L-862 type) luminaire tested at 6.6 A dc in linear scale (left) and in logarithmic scale (right)*

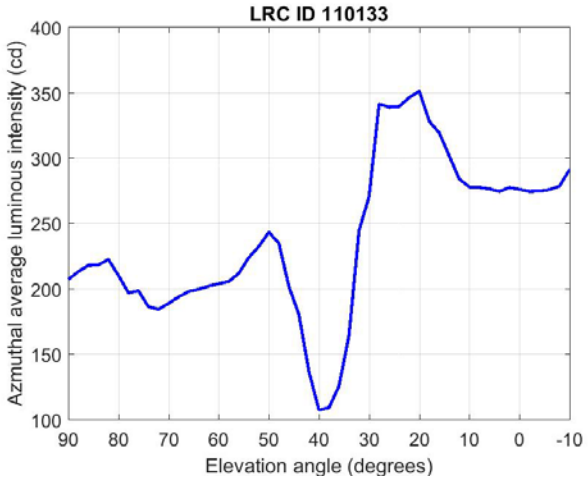


***Figure C3-2.*** *Azimuthal average intensity distribution of RE019-A (L-862 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

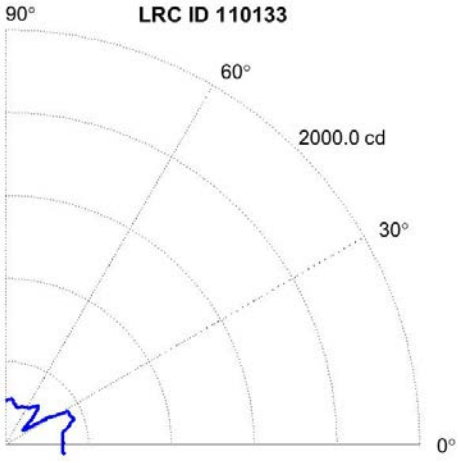


***Figure C3-3.*** *Azimuthal average intensity distribution of RE019-A (L-862 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C4 – Detailed testing results for sample RE020-A

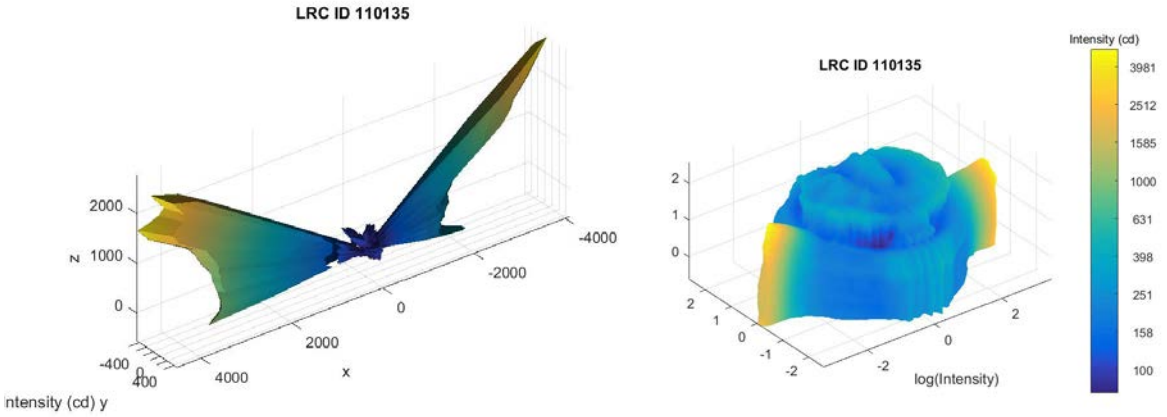


***Figure C4-1.*** *3D rendering of the intensity distribution of RE020-A (L-862 type) luminaire tested at 6.6 A dc in linear scale (left) and in logarithmic scale (right)*

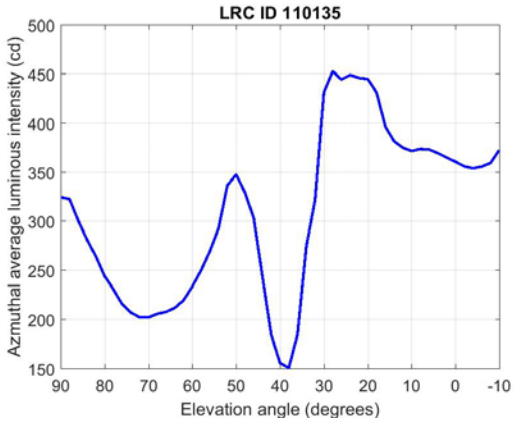


***Figure C4-2.*** *Azimuthal average intensity distribution of RE020-A (L-862 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

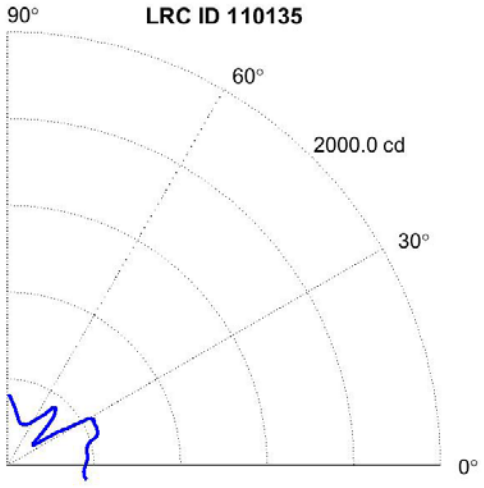


***Figure C4-3.*** *Azimuthal average intensity distribution of RE020-A (L-862 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C5 – Detailed testing results for sample RE021-A

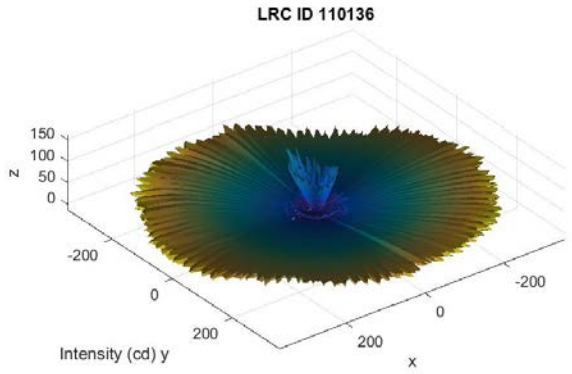


***Figure C5-1.*** *3D rendering of the intensity distribution of RE021-A (L-861 type) luminaire tested at 6.6 A dc*

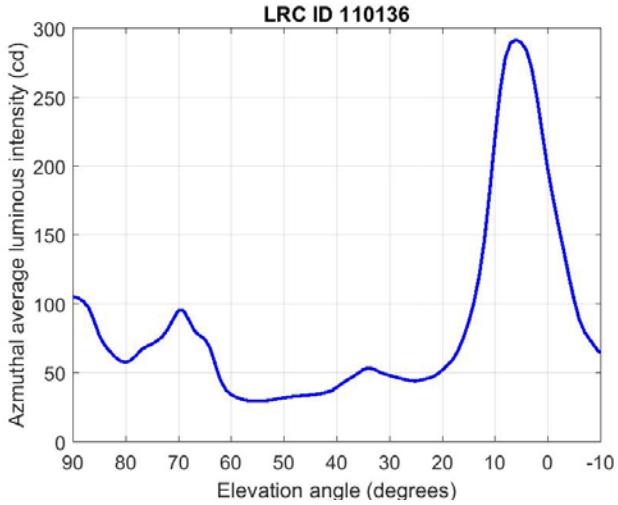


***Figure C5-2.*** *Azimuthal average intensity distribution of RE021-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

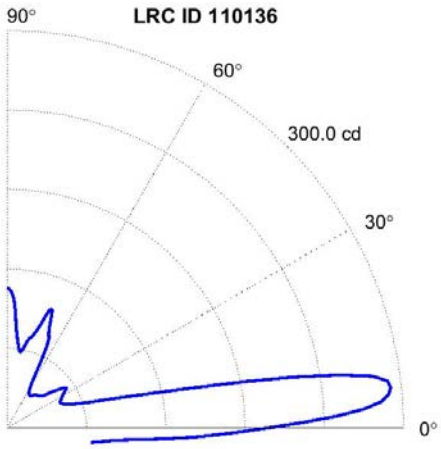


***Figure C5-3.*** *Azimuthal average intensity distribution of RE021-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C6 – Detailed testing results for sample RE022-A

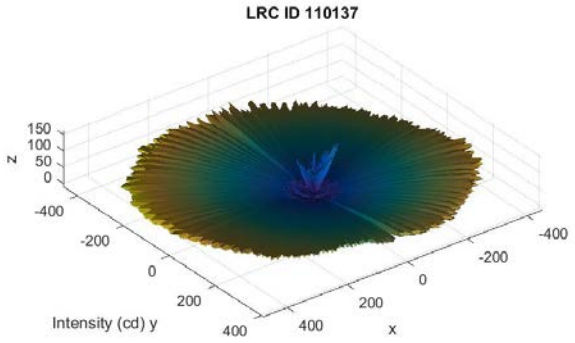


***Figure C6-1.*** *3D rendering of the intensity distribution of RE022-A (L-861 type) luminaire tested at 6.6 A dc*

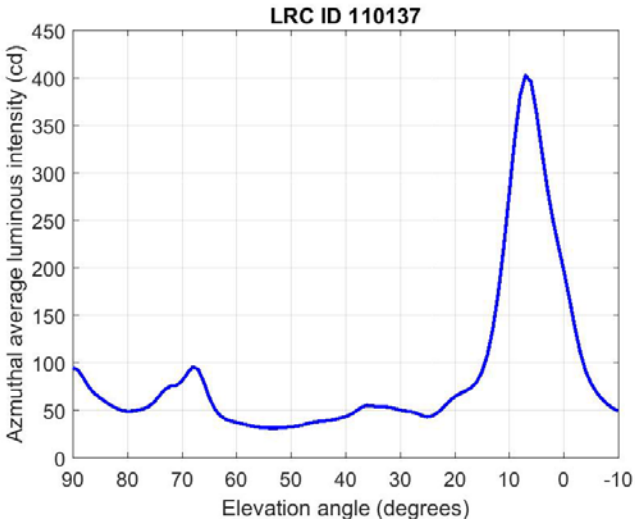


***Figure C6-2.*** *Azimuthal average intensity distribution of RE022-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

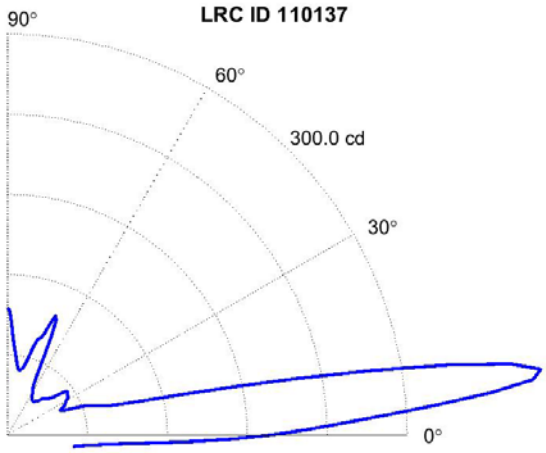


***Figure C6-3.*** *Azimuthal average intensity distribution of RE022-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C7 – Detailed testing results for sample RE023-A

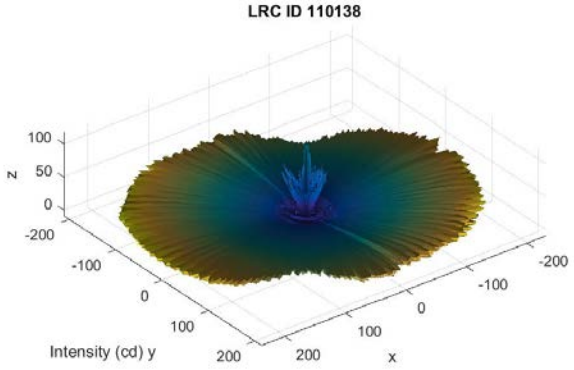


***Figure C7-1.*** *3D rendering of the intensity distribution of RE023-A (L-861 type) luminaire tested at 6.6 A dc*

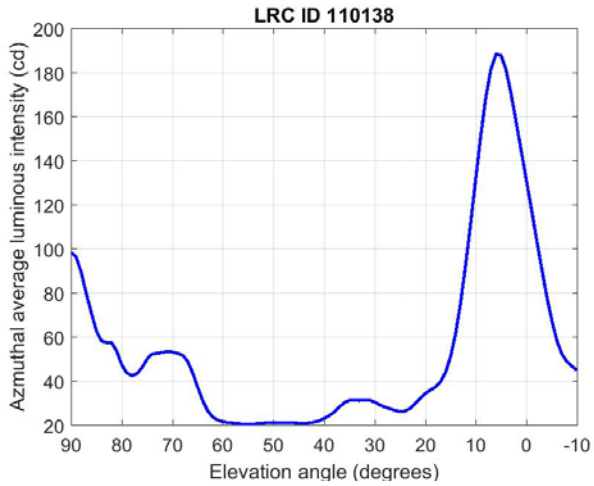


***Figure C7-2.*** *Azimuthal average intensity distribution of RE023-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

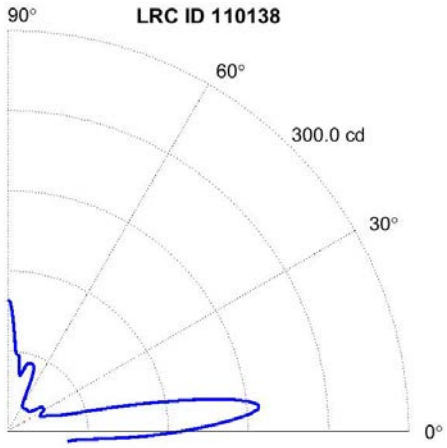


***Figure C7-3.*** *Azimuthal average intensity distribution of RE023-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C8 – Detailed testing results for sample RE024-A

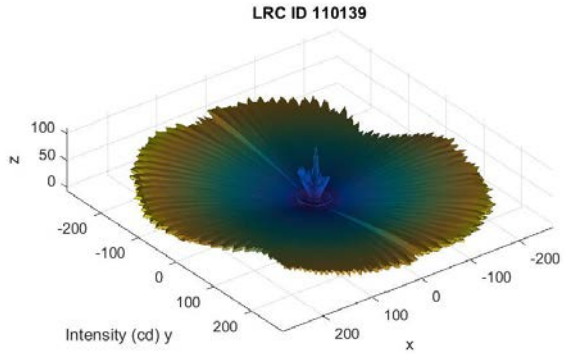


***Figure C8-1.*** *3D rendering of the intensity distribution of RE024-A (L-861 type) luminaire tested at 6.6 A dc*

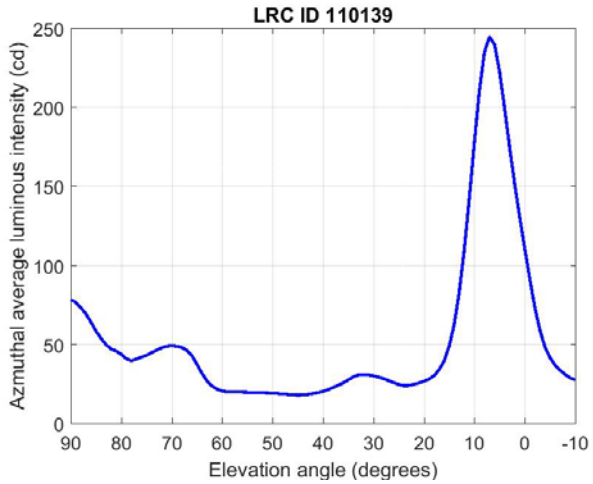


***Figure C8-2.*** *Azimuthal average intensity distribution of RE024-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

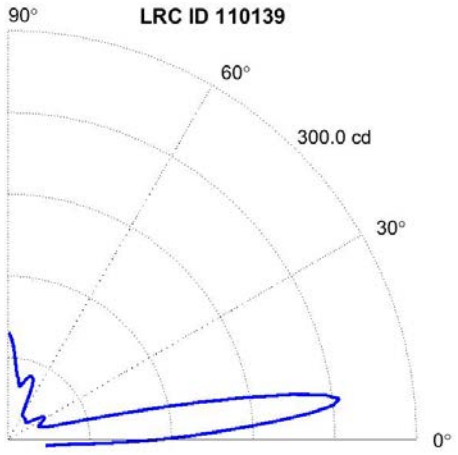


***Figure C8-3.*** *Azimuthal average intensity distribution of RE024-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C9 – Detailed testing results for sample RE025-A

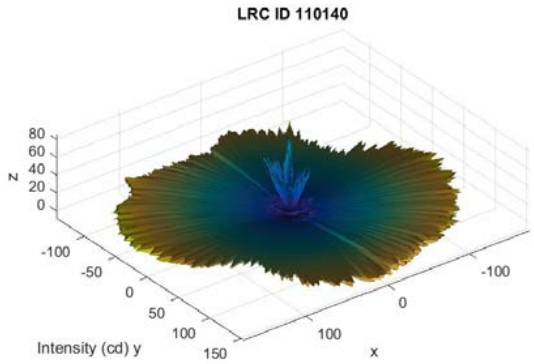


***Figure C9-1.*** *3D rendering of the intensity distribution of RE025-A (L-861 type) luminaire tested at 6.6 A dc*

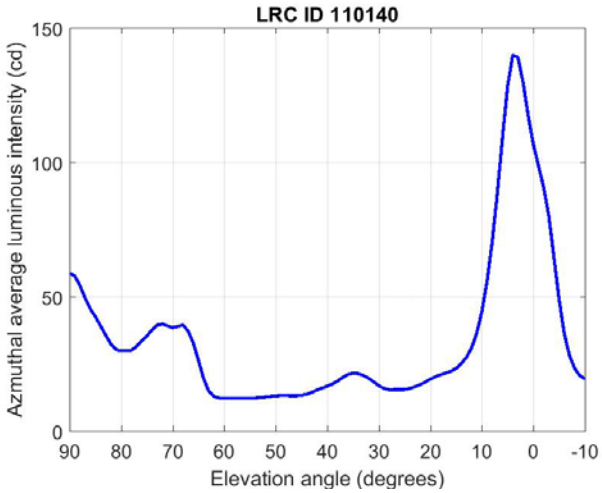


***Figure C9-2.*** *Azimuthal average intensity distribution of RE025-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

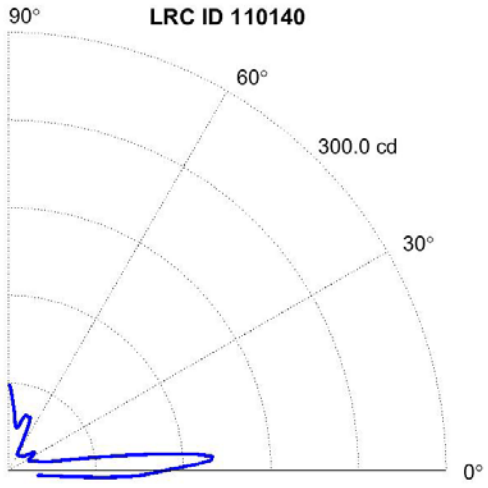


***Figure C8-3.*** *Azimuthal average intensity distribution of RE025-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C10 – Detailed testing results for sample RE026-A

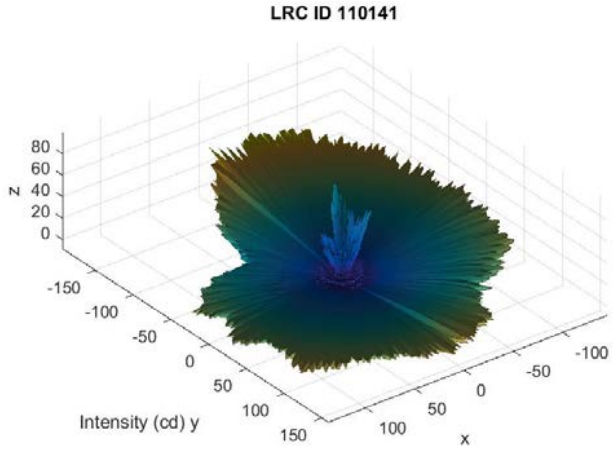


***Figure C10-1.*** *3D rendering of the intensity distribution of RE026-A (L-861 type) luminaire tested at 6.6 A dc*

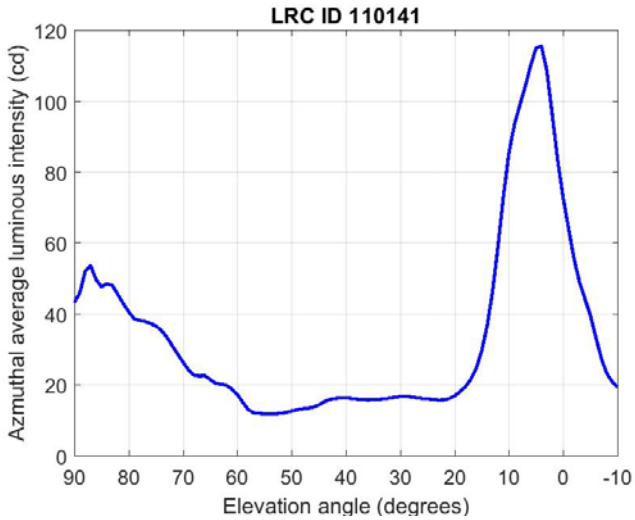


***Figure C10-2.*** *Azimuthal average intensity distribution of RE026-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

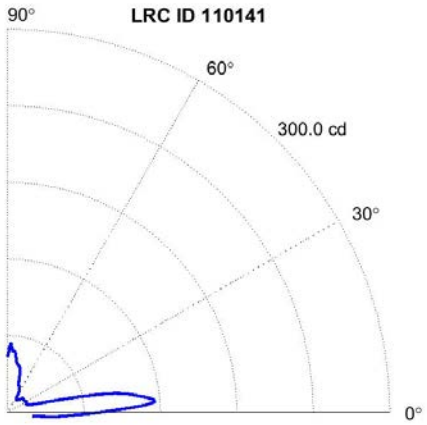


***Figure C10-3.*** *Azimuthal average intensity distribution of RE026-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C11 – Detailed testing results for sample RE027-A

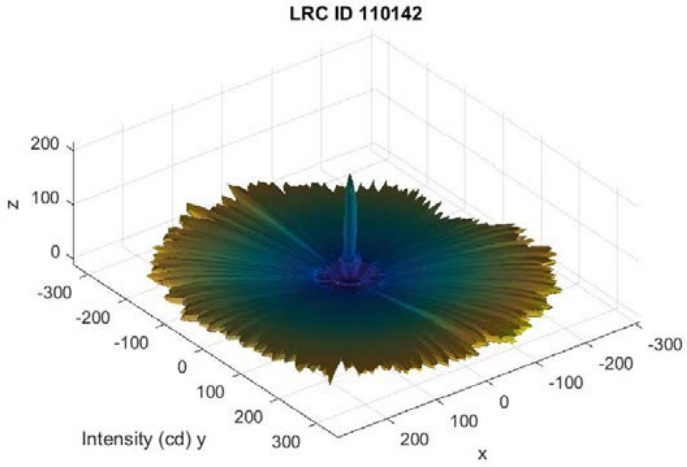


***Figure C11-1.*** *3D rendering of the intensity distribution of RE027-A (L-861 type) luminaire tested at 6.6 A dc*

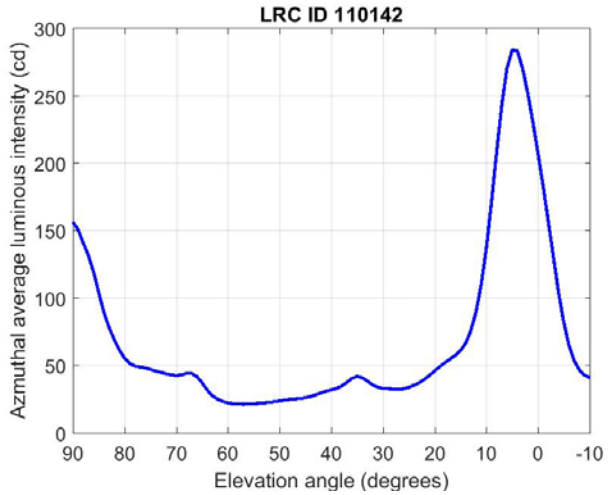


***Figure C11-2.*** *Azimuthal average intensity distribution of RE027-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

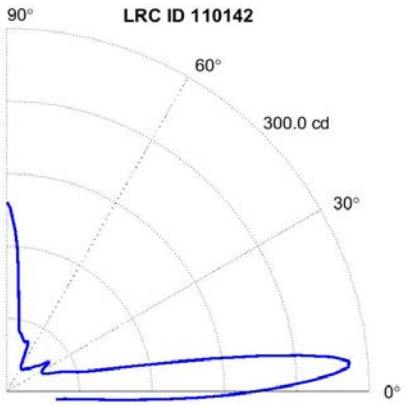


***Figure C11-3.*** *Azimuthal average intensity distribution of RE027-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C12 – Detailed testing results for sample RE028-A

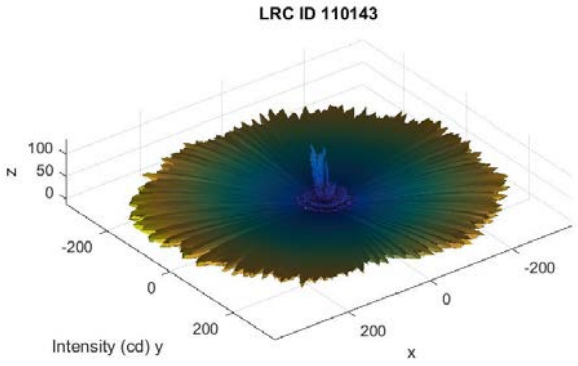


***Figure C12-1.*** *3D rendering of the intensity distribution of RE028-A (L-861 type) luminaire tested at 6.6 A dc*

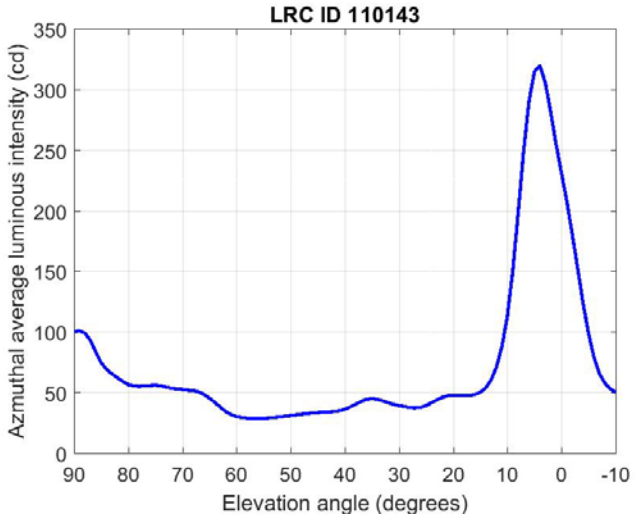


***Figure C12-2.*** *Azimuthal average intensity distribution of RE028-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

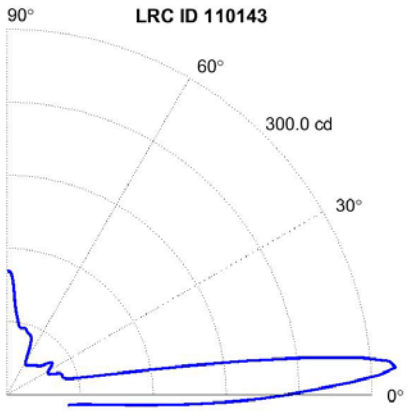


***Figure C12-3.*** *Azimuthal average intensity distribution of RE028-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C13 – Detailed testing results for sample RE029-A

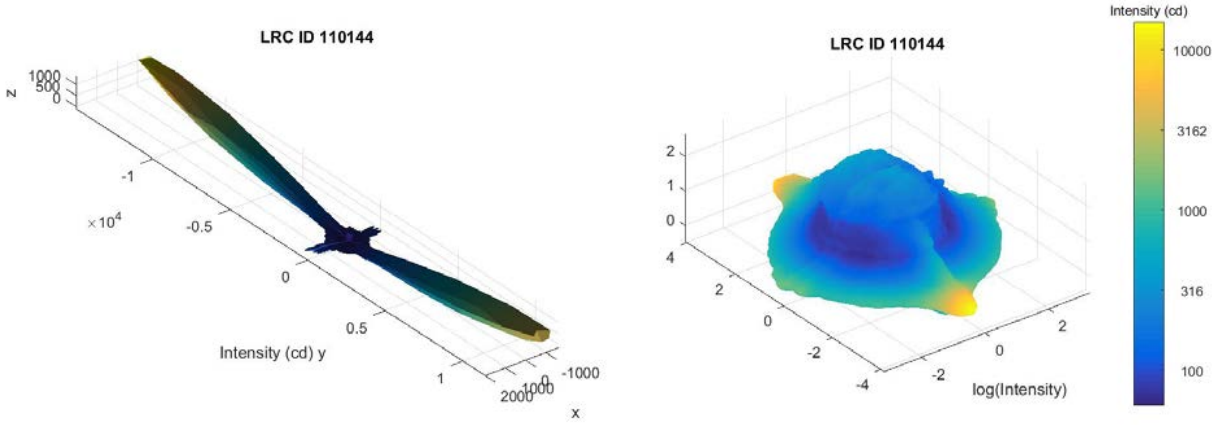


***Figure C13-1.*** *3D rendering of the intensity distribution of RE029-A (L-862 type) luminaire tested at 6.6 A dc in linear scale (left) and in logarithmic scale (right)*

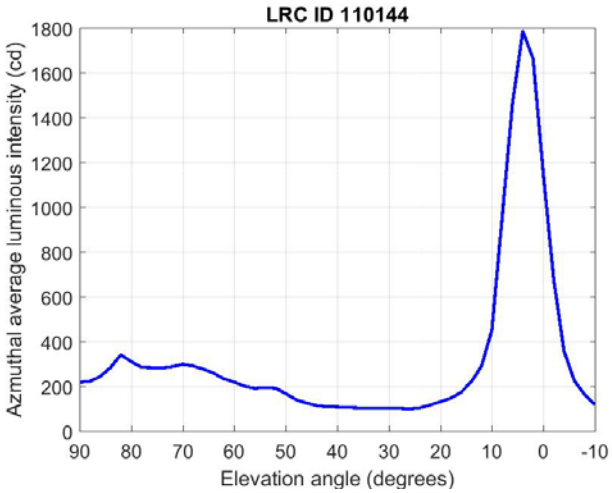


***Figure C13-2.*** *Azimuthal average intensity distribution of RE029-A (L-862 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

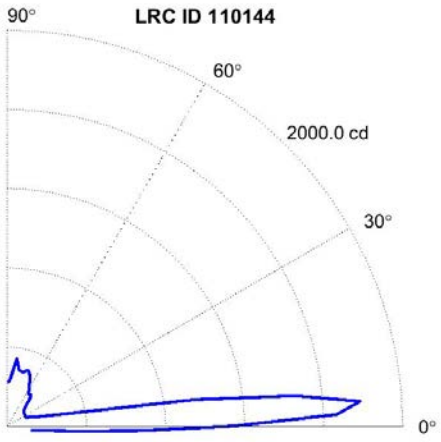


***Figure C13-3.*** *Azimuthal average intensity distribution of RE029-A (L-862 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C14 – Detailed testing results for sample RE030-A

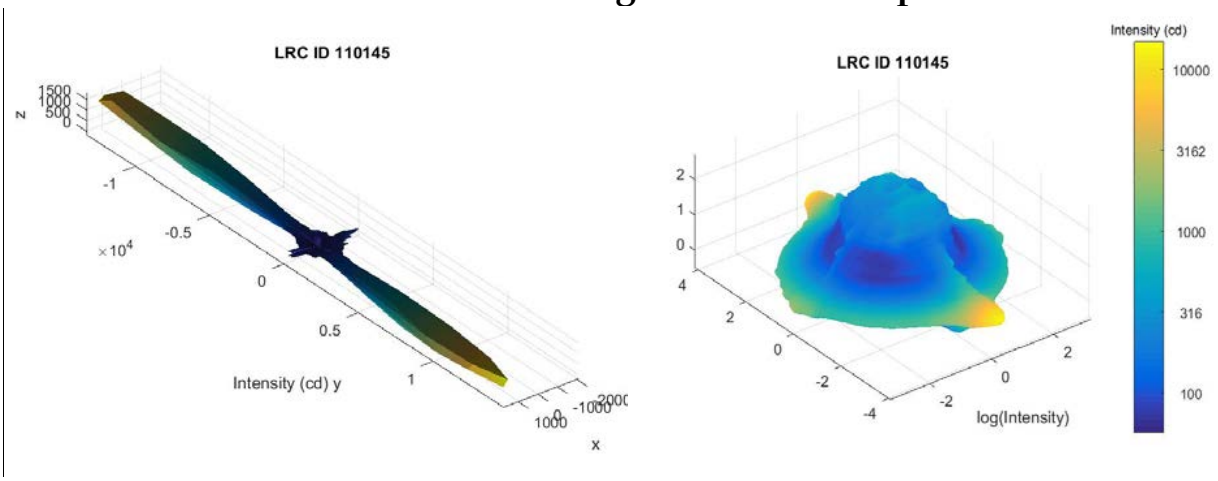


***Figure C14-1.*** *3D rendering of the intensity distribution of RE030-A (L-862 type) luminaire tested at 6.6 A dc in linear scale (left) and in logarithmic scale (right)*

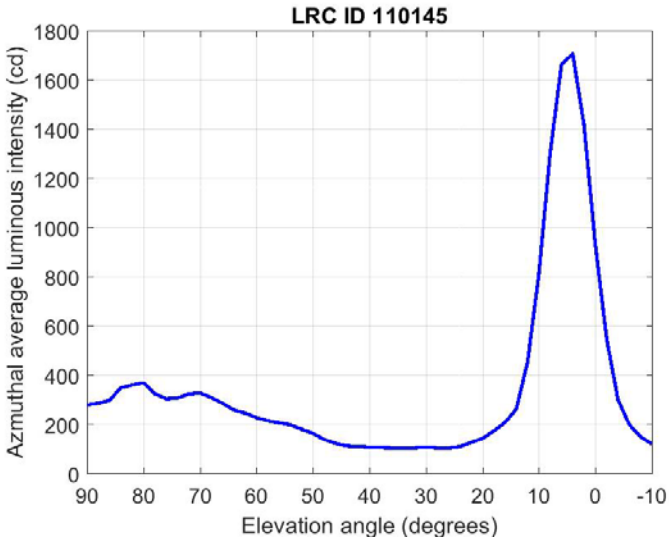


***Figure C14-2.*** *Azimuthal average intensity distribution of RE030-A (L-862 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

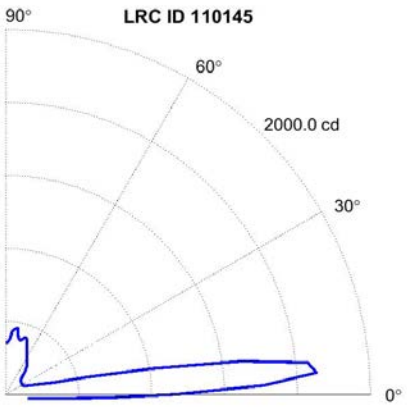


***Figure C14-3.*** *Azimuthal average intensity distribution of RE030-A (L-862 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C15 – Detailed testing results for sample RE031-A

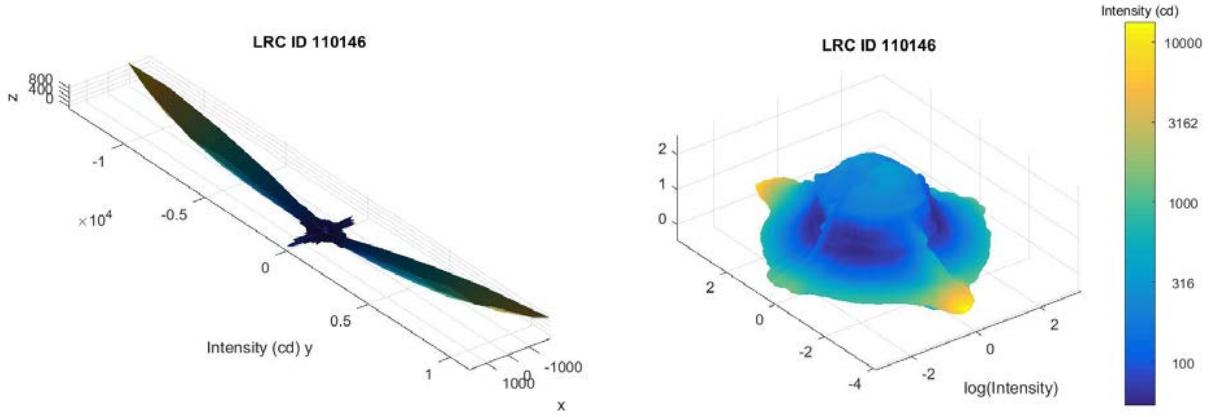


***Figure C15-1.*** *3D rendering of the intensity distribution of RE031-A (L-862 type) luminaire tested at 6.6 A dc in linear scale (left) and in logarithmic scale (right)*

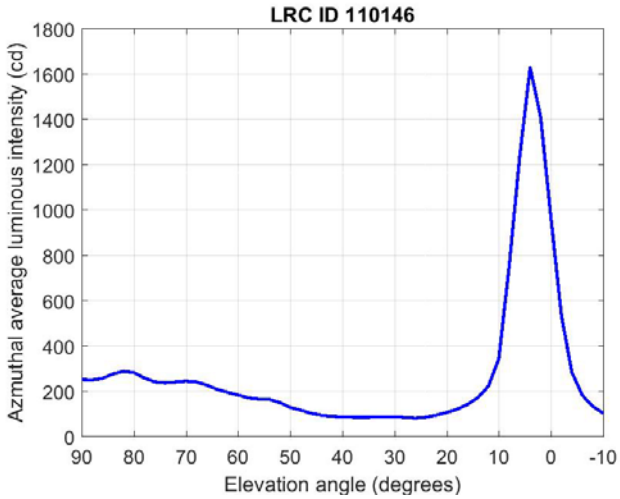


***Figure C15-2.*** *Azimuthal average intensity distribution of RE031-A (L-862 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

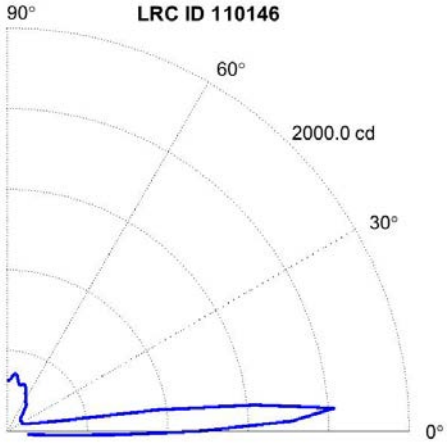


***Figure C15-3.*** *Azimuthal average intensity distribution of RE031-A (L-862 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C16 – Detailed testing results for sample RE032-A

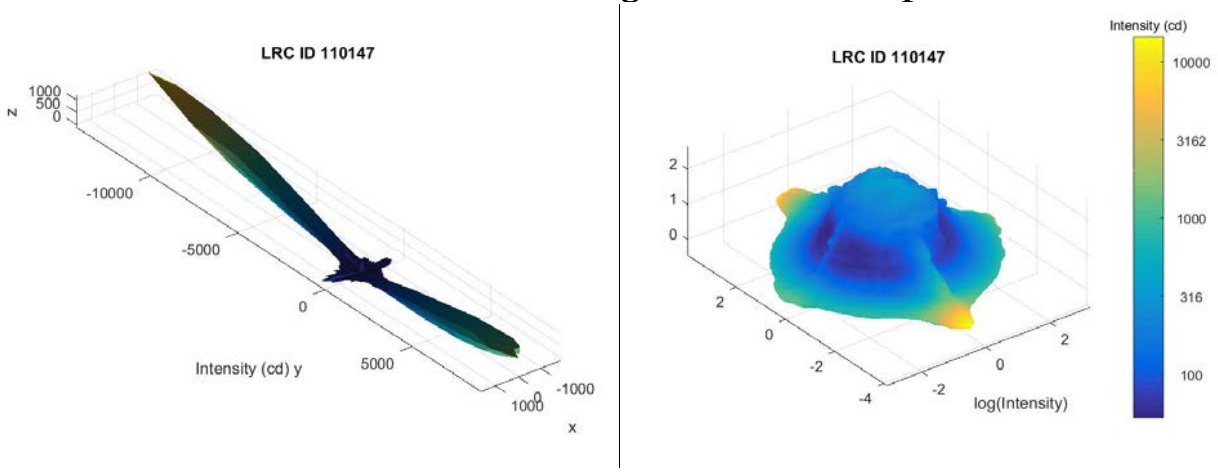


***Figure C16-1.*** *3D rendering of the intensity distribution of RE032-A (L-862 type) luminaire tested at 6.6 A dc in linear scale (left) and in logarithmic scale (right)*

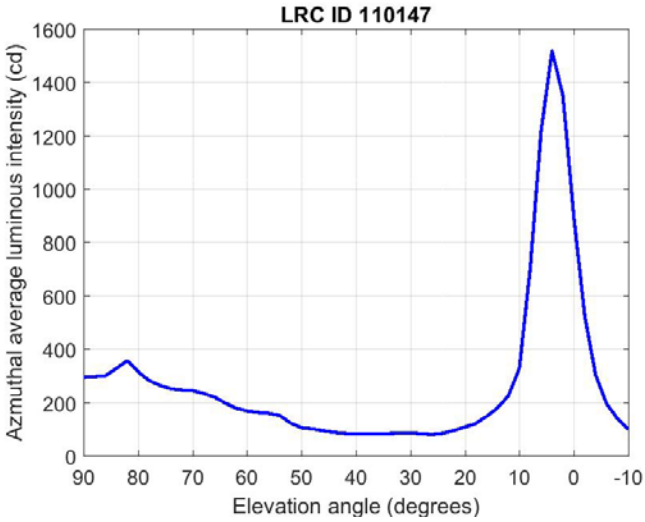


***Figure C16-2.*** *Azimuthal average intensity distribution of RE032-A (L-862 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

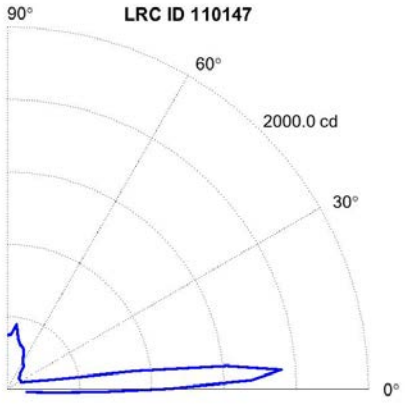


***Figure C16-3.*** *Azimuthal average intensity distribution of RE032-A (L-862 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C17 – Detailed testing results for sample RE036-A

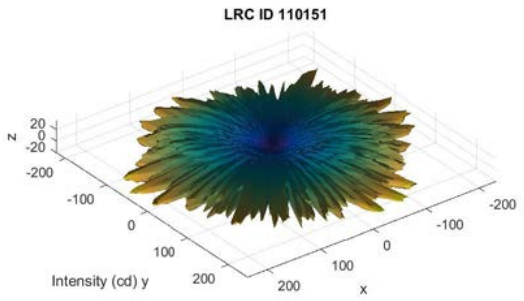


***Figure C17-1.*** *3D rendering of the intensity distribution of RE036-A (L-861 type) luminaire tested at 6.6 A dc*

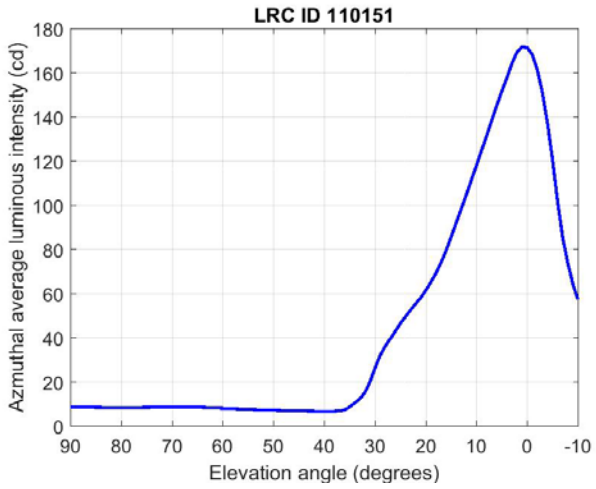


***Figure C17-2.*** *Azimuthal average intensity distribution of RE036-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

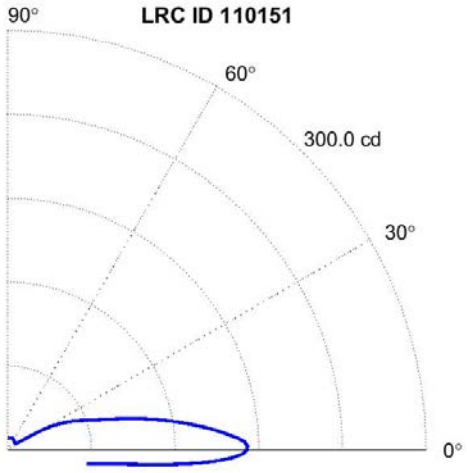


***Figure C17-3.*** *Azimuthal average intensity distribution of RE036-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C18 – Detailed testing results for sample RE037-A

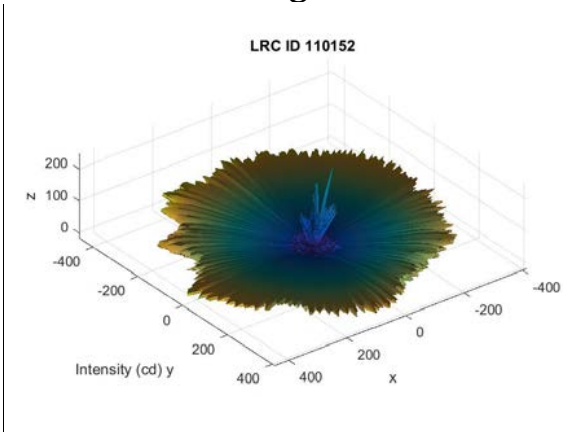


***Figure C18-1.*** *3D rendering of the intensity distribution of RE037-A (L-861 type) luminaire tested at 6.6 A dc*

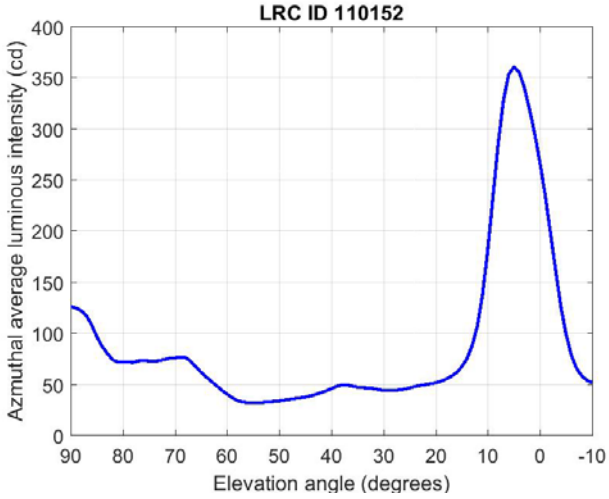


***Figure C18-2.*** *Azimuthal average intensity distribution of RE037-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

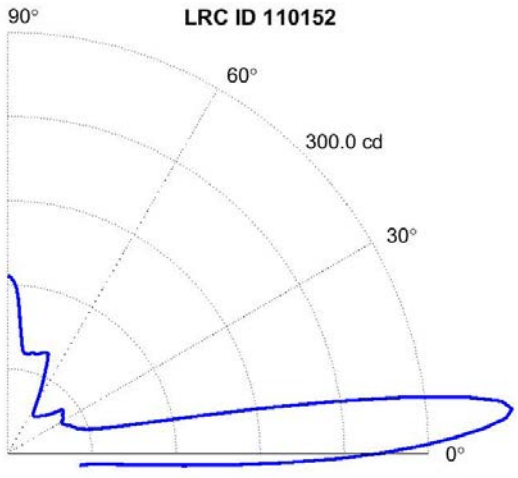


***Figure A18-3.*** *Azimuthal average intensity distribution of RE037-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

# Section C19 – Detailed testing results for sample RE038-A

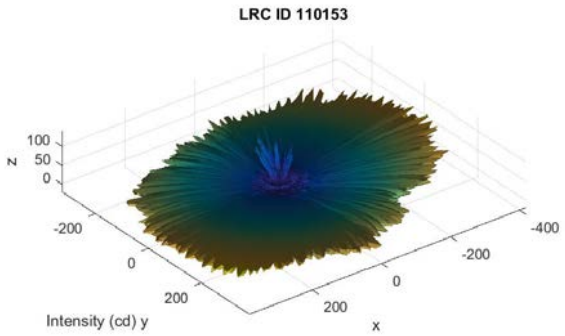


***Figure C19-1.*** *3D rendering of the intensity distribution of RE038-A (L-861 type) luminaire tested at 6.6 A dc*

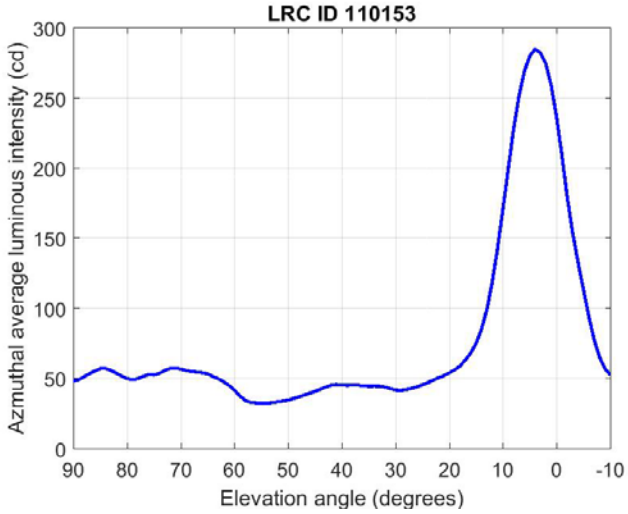


***Figure C19-2.*** *Azimuthal average intensity distribution of RE038-A (L-861 type) luminaire tested at 6.6 A dc in Cartesian coordinates*

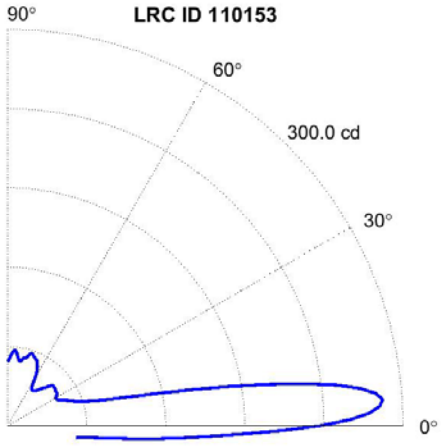


***Figure C19-3.*** *Azimuthal average intensity distribution of RE038-A (L-861 type) luminaire tested at 6.6 A dc in polar coordinates*

## SECTION D - CALCULATED LUMINOUS INTENSITY AT DIFFERENT STEP DIM LEVELS

**Table D1.** Summary of the calculated azimuthal average luminous intensity (cd) for every 5-degree zone from 0 to 90 degree elevation angle for all tested **L-861** luminaires operated at **5.5 A dc**

| FAA ID | RE021A | RE022A | RE023A | RE024A | RE025A | RE026A | RE027A | RE028A | RE036A | RE037A | RE038A |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LRC ID | 110136 | 110137 | 110138 | 110139 | 110140 | 110141 | 110142 | 110143 | 110151 | 110152 | 110153 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 78.9 | 82.8 | 45.5 | 43.9 | 32.5 | 24.2 | 77.1 | 87.4 | 54.3 | 118.7 | 84.1 |
| 5-10 | 90.4 | 121.5 | 51.1 | 66.0 | 23.3 | 26.5 | 73.0 | 75.6 | 45.0 | 117.8 | 77.3 |
| 10-15 | 49.3 | 59.1 | 27.6 | 33.0 | 8.5 | 15.3 | 29.7 | 24.4 | 34.2 | 44.7 | 38.7 |
| 15-20 | 22.1 | 24.7 | 12.1 | 10.4 | 5.6 | 5.8 | 17.1 | 15.2 | 24.3 | 22.3 | 20.3 |
| 20-25 | 15.4 | 17.5 | 8.8 | 7.2 | 4.5 | 4.1 | 12.5 | 14.3 | 18.0 | 18.8 | 15.9 |
| 25-30 | 14.6 | 15.1 | 8.0 | 7.8 | 4.0 | 4.2 | 10.3 | 12.1 | 12.8 | 17.0 | 13.7 |
| 30-35 | 16.5 | 17.1 | 9.1 | 8.7 | 5.0 | 4.2 | 11.3 | 13.2 | 5.5 | 17.3 | 13.8 |
| 35-40 | 15.2 | 16.8 | 8.2 | 7.0 | 5.1 | 4.1 | 11.7 | 13.3 | 2.4 | 18.4 | 14.2 |
| 40-45 | 11.7 | 13.3 | 6.3 | 5.5 | 4.0 | 4.1 | 9.2 | 11.0 | 2.2 | 15.9 | 14.1 |
| 45-50 | 10.8 | 11.7 | 6.2 | 5.3 | 3.5 | 3.5 | 7.9 | 10.3 | 2.3 | 13.7 | 12.1 |
| 50-55 | 9.9 | 10.4 | 6.1 | 5.6 | 3.3 | 3.1 | 7.2 | 9.5 | 2.4 | 12.5 | 10.6 |
| 55-60 | 9.9 | 10.9 | 6.1 | 5.7 | 3.2 | 3.3 | 6.8 | 9.1 | 2.6 | 12.7 | 10.8 |
| 60-65 | 15.6 | 13.9 | 7.3 | 7.2 | 3.7 | 4.9 | 8.2 | 11.2 | 2.7 | 18.4 | 14.9 |
| 65-70 | 26.8 | 27.4 | 13.7 | 12.8 | 9.0 | 5.8 | 13.1 | 15.7 | 2.9 | 26.8 | 17.2 |
| 70-75 | 26.7 | 24.1 | 15.4 | 13.6 | 10.0 | 7.9 | 13.8 | 17.0 | 2.8 | 28.1 | 17.7 |
| 75-80 | 21.2 | 17.2 | 13.1 | 11.9 | 8.3 | 9.6 | 15.3 | 17.6 | 2.8 | 27.4 | 16.2 |
| 80-85 | 20.3 | 17.2 | 16.0 | 13.8 | 8.6 | 11.5 | 22.0 | 19.7 | 2.8 | 29.2 | 17.0 |
| 85-90 | 30.2 | 24.7 | 23.2 | 19.6 | 12.9 | 12.7 | 40.1 | 28.4 | 2.8 | 43.0 | 16.8 |

**Table D2.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested **L-861** luminaires operated at **4.8 A dc**

| FAA ID | RE021A | RE022A | RE023A | RE024A | RE025A | RE026A | RE027A | RE028A | RE036A | RE037A | RE038A |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LRC ID | 110136 | 110137 | 110138 | 110139 | 110140 | 110141 | 110142 | 110143 | 110151 | 110152 | 110153 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 30.3 | 30.2 | 15.6 | 14.3 | 9.8 | 6.7 | 27.8 | 29.8 | 21.8 | 44.5 | 31.2 |
| 5-10 | 34.7 | 44.3 | 17.5 | 21.5 | 7.0 | 7.3 | 26.3 | 25.8 | 18.0 | 44.2 | 28.6 |
| 10-15 | 18.9 | 21.6 | 9.5 | 10.7 | 2.6 | 4.2 | 10.7 | 8.3 | 13.7 | 16.8 | 14.4 |
| 15-20 | 8.5 | 9.0 | 4.1 | 3.4 | 1.7 | 1.6 | 6.2 | 5.2 | 9.7 | 8.4 | 7.5 |
| 20-25 | 5.9 | 6.4 | 3.0 | 2.3 | 1.4 | 1.1 | 4.5 | 4.9 | 7.2 | 7.1 | 5.9 |
| 25-30 | 5.6 | 5.5 | 2.8 | 2.5 | 1.2 | 1.2 | 3.7 | 4.1 | 5.1 | 6.4 | 5.1 |
| 30-35 | 6.3 | 6.2 | 3.1 | 2.8 | 1.5 | 1.2 | 4.1 | 4.5 | 2.2 | 6.5 | 5.1 |
| 35-40 | 5.8 | 6.1 | 2.8 | 2.3 | 1.5 | 1.1 | 4.2 | 4.6 | 1.0 | 6.9 | 5.3 |
| 40-45 | 4.5 | 4.8 | 2.2 | 1.8 | 1.2 | 1.1 | 3.3 | 3.7 | 0.9 | 6.0 | 5.2 |
| 45-50 | 4.1 | 4.3 | 2.1 | 1.7 | 1.0 | 1.0 | 2.9 | 3.5 | 0.9 | 5.1 | 4.5 |
| 50-55 | 3.8 | 3.8 | 2.1 | 1.8 | 1.0 | 0.9 | 2.6 | 3.2 | 1.0 | 4.7 | 3.9 |
| 55-60 | 3.8 | 4.0 | 2.1 | 1.9 | 1.0 | 0.9 | 2.4 | 3.1 | 1.0 | 4.8 | 4.0 |
| 60-65 | 6.0 | 5.1 | 2.5 | 2.3 | 1.1 | 1.4 | 2.9 | 3.8 | 1.1 | 6.9 | 5.5 |
| 65-70 | 10.3 | 10.0 | 4.7 | 4.2 | 2.7 | 1.6 | 4.7 | 5.3 | 1.1 | 10.0 | 6.4 |
| 70-75 | 10.3 | 8.8 | 5.3 | 4.4 | 3.0 | 2.2 | 5.0 | 5.8 | 1.1 | 10.5 | 6.6 |
| 75-80 | 8.1 | 6.3 | 4.5 | 3.9 | 2.5 | 2.7 | 5.5 | 6.0 | 1.1 | 10.3 | 6.0 |
| 80-85 | 7.8 | 6.3 | 5.5 | 4.5 | 2.6 | 3.2 | 7.9 | 6.7 | 1.1 | 10.9 | 6.3 |
| 85-90 | 11.6 | 9.0 | 8.0 | 6.4 | 3.9 | 3.5 | 14.5 | 9.7 | 1.1 | 16.1 | 6.2 |

**Table D3.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested **L-862** luminaires operated at **5.2 A dc**

| FAA ID | RE017A | RE018A | RE019A | RE020A | RE029A | RE030A | RE031A | RE032A |
|---|---|---|---|---|---|---|---|---|
| LRC ID | 110132 | 110134 | 110133 | 110135 | 110144 | 110145 | 110146 | 110147 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 73 | 83 | 69 | 93 | 390 | 341 | 333 | 319 |
| 5-10 | 74 | 85 | 69 | 95 | 308 | 374 | 249 | 245 |
| 10-15 | 76 | 86 | 72 | 96 | 82 | 128 | 62 | 62 |
| 15-20 | 85 | 95 | 81 | 105 | 41 | 48 | 33 | 35 |
| 20-25 | 90 | 102 | 86 | 114 | 30 | 32 | 24 | 25 |
| 25-30 | 90 | 105 | 85 | 114 | 26 | 27 | 21 | 21 |
| 30-35 | 62 | 69 | 57 | 87 | 27 | 27 | 22 | 22 |
| 35-40 | 32 | 41 | 29 | 43 | 27 | 27 | 21 | 21 |
| 40-45 | 35 | 49 | 35 | 50 | 29 | 28 | 23 | 22 |
| 45-50 | 60 | 82 | 55 | 80 | 34 | 33 | 28 | 25 |
| 50-55 | 66 | 85 | 58 | 83 | 48 | 46 | 37 | 33 |
| 55-60 | 48 | 55 | 52 | 66 | 50 | 53 | 42 | 41 |
| 60-65 | 42 | 50 | 50 | 56 | 61 | 62 | 49 | 46 |
| 65-70 | 42 | 56 | 49 | 53 | 73 | 75 | 59 | 58 |
| 70-75 | 48 | 64 | 47 | 52 | 74 | 81 | 60 | 63 |
| 75-80 | 63 | 75 | 49 | 57 | 73 | 80 | 63 | 70 |
| 80-85 | 70 | 70 | 54 | 67 | 80 | 91 | 71 | 85 |
| 85-90 | 67 | 63 | 54 | 79 | 60 | 74 | 64 | 76 |

Table D4. Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested L-862 luminaires operated at 4.1 A dc

| FAA ID | RE017A | RE018A | RE019A | RE020A | RE029A | RE030A | RE031A | RE032A |
|---|---|---|---|---|---|---|---|---|
| LRC ID | 110132 | 110134 | 110133 | 110135 | 110144 | 110145 | 110146 | 110147 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 14 | 15 | 13 | 18 | 75 | 65 | 63 | 61 |
| 5-10 | 14 | 16 | 13 | 18 | 60 | 71 | 47 | 47 |
| 10-15 | 14 | 16 | 14 | 18 | 16 | 24 | 12 | 12 |
| 15-20 | 16 | 18 | 15 | 20 | 8 | 9 | 6 | 7 |
| 20-25 | 17 | 19 | 16 | 22 | 6 | 6 | 5 | 5 |
| 25-30 | 17 | 20 | 16 | 22 | 5 | 5 | 4 | 4 |
| 30-35 | 12 | 13 | 11 | 17 | 5 | 5 | 4 | 4 |
| 35-40 | 6 | 8 | 6 | 8 | 5 | 5 | 4 | 4 |
| 40-45 | 7 | 9 | 7 | 9 | 6 | 5 | 4 | 4 |
| 45-50 | 11 | 15 | 10 | 15 | 7 | 6 | 5 | 5 |
| 50-55 | 13 | 16 | 11 | 16 | 9 | 9 | 7 | 6 |
| 55-60 | 9 | 10 | 10 | 13 | 10 | 10 | 8 | 8 |
| 60-65 | 8 | 9 | 9 | 11 | 12 | 12 | 9 | 9 |
| 65-70 | 8 | 10 | 9 | 10 | 14 | 14 | 11 | 11 |
| 70-75 | 9 | 12 | 9 | 10 | 14 | 15 | 11 | 12 |
| 75-80 | 12 | 14 | 9 | 11 | 14 | 15 | 12 | 13 |
| 80-85 | 13 | 13 | 10 | 13 | 15 | 17 | 13 | 16 |
| 85-90 | 13 | 12 | 10 | 15 | 12 | 14 | 12 | 15 |

**Table D5.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested **L-862** luminaires operated at **3.4 A dc**

| FAA ID | RE017A | RE018A | RE019A | RE020A | RE029A | RE030A | RE031A | RE032A |
|---|---|---|---|---|---|---|---|---|
| LRC ID | 110132 | 110134 | 110133 | 110135 | 110144 | 110145 | 110146 | 110147 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 3.3 | 3.5 | 3.0 | 4.1 | 18.2 | 15.3 | 15.1 | 14.4 |
| 5-10 | 3.3 | 3.6 | 3.0 | 4.2 | 14.4 | 16.8 | 11.2 | 11.0 |
| 10-15 | 3.4 | 3.7 | 3.2 | 4.2 | 3.8 | 5.8 | 2.8 | 2.8 |
| 15-20 | 3.8 | 4.0 | 3.5 | 4.6 | 1.9 | 2.2 | 1.5 | 1.6 |
| 20-25 | 4.1 | 4.3 | 3.8 | 5.0 | 1.4 | 1.4 | 1.1 | 1.1 |
| 25-30 | 4.0 | 4.4 | 3.7 | 5.0 | 1.2 | 1.2 | 0.9 | 0.9 |
| 30-35 | 2.8 | 2.9 | 2.5 | 3.8 | 1.2 | 1.2 | 1.0 | 1.0 |
| 35-40 | 1.4 | 1.7 | 1.3 | 1.9 | 1.3 | 1.2 | 1.0 | 1.0 |
| 40-45 | 1.6 | 2.1 | 1.6 | 2.2 | 1.3 | 1.3 | 1.0 | 1.0 |
| 45-50 | 2.7 | 3.5 | 2.4 | 3.5 | 1.6 | 1.5 | 1.2 | 1.1 |
| 50-55 | 3.0 | 3.6 | 2.6 | 3.6 | 2.2 | 2.1 | 1.7 | 1.5 |
| 55-60 | 2.1 | 2.3 | 2.3 | 2.9 | 2.4 | 2.4 | 1.9 | 1.9 |
| 60-65 | 1.9 | 2.1 | 2.2 | 2.5 | 2.8 | 2.8 | 2.2 | 2.1 |
| 65-70 | 1.9 | 2.4 | 2.1 | 2.3 | 3.4 | 3.4 | 2.7 | 2.6 |
| 70-75 | 2.2 | 2.7 | 2.0 | 2.3 | 3.5 | 3.6 | 2.7 | 2.9 |
| 75-80 | 2.8 | 3.2 | 2.2 | 2.5 | 3.4 | 3.6 | 2.8 | 3.2 |
| 80-85 | 3.1 | 3.0 | 2.4 | 2.9 | 3.7 | 4.1 | 3.2 | 3.8 |
| 85-90 | 3.0 | 2.7 | 2.4 | 3.5 | 2.8 | 3.3 | 2.9 | 3.4 |

**Table D6.** Summary of the azimuthal average luminous intensity (cd) for every 5 degree zone from 0 to 90 degree elevation angle for all tested **L-862** luminaires operated at **2.8 A dc**

| FAA ID | RE017A | RE018A | RE019A | RE020A | RE029A | RE030A | RE031A | RE032A |
|---|---|---|---|---|---|---|---|---|
| LRC ID | 110132 | 110134 | 110133 | 110135 | 110144 | 110145 | 110146 | 110147 |
| Elevation angle range (degree) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) | I (cd) |
| 0-5 | 0.5 | 0.5 | 0.5 | 0.7 | 3.1 | 2.5 | 2.5 | 2.3 |
| 5-10 | 0.5 | 0.5 | 0.5 | 0.7 | 2.5 | 2.7 | 1.9 | 1.8 |
| 10-15 | 0.5 | 0.6 | 0.5 | 0.7 | 0.7 | 0.9 | 0.5 | 0.5 |
| 15-20 | 0.6 | 0.6 | 0.6 | 0.8 | 0.3 | 0.4 | 0.2 | 0.3 |
| 20-25 | 0.6 | 0.6 | 0.6 | 0.8 | 0.2 | 0.2 | 0.2 | 0.2 |
| 25-30 | 0.6 | 0.7 | 0.6 | 0.8 | 0.2 | 0.2 | 0.2 | 0.2 |
| 30-35 | 0.4 | 0.4 | 0.4 | 0.6 | 0.2 | 0.2 | 0.2 | 0.2 |
| 35-40 | 0.2 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 |
| 40-45 | 0.2 | 0.3 | 0.3 | 0.4 | 0.2 | 0.2 | 0.2 | 0.2 |
| 45-50 | 0.4 | 0.5 | 0.4 | 0.6 | 0.3 | 0.2 | 0.2 | 0.2 |
| 50-55 | 0.5 | 0.5 | 0.4 | 0.6 | 0.4 | 0.3 | 0.3 | 0.2 |
| 55-60 | 0.3 | 0.4 | 0.4 | 0.5 | 0.4 | 0.4 | 0.3 | 0.3 |
| 60-65 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.4 | 0.3 |
| 65-70 | 0.3 | 0.4 | 0.3 | 0.4 | 0.6 | 0.5 | 0.4 | 0.4 |
| 70-75 | 0.3 | 0.4 | 0.3 | 0.4 | 0.6 | 0.6 | 0.5 | 0.5 |
| 75-80 | 0.5 | 0.5 | 0.4 | 0.4 | 0.6 | 0.6 | 0.5 | 0.5 |
| 80-85 | 0.5 | 0.4 | 0.4 | 0.5 | 0.6 | 0.7 | 0.5 | 0.6 |
| 85-90 | 0.5 | 0.4 | 0.4 | 0.6 | 0.5 | 0.5 | 0.5 | 0.6 |