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Lighted X Runway Closure Marker—Flight Testing

March 2026

Final Report

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16. Abstract

On July 7, 2017, an Airbus A320 nearly collided with another aircraft on Taxiway C at San Francisco International Airport. The A320 mistakenly aligned with the taxiway instead of the parallel runway on which they were cleared to land. Because of this incident, the National Transportation Safety Board (NTSB) made a safety recommendation to improve the conspicuity of closed runways, particularly under nighttime conditions when at least one parallel runway remains in use. The Federal Aviation Administration (FAA) Office of Airports tasked the National Institute of Standards and Technology (NIST) to evaluate different configurations of Lighted X (LX) systems. NIST's laboratory experiments with pilot participants revealed that larger 28-foot LX configurations were more recognizable from greater distances. However, the findings needed validation through real-world flight testing in varied lighting conditions to confirm their practical applicability. The FAA Airport Technology Research and Development (ATR) Branch conducted research to test and evaluate LX runway closure markers (RCMs) in real-world scenarios to validate NIST's laboratory results. Eighty-eight test configurations were considered to evaluate the optimal intensity, size, and flash rate of the RCMs. Given this large test set and the costs associated with conducting flight testing, ATR conducted a two-phase test approach: ground tests at the Lakehurst Naval Air Warfare Center Aircraft Division (NAWCAD) and flight tests at Cape May Airport (WWD). Results from ground observations were used to eliminate RCM configurations that pilots found least viable, leading to a reduction from 88 test configurations to 33 based on pilot feedback. This report focuses on the results gathered from Phase 2 and provides a comprehensive summary of flight testing and recommends optimal LX configurations for intensity, size, and flash rate to better signal runway closures to pilots during operations.

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LIST OF ACRONYMS

AAS	Office of Airport Safety and Standards
AC	Advisory Circular
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Above ground level
ARP	Office of Airports
ATR	Airport Safety Research and Development Branch
CCT	Correlated color temperature
cd	Candela
CFII	Certified Flight Instructor-Instrument
CTAF	Common Traffic Advisory Frequency
DOT	Department of Transportation
FAA	Federal Aviation Administration
FBO	Fixed-base operator
EFB	Electronic flight bag
KIAS	Knots indicated airspeed
LED	Light-emitting diode
LX	Lighted X
LX20	Incandescent or LED 20-ft LX runway closure marker
LX28	Incandescent or LED 28-ft LX runway closure marker
NAWCAD	Naval Air Warfare Center Aircraft Division, Lakehurst, New Jersey
NIST	National Institute of Standards and Technology
NM	Nautical miles
NTSB	National Transportation Safety Board
PF	Pilot flying
PM	Pilot monitoring
R&D	Research and development
RCM	Runway closure marker
RNAV	Area navigation
SFO	San Francisco International Airport
VFR	Visual flight rules
VMC	Visual meteorological conditions
WWD	Cape May Airport

EXECUTIVE SUMMARY

Lighted X (LX) runway closure markers (RCMs) are critical for enhancing the visibility of closed runways to pilots. However, since their introduction, some pilots have noted that current light-emitting diode (LED) LX markers appear excessively bright during nighttime operations, raising concerns about their effectiveness and usability. Underscoring the potential role of inadequate signage and lighting for pilots' visibility, in 2017, an Air Canada Airbus A320 nearly landed on a taxiway parallel to a runway at San Francisco International Airport (SFO), which prompted a Safety Recommendation from the National Transportation Safety Board (NTSB).

In response to this Safety Recommendation, the Federal Aviation Administration (FAA) Office of Airport Safety and Standards tasked the National Institute of Standards and Technology (NIST) to perform a human factors research project to evaluate various LX configurations. NIST conducted laboratory-based simulation testing to gain pilot input on preferred size, intensity, and flash rate. To validate the findings from the human factors laboratory, the FAA Airport Technology Research and Development (R&D) (ATR) Branch conducted research to test and evaluate LX RCMs in real-world scenarios using a two-phase test approach, conducted during daytime and nighttime conditions. In Phase 1, ground testing was conducted at the Lakehurst Naval Air Warfare Center Aircraft Division (NAWCAD), which used pilot feedback to refine configurations and reduce the original 88 test configurations to 33 configurations. In Phase 2, flight testing was conducted at Cape May Airport (WWD), which assessed intensity, size, and flash rate of different LX configurations across 16 pilots in 8 aircraft in daytime and nighttime conditions.

Flight testing was executed over three days/nights. Pilots were instructed to fly a traffic pattern around WWD approaching simulated Runway 5/23, where four LX markers were deployed. Upon completion of each pass of simulated Runway 5/23, pilots were instructed to complete a questionnaire to capture their impression on the conspicuity of the LX marker. This report will detail the execution of flight testing, discuss analysis of pilot responses, and recommend specifications for LX RCMs to maximize conspicuity.

Key findings from the flight tests include:

Daytime Results

- **Intensity Preference:** Intensities of 35,000 cd and 70,000 cd met the visibility requirement of 1.5 NM for all four LXs. Pilots favored the LED LX28 at 70,000 cd for its visibility and recognizability from greater distances.
- **Size Preference:** Pilots preferred the larger 28-foot LX when compared to the 20-foot LX.
- **Flash Rate Preference:** A flash rate of "1.5 seconds on / 1.5 seconds off" was preferred for both LED configurations. Incandescent LXs were limited to "2.5 seconds on / 2.5 seconds off" due to their lamp characteristics.

Nighttime Results

- **Intensity Preference:**
  - Intensities of 500 cd, 1,000 cd, and 2,000 cd satisfied visibility requirements of 1.5 NMfor all four LXs.
  - The LED LX28 and Incandescent LX28 at 2,000 cd performed best for acquisition distance.
  - The Incandescent LX28 at 1,000 cd performed best for shape recognition distance.
- **Size Preference:** Pilots preferred the larger 28-foot LX when compared to the 20-foot LX.
- **Flash Rate Preference:** A flash rate of "1 second on / 0.5 seconds off" was the preferred, while incandescent markers were limited to "2.5 seconds on / 2.5 seconds off."

These results provide actionable insights for optimizing LXs for improved visibility and usability that will enhance runway safety and address pilot concerns. These test results diverge from previous NIST laboratory results, particularly regarding nighttime intensity preferences. These differences highlight the importance of real-world testing conditions. The findings from this flight test evaluation provide valuable insights into the performance of RCMs under real-world conditions, which can help refine future implementation and usage guidelines.

1. INTRODUCTION

Runway closure markers (RCMs) are crucial for ensuring the safety and efficiency of airport operations. Lighted X (LX) markers are used to indicate to pilots that a runway is closed and not safe for landing or takeoff. This is intended to prevent pilots from inadvertently using runways that may be under maintenance or construction or are otherwise unsafe due to debris or other hazards. The Federal Aviation Administration (FAA) mandates specific standards for these markers to ensure they are highly visible and easily recognizable. By providing clear visual cues, RCMs help maintain orderly and safe air traffic management, reducing the risk of accidents and enhancing overall airport safety. Advisory Circular (AC) 150/5345-55A (FAA, 2007) provides guidance for the design of a lighted visual aid to indicate temporary runway closure (L-893).

LX RCMs enhance the visibility of closed runways to pilots. However, pilots have noted that current light-emitting diode (LED) LX markers appear excessively bright during nighttime operations, raising concerns about their effectiveness and usability. This FAA research addresses the pilots' concerns and improves the overall efficiency of LX markers to mitigate the safety risks of mistakenly using a closed runway. The research outlined in this report was conducted by the FAA Airport Technology Research & Development Branch (ATR) in a two-phase approach. Phase 1 focused on ground-based testing, and Phase 2 focused on flight testing, which is the focus of this report. The Phase 2 flight testing took place at the Cape May Airport (WWD) in Lower Township, New Jersey, within the framework of a Memorandum of Understanding between the William J. Hughes Technical Center for Advanced Aerospace in Atlantic City International Airport, New Jersey, and the Delaware River & Bay Authority, who own and operate WWD.

The research objectives were:

- Test the intensity, size, and flash rates that were recommended based on the Phase 1 ground-based test results.
- Analyze pilots' preferences regarding LX characteristics to enhance the conspicuity of the LX and more effectively signal a closed runway.

1.1 BACKGROUND

On July 7, 2017, an Airbus A320-211 was cleared to land on Runway 28R at San Francisco International Airport (SFO) but mistakenly aligned with parallel Taxiway C, where four air carriers were positioned awaiting takeoff from Runway 28R. The A320 descended to an altitude of 100 ft above ground level (AGL), flying over the first aircraft on the taxiway. The A320 crew then performed a go-around maneuver, descending to a minimum altitude of 60 ft above a second aircraft on the taxiway before starting to climb. Although no injuries or damage to the aircraft involved were reported, this near catastrophic event led the National Transportation Safety Board (NTSB) to issue Safety Recommendation A-18-28:

> Conduct human factors research to determine how to make a closed runway more conspicuous to pilots when at least one parallel runway remains in use and implement a

method to more effectively signal a runway closure to pilots during ground and flight operations at night. (NTSB, 2018)

In response, the FAA tasked the Office of Airports (ARP) with addressing this safety recommendation. The Office of Airport Safety and Standards (AAS) initiated a human factors-based research and development (R&D) project, led by ATR. The primary focus was to investigate innovative lighting systems to improve the conspicuity of closed parallel runways. This included evaluating variations of the standard LX method, as described in AC 150/5345-55A, *Specification for L-893, Lighted Visual Aid to Indicate Temporary Runway Closure* (FAA, 2007).

Prior to this, ATR initiated another study in 2016, on request from AAS Airport Engineering Division (AAS-100), to conduct tests and evaluate the use of an LX RCM to indicate temporary closure of a runway. The study evaluated a 20-ft L-893 and a 28-ft L-893X(L) LX with both incandescent and LED lamp configurations.

This study (Bassey, 2018) had two phases. Phase 1 consisted of testing the L-893X(L) to the performance standards of the incandescent RCM (L-893) referenced in AC 150/5345-55, *Specification for L-893, Lighted Visual Aid to Indicate Temporary Runway Closure* (FAA, 2007). The L-893X(L) met 8 of the 11 performance standards discussed in AC 150/5345-55. It did not meet the following performance standards: color of the arms, light-source spacing, and setup.

Phase 2 conducted flight testing and evaluation of three L-893 LXs and two L-893X(L) LXs of the same make and model. Flights were conducted during daytime and nighttime visual meteorological conditions (VMC) to determine whether the LXs met the AC performance standards for acquisition distance, shape recognition distance, and the vertical and horizontal coverage listed in FAA Technical Note DOT/FAA/CT-TN87/3 (Marinelli, 1987). In addition, the shape, perceived visibility, brightness, and glare of the L-893 and L-893X(L) LXs were evaluated.

In the 2018 study (Bassey, 2018), all three L-893 LXs met the AC performance standards for shape recognition distance and vertical and horizontal coverage, and two out of three L-893 LXs met the AC performance standards for minimum acquisition distance. Both L-893X(L) LXs met the AC performance standards for acquisition distance, shape recognition distance, and vertical and horizontal coverage. The survey questionnaire results and comments from this study also indicated that pilots could not accurately identify the shapes of either the L-893 LXs or L-893X(L) LXs because they were too bright at night.

Based on the results of this 2018 study, it was determined that further research was needed to determine the maximum and minimum daytime and nighttime intensities of the L-893 and L-893X(L) LXs, in continuous and flashing modes, so that pilots could accurately identify the RCM.

As a follow-on to this original effort and to aid the human factors-based research and development project, AAS-100 tasked the National Institute of Standards and Technology

(NIST) to investigate the effectiveness of the current LX design with a focus on anecdotal evidence that the current LED LXs can appear too bright during nighttime operations. The current LED LXs are manufactured to meet the minimum intensity requirement in FAA AC number 150/5345-55A. Preliminary findings from the NIST study were presented to the FAA on October 1, 2019, (Ohno, Litorja, Miller, & Zong, 2019).

The NIST Study:

For the NIST testing approach, researchers conducted a stationary nighttime simulation with 20 pilot participants, using a scale model in a darkened laboratory setting. The scale model was configurable to allow for simulation of the following test configurations:

- LX arm lengths of 14, 21, and 28 ft
- LX configurations of 9, 13, and 17 lamps
- Effective intensity range between 10 candelas (cd) and 10k[1] cd
- Correlated color temperatures (CCT) of 5,700 K[2] (for LED) and 2,950 K (for incandescent)

The NIST laboratory-based simulation testing concluded that for both the LED (5,700 K) and incandescent (2,950 K) configurations, the 28-ft LX was far more recognizable at 1.5 nautical miles (NM) than either the 14- or 20-ft LXs. NIST concluded that a minimum nighttime intensity of 2,000 cd as defined in section 3.3f of AC 150/5345-55 (FAA, 2007) was too high, caused glare, and made the "X" shape difficult to recognize. The NIST experiments suggested that the best nighttime visibility occurs at intensities between 100 cd and 300 cd for the LED and incandescent lamps, respectively.

The NIST findings were presented to the FAA in a PowerPoint presentation on October 1, 2019 (Ohno, Litorja, Miller, & Zong, 2019). These findings were an important first step in the analysis of LX effectiveness, but it must be noted that NIST testing was conducted in a strictly controlled (artificially dark) laboratory environment with partially dark-adapted[3] participant pilots.
To further assess the effectiveness of the LXs, AAS directed ATR to evaluate the NIST laboratory results (both signage and lighting modifications) in a real-world setting with flight testing under both daytime and nighttime VMC. The objectives and requirements for this testing have been documented by AAS in an email dated November 18, 2019, to ATR and are listed in Sections 1.3 and 1.4. The scope, details, assumptions, and results for this testing effort are included in the subsequent sections of this report.

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[1] In discussing candela (cd), this report will use k as shorthand for 1,000 (e.g., "17k cd" for 17,000 cd)

[2] The NIST Laboratory Experimental Testing approach used 5,700 K LEDs lamps since it was decided that 5,700 K LEDs best matched the CCTs of 2,950 K incandescent lamps. For testing purposes, 5,000 K LED RCM (both 20 and 28 ft) will be used for testing since they are a pre-engineered LED light module and are in stock. It has been determined that 5,000 K LEDs closely match the color of the 5,700 K LED lamps on the existing LX. In that context, 5,000 K LEDs will be used during testing since the difference between the 5,000 K LED and 5,700 K LED is insignificant.

[3] Partially dark-adapted means that the observer's eyes were not exposed to any light for two minutes. This increases the sensitivity of rods in the retina, aiding in adapting to night vision. Notice that full dark adaptation typically takes 20–30 minutes.

1.2 OVERVIEW OF CUSTOM-MADE LIGHTED XS

This section contains an overview of the custom-made LXs that were acquired from approved manufacturers for use in this test effort. The test consisted of four different types of LX markers, with parameters as shown in Table 1.

Table 1. Lighted X Parameters

Model	Arm Length	Approximate Height	Lamp Type	Number of Lamps
L-893	20 ft	14 ft	Incandescent	20
L-893	20 ft	14 ft	LED	21
L-893X(L)	28 ft	20 ft	Incandescent	24
L-893X(L)	28 ft	20 ft	LED	25

The first custom-made, 20-ft incandescent LX (LX20) test article referenced in Table 1 has a 20-ft arm length with a total of 20 incandescent lamps and no overlapping center lamp at the intersection of the two arms. Figure 1 shows a notional view of this configuration.

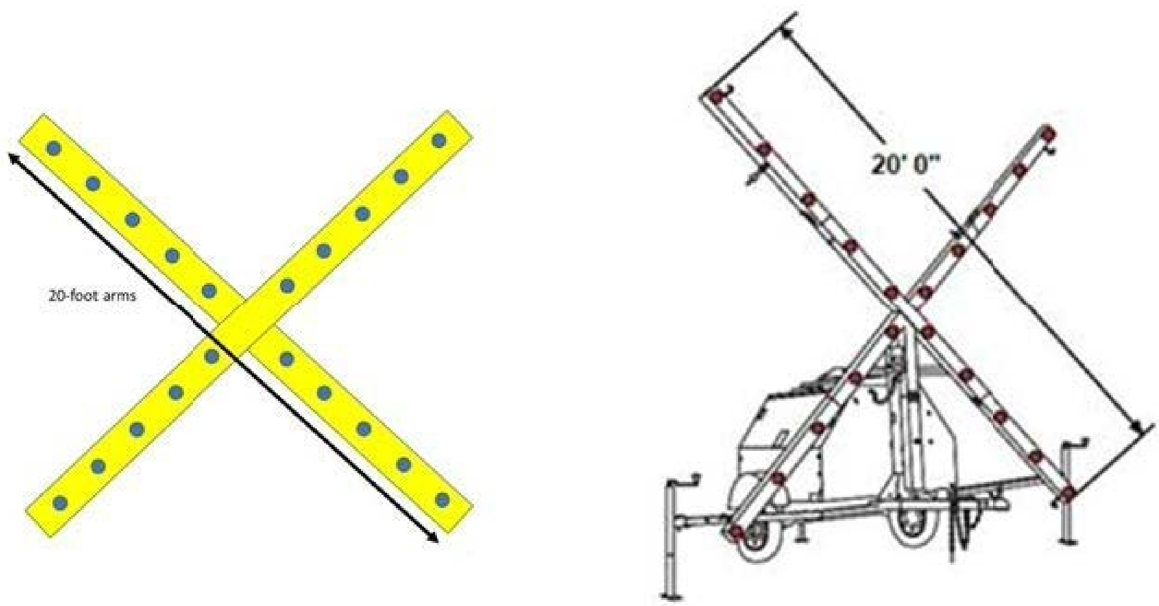

Figure 1. Custom-Made 20-ft Incandescent Lighted X (LX20)

In addition to the custom LX shown in Figure 1, three additional custom LXs were acquired to allow comparison across all combinations of size (20 ft versus 28 ft) and lamp type (incandescent versus LED).

The second test article was an LED 20-ft LX (LED LX20) and is notionally depicted in Figure 2. This configuration has 21 total LED lamps with an overlapping center lamp.

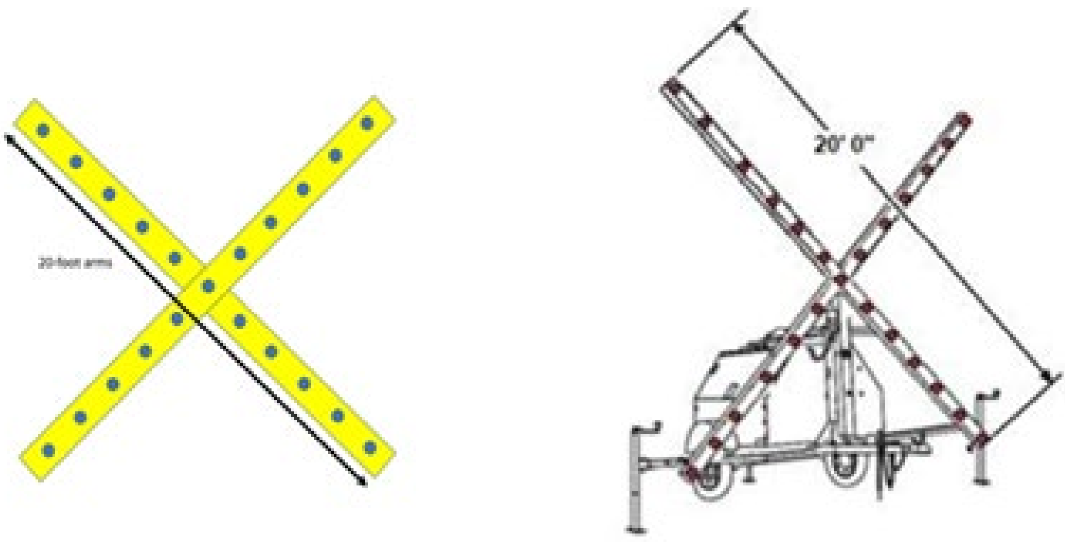

Figure 2. Custom-Made 20-ft LED Lighted X (LX20)

The third test article was an incandescent 28-ft LX (LX28) and is notionally depicted in Figure 3. This configuration has 24 total incandescent lamps with no overlapping center lamp.

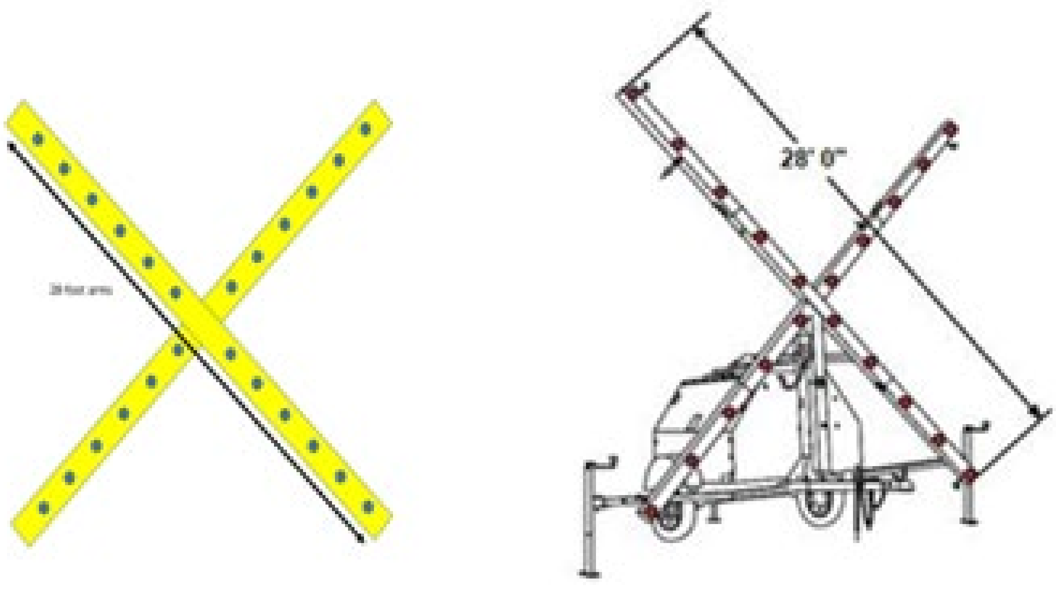

Figure 3. Custom-Made 28-ft Incandescent Lighted X (LX28)

The fourth test article was an LED 28-ft LX (LED LX28) and is notionally depicted in Figure 4. This configuration has 25 LED lamps with an overlapping center lamp. All LXs were customized to allow for their respective lamp intensities to be varied during the testing process.

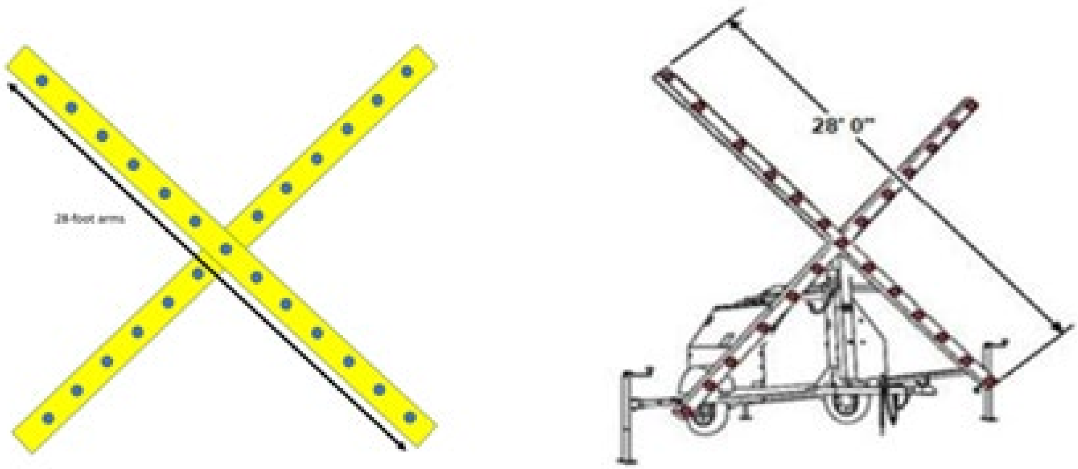

Figure 4. Custom-Made 28-ft LED Lighted X (LED LX28)

All effective beam intensity values shown in Table 2 are measured at the beam center. If the intensity value for a 10-degree radius offset or a 15-degree radius offset is required, the intensity data found in AC 150/5345-55 (FAA, 2007) can be used to calculate the ratios between the beam center and the 10- and 15-degree beam offsets. Table 2 shows the values of these calculated ratios. For example, a 100-cd bulb intensity at beam center would be expected to have a 49-cd intensity at a 10-degree offset and a 19-cd intensity at a 15-degree offset. Table 3 and Table 4 reflect candela values of each bulb for both daytime and nighttime.

Table 2. Effective Beam Intensity

Light-Intensity Focus	**Brightness (cd)**	**% of Beam Center**
Beam Center	70,000	100%
10-Degree Radius	34,000	49%
15-Degree Radius	13,000	19%

Table 3. Individual Fixture Intensities During Daytime Flight Evaluation

Effective Intensity for Entire Fixture (25 bulbs)	**Intensity for Each Bulb**		
All Values in cd	**Beam Center**	**10-Degree Radius**	**15-Degree Radius**
70,000	2,800	1,360	520
35,000	1,400	680	260

Table 4. Individual Fixture Intensities During Nighttime Flight Evaluation

Target Effective Intensity for Entire Fixture (25 bulbs)	**Target Intensity for Each Bulb**		
All Values in cd	**Beam Center**	**10-Degree Radius**	**15-Degree Radius**
2,000	80	39	15
1,000	40	19	7
500	20	10	4

The LXs were positioned side by side across the width of the test runway to enable size and flash rate comparisons. Figure 5 shows the actual placement of LXs on the simulated test runway.

Figure 5. Lighted X Setup for Flight Tests

1.3 FLIGHT TEST OBJECTIVES

The scope, objectives, and requirements of the LX flight test plan were based on AAS-100's email request, technical discussions with ATR, and content from the NIST experiment results; and evolved from the Phase 1 test results. The objectives can be summarized as follows:

1. Evaluate NIST recommendations in a real-world setting without consideration for natural weather conditions (e.g., precipitation, fog, snow).
2. Identify minimum and maximum intensities during daytime and nighttime operations.
3. Record optimum effective intensities for shape recognition at 1.5 NM and beyond.
4. Evaluate effectiveness of various flash rates.

1.4 FLIGHT TEST REQUIREMENTS

- The LX requirements specify two sizes to be used: 20 ft and 28 ft.

  - The larger LXs have an arm length of 28 ft (diagonal distance) and a height and width of approximately 20 ft.
  - The smaller LXs have an arm length of 20 ft (diagonal distance) and a height and width of about 14 ft.
- All LXs used in testing must transmit an aviation white color per SAE-AS-25050 (SAE International, 2006) as referenced in Engineering Brief (EB) No. 67D *Light Sources Other Than Incandescent and Xenon For Airport and Obstruction Lighting Fixtures* (FAA, 2012).
- Daytime evaluations must be conducted with LXs that are configurable to have a variable effective intensity of 35k cd and 70k cd at the beam center as indicated in AC 150/5345-55A (FAA, 2007).
- Nighttime evaluations must be conducted with effective intensities of 500 cd, 1,000 cd, and 2,000 cd at the beam center.
- Individual lamp intensities are assumed to be the required effective intensity divided by the total number of lamps in the LX (i.e., 25) per AC 150/5345-55A (FAA, 2007).
  - Table 2, Table 3, and Table 4 can be referred for individual lamp values calculated based on the number of lamps in a respective LX.
- All other parameters of the LX should also adhere to the specifications in AC 150/5345-55, including meeting the physical performance requirements necessary for assessment during daytime and nighttime operations.
- The evaluation process includes both daytime and nighttime flight evaluations with 16 pilot participants, matching the efforts of NIST and the Ground Test.
  - The optimum effective intensities from the ground test will be used for the flight test, based on pilot responses.

If unexpected issues such as glare arise during the flight test, consultation with NIST will be conducted to fine-tune the intensity values.

2. TESTING APPROACH

Phase 1 (ground-based tests) of this research was successfully completed in August 2023. Based on the ground-based test results, the following types of tests were recommended for flight testing:

- Intensity Evaluation—Part one of the flight testing should evaluate the visual recognition of all four LXs for daytime (35k cd and 70k cd) and for nighttime (500 cd, 1,000 cd, and 2,000 cd). The intensity values for daytime and nighttime were rated based on when the pilots first see the LX, when the LX shape becomes recognizable, and when (if applicable) the LX shape becomes unrecognizable. The pilots and copilots were requested to record the altitude/distance for additional data on acquisition distance when they first see the LX.
- LX Size Comparison—During the ground testing, results of the size comparison test were not conclusive for LED LX20 and LED LX28 in comparison to the incandescent. Therefore, the flight test was focused on obtaining pilots' preference on the LED RCMs size comparison. The pilots were requested to mark their preference on the questionnaire based on their observation.

- Flash Rate Tests—Additional testing was planned to assess three different flash rates for LED LXs. LED light bulbs turn off and on instantly, while incandescent light bulbs can take a minimum of 2.5 s to reach full intensity and to subside completely from full intensity. Because of this difference, it is important to establish a flash rate that works for LED LXs so they effectively attract the pilot's attention to indicate a closed runway. In the previous test phase, pilots preferred the RCM to be off for a shorter duration than 2.5 s. Preferred flash rates (1 s/0.5 s, 2.5 s/1 s, and 1.5 s/1.5 s) established from ground testing were tested further to determine the best flash rates for day and nighttime.

3. METHODS

3.1 PARTICIPANTS

Sixteen Certified Flight Instructor-Instrument (CFII) pilots, ranging from 22 to 79 years in age, participated in this testing activity. All were instrument-current and had a valid Class III or higher medical certificate. Total flight experience among the group ranged from 299 to 20,000+ hours, with a median of 733 hours. Two age groups were defined: 55 years or younger and over 55 years. Age and experience details of the pilot sample are shown in Table 5, both for the whole group (n = 16), and for each identified age group. The table provides the background characteristics for the 16 pilot participants, where *Time-in-type* represents total time in all high-wing Cessna variants (e.g., 150, 152, 172, 182, 206, and 210).

Table 5. Background Characteristics (Age and Experience), Pilots (n = 16)

	Age Range	**Mean Age**	**Median Age**	**Flight Hours (Range)**	**Flight Hours (Mean)**	**Flight Hours (Median)**	**Time-in-Type (Range)**	**Time-in-Type (Mean)**	**Time-in-Type (Median)**
All pilots	22–79	43.8	31	261–20,000	2,839	733	20–2,000	480	459
Younger (≤ 55) pilots	22–55	30.4	25	299–1,180	630	493	20–656	314	330
Older (> 55) pilots	56–79	74	73.5	3,876–20,000	9,466	4,522	460–2,000	978	475

3.2 TEST AIRCRAFT

Eight Cessna single-engine aircraft were used for testing: seven of these were C172 Skyhawk models, and one was a C152. Although the C152 is a slightly smaller two-seat variant of the C172, it is similar in approach speeds, handling characteristics, and view out of the windscreen. The aircraft were able to closely match one another's speeds around the traffic pattern. Aircraft were required to have Automatic Dependent Surveillance Broadcast (ADS-B) Out capability (Automatic Dependent Surveillance-Broadcast (ADS-B) Out Equipment and Use, 2019). Aircraft were also required to have two communications radios to permit simultaneous monitoring of both the WWD 122.7 MHz Common Traffic Advisory Frequency (CTAF) and the 123.45 MHz designated test frequency (used for air-to-air, and research team-to-air communications), described in Section 3.4.6.

3.3 EQUIPMENT

ADS-B technology was key to traffic monitoring and situation awareness during flight testing, both for reasons of station keeping (position monitoring and maintaining safe distance from other aircraft) among multiple test aircraft in the flight pattern and watching for potential intruder aircraft. ATR provided Appareo Stratus 3 portable ADS-B In receivers (left image, Figure 6) (one per aircraft), which fed an Apple iPad-based Foreflight electronic flight bag (EFB) application, or app, which, in turn, provided a moving map (Visual Flight Rules [VFR] sectional chart) view (right image, Figure 6) of the local area, showing test traffic pattern waypoints and real-time traffic (participant aircraft and intruder aircraft).

Figure 6. Appareo Stratus Portable ADS-B In Receiver (left) and ForeFlight EFB App, on iPad (right)

3.4 PROCEDURES

The steps followed to develop the procedure for conducting the flight tests are described in Sections 3.4.1 through 3.4.6.

3.4.1 Test Route Creation

WWD airport has two operating runways, 1/19 and 10/28, as shown in Figure 7. The LXs were set up on the FAA Cape May Airport Research Taxiway, which was designated as a simulated Runway 5/23, for test purposes only, with broadcasts only on the test radio frequency (never on CTAF). Based on early informal flight observations and consultations with pilots about required spacing, simulated approaches were designed for Runway 5/23. To allow for variations in wind, two separate approaches (Figure 7) were devised: an approach from the south to Runway 5 with the LXs positioned at the pseudo waypoint “JASON,” and an approach from the north to Runway 23 with the LXs positioned at “KELCE.” The winds during test week consistently favored Runway 23, so the following description will only refer to the north side pattern. Early pretesting drove the design of a standard left-hand traffic pattern, as shown in Figure 8. The distance from LXs (KELCE) to WHALE, SHARK, and OCEAN was 1.5, 6.5, and 12 NM, respectively. As shown in Figure 7, waypoints were defined to designate the pattern corners (where aircraft would be expected to turn crosswind, downward, base, and final).

The traffic pattern simulated an area navigation (RNAV) approach, in which pilots are provided lateral but not vertical guidance. It was important that research staff did not impose altitude restrictions on pilots. Pilots were instructed to maintain approximately 2,000 ft AGL altitude on the final approach leg (though in the end the choice of altitude was left to pilot discretion) and to intercept and fly a typical visual glide slope, as they would on any “unaided” (i.e., no visual approach system indicator or precision approach path indicator) approach.

After establishing the traffic pattern, latitude/longitude waypoints were converted into a single Keyhole Markup Language custom waypoint file that was made available to pilots for upload to iPads in advance of flight testing. Each pilot had an iPad and ForeFlight EFB app displaying a sectional chart moving map available throughout each flight with the test traffic pattern displayed.

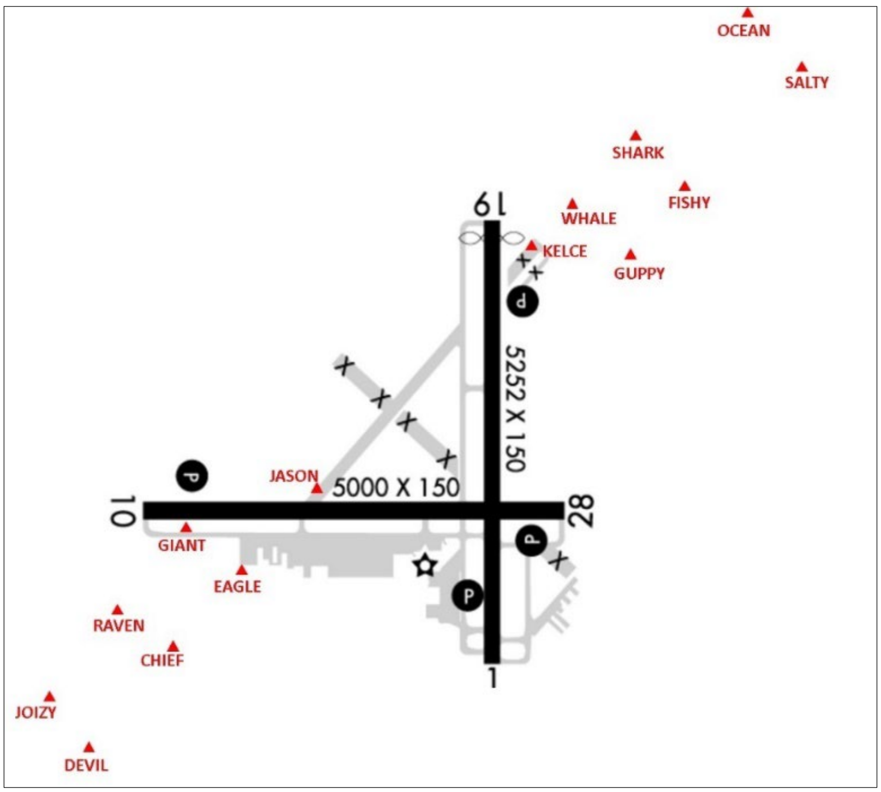

Figure 7. Flight Test Pattern at Cape May Airport, Showing Pseudo Waypoints and Simulated Runway 5/23 (not to scale)

3.4.2 Research Team Coordination

Throughout testing, research staff were stationed at two locations: the technicians, or the Tech Team, were stationed near the research taxiway, close to the LXs. The Tech Team was responsible for overseeing the LX equipment and its experimental configurations for each flight pass. Research operations personnel, or the Ops Team, were stationed inside the WWD Fixed-Base Operator (FBO) facility (with a view to the active Runway 10/28). The Ops Team was responsible for monitoring test aircraft, watching for intruder traffic, and communicating as necessary (on CTAF and/or test frequency, as appropriate). During testing, the Tech and Ops teams were in constant radio contact to coordinate test sequences, share flight progress, and other communications.

3.4.3 Pretesting

Pretesting was conducted on March 5, 2024, one week before scheduled flight testing. As with the flight test, pretesting took place at WWD. The aims of pretesting were to:

- Confirm the approximate dimensions of the flight test pattern, in terms of likely acquisition and visibility distance
- Make an initial check of the traffic pattern in terms of timing, spacing, and general flight procedures
- Test the ADS-B traffic monitoring equipment, both for test aircraft and potential intruder aircraft
- Test the intended two-frequency communication procedures (including transmission range)
- Test location and configuration control of the LX
- Test technical setup and communication/coordination procedures between the Tech and Ops teams

The pretest results assisted in establishing the following for the flight tests.

During the pretest, radio communication with two frequencies (CTAF and 122.75) was tested to establish the communication procedure and to verify the feasibility of using separate frequency (122.75) for flight testing activity. On the ground, it was determined that the frequency 122.75 was noisy and was almost unusable due to interference.

Pretest also helped with determination of an appropriate location to house the Ops team. Initially, the plan was to establish the team right outside the FBO to be able to spot intruder aircraft. However, during pretesting it was determined that the location was too noisy to be able to communicate with pilots effectively. Hence, the Ops Team was housed in a room within the FBO that had a large window opening towards Runway 10/28. This was preferred because spotters could be outside the window and still be able to communicate with other Ops Team members.

The feasibility of both southwest and northeast traffic patterns were tested, and it was established that the northeast traffic pattern was a more practical pattern to be followed during the flight tests (Figure 8).

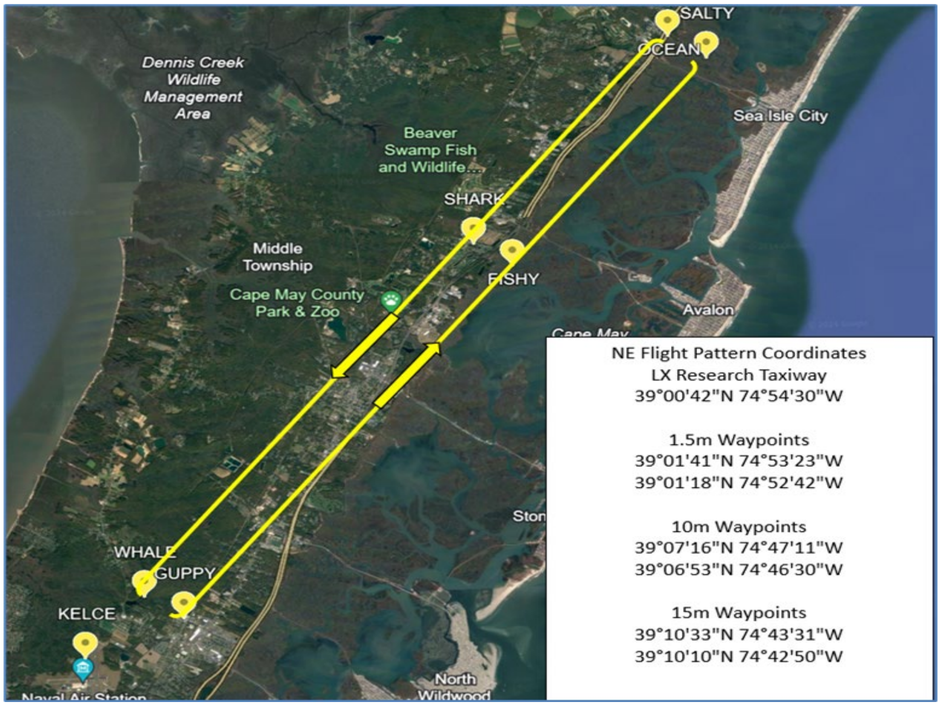

Figure 8. Northeast Flight Pattern

The Ops Team verified the feasibility of using ADS-B for aircraft tracking at the communications station. Another goal with ADS-B testing was to gauge the delay in receiving aircraft location on an iPad (fed via an ADS-B on the ground) versus the real-world aircraft location (Figure 9).

Figure 9. Aircraft Tracking

The predetermined location of LXs (Figure 10) was also verified during the pretesting activity with a single LX to ensure the placement will work for final testing with the planned route of the test aircraft and will not interfere with the normal operations of the airport.

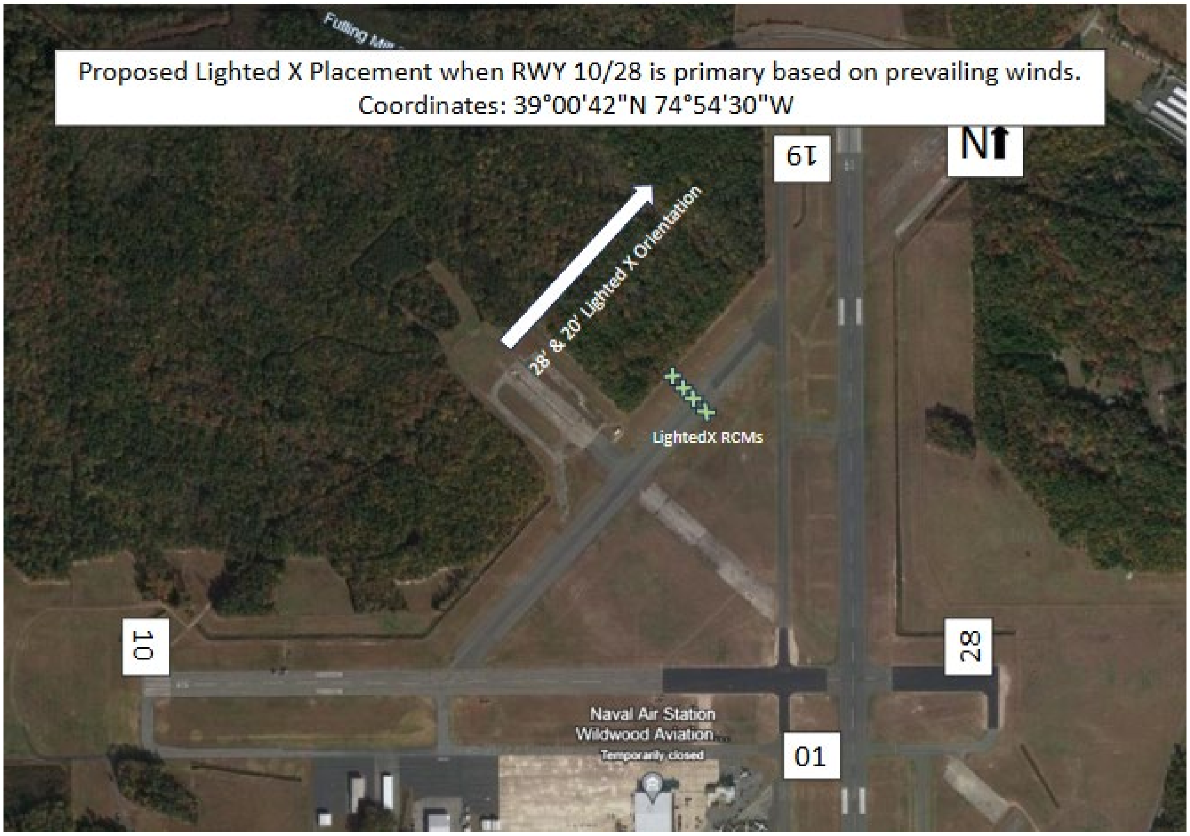

Figure 10. Lighted X Placement

3.4.4 Flight Trials

Before the flight trials, pilots were briefed (see Appendices B and C) on the goals and specific flight and data collection procedures. Pilots were assigned to each of the eight aircraft (most pilots and aircraft came from flight schools, so there was de facto aircraft assignment on arrival). After the briefing, completion of consent forms, verification of EFB and waypoint installations, and answering of any remaining questions, pilots departed Runway 10 (winds favored Runway 10 throughout flight testing, and it remained the active runway the entire time) and established a flight formation of approximately 1.5 NM in trail spacing. First, pilots made an initial pass where the aircraft turned base-to-final at OCEAN (Figure 8) and proceeded inbound via SHARK and WHALE. Although pilots were instructed to follow a standard visual glide slope, altitude was left to the pilots' discretion. Pilots were instructed to treat WHALE as a missed approach point, at which they would make a climbing left turn via GUPPY to join a left downwind leg. After the first (acquisition) approach, the aircraft followed a tighter pattern turning left base at FISHY. Testing required consistent trail spacing. Based on pilot feedback during pretesting and preliminary runs during flight testing, a suggested approach speed of 90 knots indicated airspeed (KIAS) was chosen by participants.

Flight testing was scheduled for March 10 through March 14, 2024, but was conducted over three days/nights, from March 12, 2024, to March 14, 2024. The first two days of scheduled flight tests (provided in Appendix B) were cancelled due to high wind conditions. Once the weather improved, the flight test began. Two sessions (one day and one night) were conducted on day one. On day two, two sessions were conducted during the day and two at night to take advantage of clear weather. This determination was made because of the weather delay on days one and two. This ensured that additional time would be available if any night tests needed to be repeated; however, it proved to be a difficult schedule for the pilots. A delayed start was planned for day three to give the pilots the opportunity to rest.

Breaks of at least 60 minutes were provided between flight sessions. Flight tests were conducted during morning, afternoon, and evening sessions, with meal and inter-session breaks. Breaks were used to:

- Debrief pilots on the preceding flight session (e.g., LX characteristics)
- Allow pilots to rest and recover
- Refuel aircraft as necessary
- Brief pilots on the upcoming flight session

The estimated time for each aircraft to complete one flight pattern was 15 minutes, but the actual time (through FlightAware tracking) was 12 minutes. Each flight test took about 1.5 hours for each segment (flight pattern) of test during daytime and nighttime flights. Researchers anticipated the tests would occur over four days, but with extra hours of testing on days two and three, test scenarios were completed in three days (day and night).

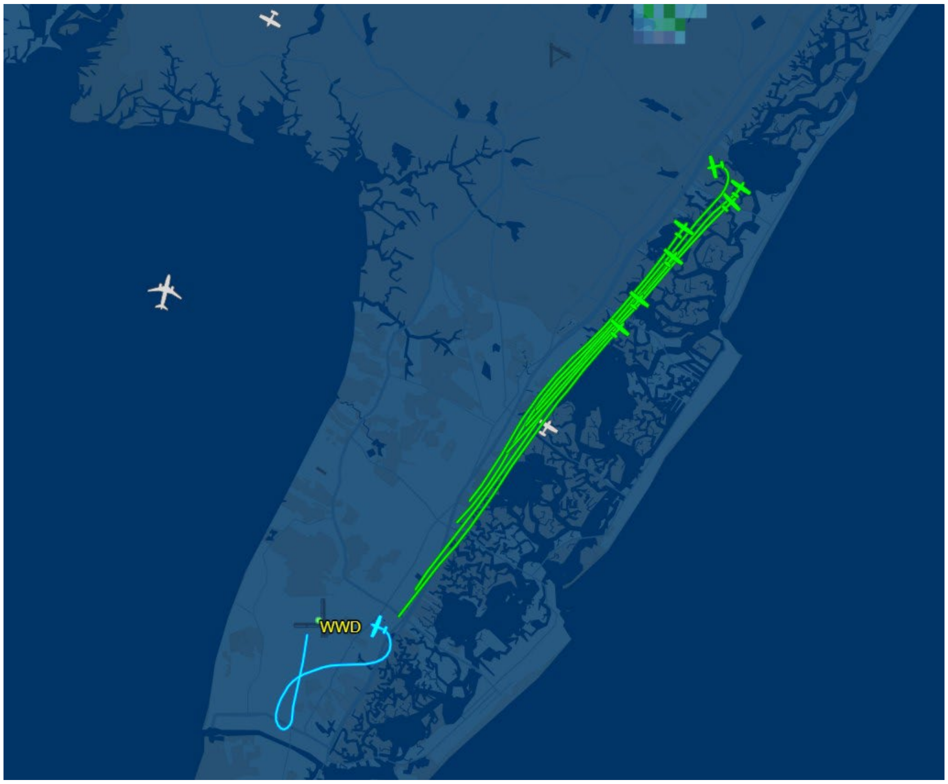

Figure 11. Test Flight Paths

3.4.5 Data Collection Procedures

ADS-B data in each aircraft provided location information, including distance from waypoints. During each approach, in each experimental condition, pilots noted independently, using a paper-and-pencil worksheet, the following information:

- Their role, Pilot Flying (PF) or Pilot Monitoring (PM)
- Altitude
- Distance from KELCE (i.e., the location of the LX)
- Other test-specific data

For experimental control and to reduce the risk of fatigue, pilots were asked to trade roles (PF versus PM duties) every four flights, and pilots noted their role at the time of each data recording.

3.4.6 Traffic Surveillance and Air-Ground Communications

Traffic monitoring and communication procedures were critical and required significant pretesting and refinement. For example, ADS-B in traffic alerts would normally complicate this type of formation flying, as test aircraft would trigger each other's alerting systems and cause undue disturbance. Disabling traffic alerts, however, would expose test aircraft to unreasonable risk from potential intruders. In the end, a hybrid approach was chosen that involved redundant monitoring and communication from the ground Ops Team for potential intruders and alerting via the test radio tower frequency.

While in flight, each aircraft monitored both TEST (123.45) and CTAF (122.7) radio frequencies. While interacting with normal airport traffic (i.e., in the standard pattern) test aircraft transmitted position reports on CTAF. Once out of the standard traffic pattern, aircraft coordinated their flights (in-trail spacing, experimental condition, and other test issues) to ground and other aircraft via the test frequency.

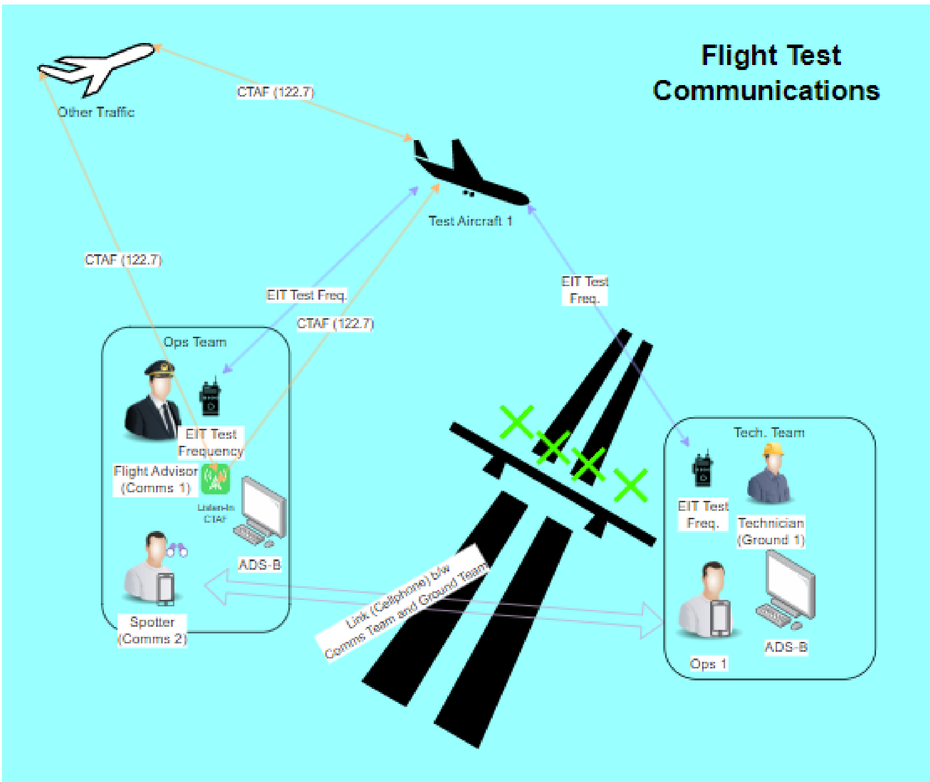

Figure 12. Flight Test Communications

3.5 EXPERIMENTAL CONDITIONS

Based on the results of earlier ground-based test results (in August 2023), it was decided to evaluate three parameters: LX intensity, size, and flash rate, as described in Sections 3.5.1 through 3.5.3. Each of the six flight sessions systematically varied one of the three parameters.

3.5.1 Intensity Evaluation

Flight testing compared intensities of 35k cd and 70k cd (under daytime conditions) and 500 cd, 1,000 cd, and 2,000 cd (for nighttime), in terms of their impact on visual recognition. Table 6 lists the intensities recommended for flight tests.

Table 6. Lighted X Lamp Intensity Values for Flight Testing

Daytime/Nighttime	Intensity (cd)
Daytime	35,000
Daytime	70,000
Nighttime	500
Nighttime	1,000
Nighttime	2,000

During each intensity-evaluation session, pilots independently evaluated and recorded the following information on their personal response sheet:

- Acquisition distance (i.e., the distance at which the pilot first saw the LX)
- Recognition distance (i.e., the distance at which the "X" shape of the LX was first recognized)
- Whether the LX was still recognizable as an "X" from 1.5 NM away
- Loss-of-recognition distance (the distance at which the LX is no longer recognizable as an "X")

3.5.2 Lighted X Size Evaluation

Ground-based testing with 35k cd LED LXs did not yield a definitive conclusion regarding pilot preference for size (between 20 and 28 ft). Given that 35k cd was chosen as the minimum daytime intensity for subsequent flight testing, it was crucial to determine the preferred size for pilot accommodation. This data point would then be evaluated alongside results from other scheduled tests.

The decision to focus solely on one configuration during this flight test was guided by both scientific and economic considerations. Expanding the scope to include additional configurations would have necessitated a significant increase in flight rounds, thereby extending the testing period and accumulating additional flight hours. Furthermore, prior ground tests involving size comparisons for other configurations had already revealed distinct pilot preferences. Therefore, retesting these configurations was deemed unnecessary. Appendix B provides a list of the test RCM configuration comparisons.

In this session dedicated to size evaluation, pilots participated in an independent assessment. Each pilot individually recorded their preference for LX size on a designated response sheet. This evaluation was conducted under daytime conditions and involved a comparison of the LED LX20 and LED LX28 lighted X sizes. Both configurations were tested at an intensity level of 35k cd.

3.5.3 Flash Rate Evaluation

Flight testing for flash rate evaluation compared a fixed incandescent flash rate (2.5s ON/2.5s OFF) against a set of three flash rates for LED LXs (as shown in Table 7). These were evaluated for both 20- and 28-ft LX versions. The purpose of this test was to identify the most suitable flash rate, ideally balanced with optimal intensity, for LED LXs. The objective was to ensure the markers effectively captured the attention of pilots during runway maintenance operations without causing distraction or compromising pilots' visual acuity. Appendix B presents a complete list of test configurations for this evaluation.

During this session, pilots independently evaluated and recorded their preferred flash rate on a designated response sheet. The pilots (flight observers) were asked in their worksheet if flash rates on LED LXs (20-ft and 28-ft) are better than their corresponding incandescent LXs' traditional flash rate of 2.5s ON/2.5s OFF. Pilots selected from three options (Disagree, Same, or Agree) in their questionnaire. Responses from all pilots were then analyzed to determine the preferred flash rate for day and night for LED LXs. Table 7 lists the flash rates evaluated during flight testing.

Table 7. Predetermined LED Flash Rates

LED Flash Rates (in seconds)		
Type	**ON**	**OFF**
Asymmetrical	1	0.5
Asymmetrical	2.5	1.0
Symmetrical	1.5	1.5

4. PHASE 2: FLIGHT TEST RESULTS

Inconsistencies were observed comparing the results of the flight testing and the NIST Laboratory Study, such as the results from the intensity and LX size evaluation tests discussed in Section 4.1. Section 4 describes how the observers rated the LXs for different tests and the overall results after the responses were analyzed.

4.1 INTENSITY EVALUATION

4.1.1 Intensity Evaluation Test Results—Daytime

Table 8 and Figure 13 show the test results for daytime intensity evaluation tests that were performed with intensities of 35k cd and 70k cd.

Table 8. Intensity Test Results—Daytime

Intensity/Size Evaluation—Daytime					
#	**Test Configurations**	**Acquisition**		**Recognition**	
		Average Altitude (ft)	**Average Distance (NM)**	**Average Altitude (ft)**	**Average Distance (NM)**
Segment 1					
1	Incandescent LX20 at Intensity 35,000 cd	1,084	3.04	897	2.16
2	LED LX20 at Intensity 35,000 cd	1,063	3.06	872	2

Intensity/Size Evaluation—Daytime					
#	**Test Configurations**	**Acquisition**		**Recognition**	
		Average Altitude (ft)	**Average Distance (NM)**	**Average Altitude (ft)**	**Average Distance (NM)**
3	Incandescent LX28 at Intensity 35,000 cd	1,138	3.31	953	2.46
4	LED LX28 at Intensity 35,000 cd	1,167	3.77	1,014	2.84
Segment 2					
5	Incandescent LX20 at Intensity 70,000 cd	1,913	7.16	1,206	3.55
6	LED LX20 at Intensity 70,000 cd	1,847	7.26	1,206	3.98
7	Incandescent LX28 at Intensity 70,000 cd	1,766	6.92	1,288	4.13
8	LED LX28 at Intensity 70,000 cd	1,797	6.81	1,344	4.23

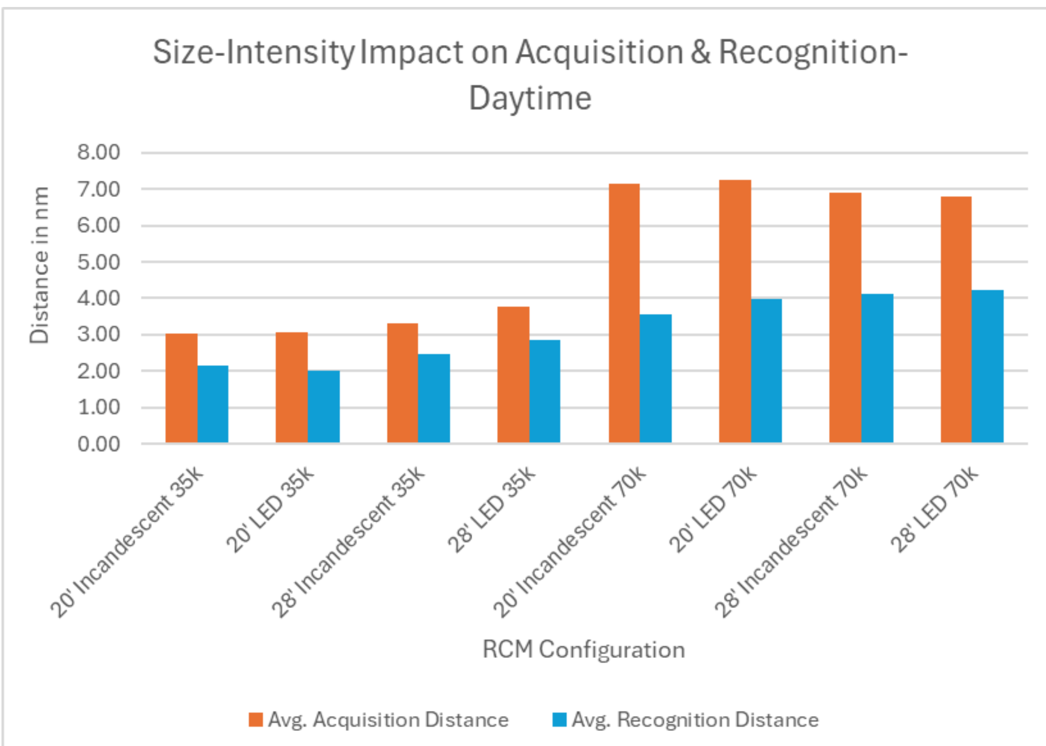

Figure 13. Intensity Evaluation Results—Daytime

4.1.1.1 Synopsis of Intensity Evaluation Results—Daytime

The Daytime Intensity Evaluation Test required pilots to provide the distance they were from the LX when they first acquired the LX (noticed a light on the runway) and when they first recognized the "X" shape.

Overall, the pilots were able to recognize the "X" shape beyond the threshold distance of 1.5 NM from the test runway for all intensity/size combinations. With an intensity of 70k cd, the acquisition distance of the LX significantly increased to more than 6 NM compared to 3 NM for the 35k cd intensity. The LED LXs have a slightly improved recognition distance over their incandescent counterparts. In terms of size, both types of 28-ft LXs performed better than the 20-ft LXs on the recognizability of "X" shape. One interesting exception is the initial acquisition visibility of LX20s at 70k cd in which the LX20 of both types performed better than LX28s. At no point on the flight path up to 1.5 NM from the location of LXs did any of the LXs become unrecognizable to the pilot after the "X" shape was identified.

4.1.1.2 Effect of Sunlight on Acquisition and Recognition Distance

A subset of the intensity tests was executed twice during different times of the day to gauge the effect of sunlight on the acquisition and recognition distances. Figure 14 and Figure 15 show the difference in the average acquisition and recognition distance reported by pilot observers when sun was in their line of sight versus when it was not, based on the following information:

- **Avg. Acq Distance (Sunlight LoS)** – When the sun was in front of the pilots approaching the runway close to their line of sight
- **Avg. Acq Distance** – When the sun was not in front of the pilots approaching the runway
- **Avg. Recog Distance (Sunlight LoS)** – When the sun was in front of the pilots approaching the runway close to their line of sight
- **Avg. Recog Distance** – When the sun was not in front of the pilots approaching the runway

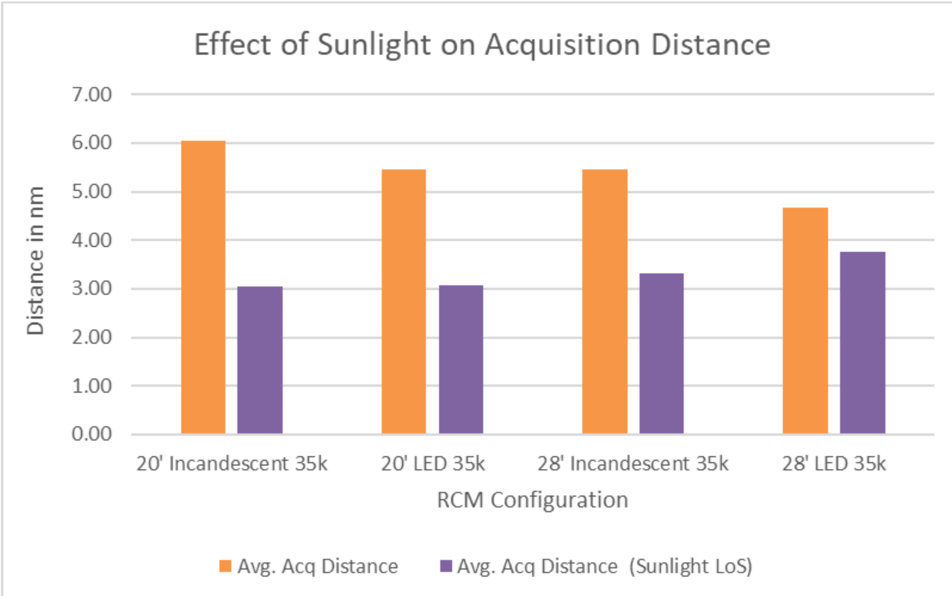

Figure 14. Intensity Test—Effect of Sunlight on Acquisition Distance

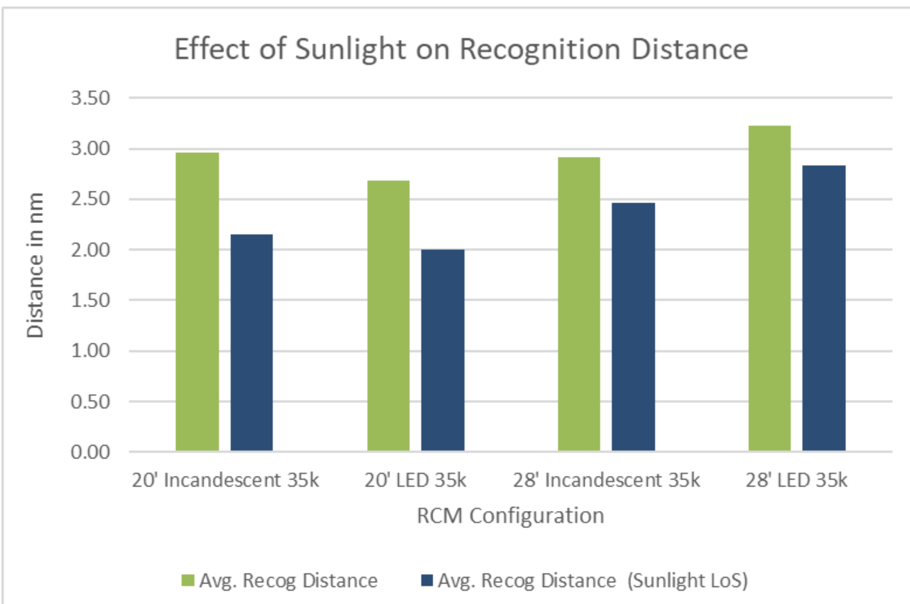

Figure 15. Intensity Test—Effect of Sunlight on Recognition Distance

In summary:

- The acquisition distance improves significantly (Figure 14), almost doubling for smaller LXs when the sun is not in the line of sight of pilots approaching the runway. However, the improvement for the LED LX28 is more moderate.
- The recognition distance improves moderately (Figure 15) when the sun is not in the line of sight of pilots approaching the runway.

The moderate improvement in recognition versus more significant improvement in acquisition distance could be because of distance when the recognition happens and the fact that pilots are looking downwards at sharper angles towards the ground.

4.1.2 Intensity Evaluation Test Results—Nighttime

Table 9 and Figure 16 show the test results for nighttime intensity evaluation tests that were conducted with three different intensities (500 cd, 1,000 cd, and 2,000 cd).

Table 9. Intensity Test Results—Nighttime

Intensity/Size Evaluation—Nighttime					
#	**Test Description**	**Acquisition**		**Recognition**	
		Avg Altitude (ft)	**Avg Distance (NM)**	**Avg Altitude (ft)**	**Avg Distance (NM)**
Segment 1					
1	Incandescent LX20 at 500 cd	1,384	4.97	1,067	2.87
2	LED LX20 at 500 cd	1,488	5.76	894	2.27
3	Incandescent LX28 at 500 cd	1,633	7.92	1,025	3.35
4	LED LX28 at 500 cd	1,672	7.74	956	3.12
5	Incandescent LX20 at 1,000 cd	1,850	9.04	1,236	3.04
6	LED LX20 at 1,000 cd	1,750	8.55	938	1.7
Segment 2					
7	Incandescent LX28 at 1,000 cd	1,844	8.92	1,484	5.11
8	LED LX28 at 1,000 cd	1,900	8.50	1,334	3.54
9	Incandescent LX20 at 2,000 cd	1,950	9.92	1,025	2.67
10	LED LX20 at 2,000 cd	2,019	10.70	1,156	3.06
11	Incandescent LX28 at 2,000 cd	2,000	11.03	1,294	3.68
12	LED LX28 at 2,000 cd	2,043	10.98	1,331	3.15

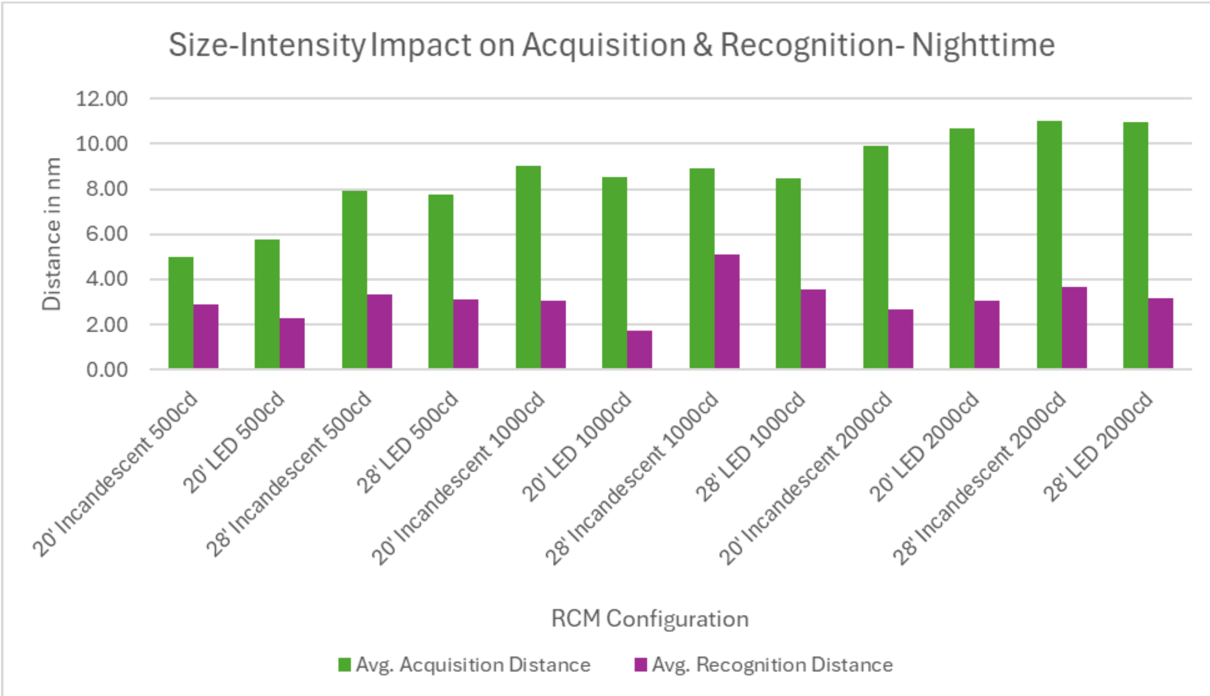

Figure 16. Intensity Evaluation Results—Nighttime

4.1.2.1 Synopsis of Intensity/Size Results—Nighttime

The Nighttime Intensity Evaluation Test required pilots to provide the distance they were from the LX when they first acquired the LX (noticed a light on the runway) and when they first recognized the "X" shape.

Although the LEDs were deemed brighter by pilots, the data in Table 9 show that the incandescent LXs performed better than LED LXs in several configurations at nighttime. This could be due to the amber color of the light it produces. Similar observations were noted by some pilots in their post-test session debrief (see observer comments in Section 6.   of this report). Overall, the pilots were able to recognize the "X" shape beyond the threshold distance of 1.5 NM from the test runway. The LX28 at 2,000 cd (both LED and incandescent) had the best acquisition distance. However, for recognition distance, the incandescent LX performed better than the LED.

The incandescent LX28 performed consistently better at all intensities than other LXs. Some pilots provided comments about LED LX20 at 2,000 cd being too bright, which caused its shape to be unrecognizable as "X." Comments are discussed in Section 6. . The incandescent LX28 at 1,000 cd seemed to be the best performing configuration as the time of recognition as an "X" from the farthest distance (5.11 NM). Acquisition distance was close to 10 NM from the LX location, which exceeds requirements to meets AC 150/5345-55A (FAA, 2007).

The closest any LED LX came to incandescent LX28 results was the LED LX28, which was the second-best performing LX. The LED LX28 was at its best performance at 1,000 cd ("X" shape recognized at 3.54 NMm).

4.2 SIZE COMPARISON

This test was conducted to compare the recognizability of the LX shape across sizes (20 ft versus 28 ft) to confirm the size preference by pilots at 35k cd. The LED LX20 was compared with LED LX28 at 35k cd intensity. Results were inconclusive on what was more recognizable at 1.5 NM during the Phase 1 ground-based testing for this configuration.

To conduct this test, both sizes (LED LX20 and LED LX28) of LED LXs were illuminated at the same time. They were placed next to each other, as shown in Appendix A.

The results, as shown in Figure 17, the LED LX28 was preferred by pilots and was visible from beyond 1.5 NM from the location of LX.

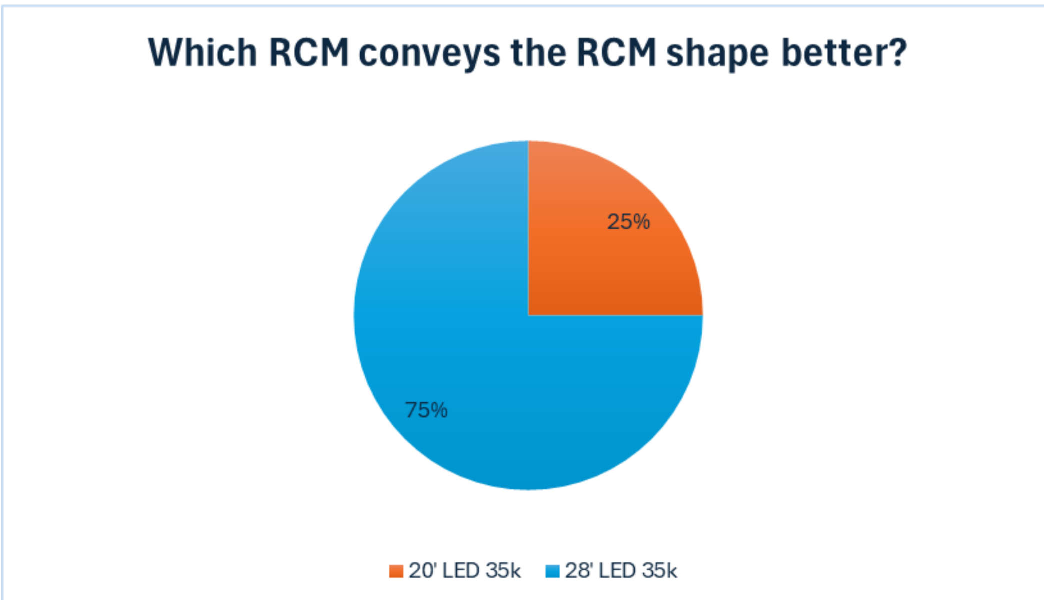

Figure 17. Size Comparison Result—Daytime

For this test configuration, the results indicated that 4 pilots (25%) preferred the LED LX20, whereas 12 pilots (75%) preferred the LED LX28.

4.3 FLASH RATE TESTING

This test consisted of pilots evaluating three separate flash rates to determine which may prove most effective in getting pilots' attention. The flash rates tested are shown in Table 10.

Table 10. Predetermined LED Flash Rates

LED Flash Rates (in seconds)		
Type	**ON**	**OFF**
Asymmetrical	1	0.5
Asymmetrical	2.5	1.0
Symmetrical	1.5	1.5

The test setup comprised locating two LXs of the same size side by side on the taxiway: one incandescent and the other LED. Both LXs were illuminated simultaneously at the same intensity, with the incandescent LX flash rate set to 2.5s ON/2.5s OFF and the LED LX flash rate set to one of the three different flash rates shown in Table 10. A comparison was made for each of the flash rates, for both daytime and nighttime conditions, and for both the 20-ft and 28-ft LXs.

The pilots/copilots compared both LXs and completed the provided questionnaires to record their observations for each flash rate at each intensity level. The complete questionnaire for flash rate testing can be found in Appendix B.

For analysis purposes, the observers were given a questionnaire and asked if LED RCM was more effective than the incandescent. Observers chose from the following options:

- Disagree (flash rate (2.5 ON/2.5 OFF) of incandescent RCM is preferred)
- Same (both flash rates are at the same level of preference)
- Agree (LED flash rate is better than the incandescent flash rate of 2.5 ON/2.5 OFF)

4.3.1 Flash Rate Test Results—Daytime

The test was conducted during the daytime at 35k cd, and the flash rate was varied (Table 11) for each segmented flight observation. There were six passes made to observe the LX at various flash rates. Figure 18 and Figure 19 show the daytime flash rate results for the 20-ft and 28-ft RCM, respectively.

Table 11. Flash Rate Results—Daytime

Flash Rate Comparison—Daytime (at 35,000 cd)						
#	**RCM (LX)**	**Left RCM (Incandescent)**	**Right RCM (LED)**	**ON/OFF interval of "X" displayed by right RCM is better than left RCM?**		
		Flash rate (On/Off)	**Flash rate (On/Off)**	**Disagree (Count)**	**Same (Count)**	**Agree (Count)**
Segment 1						
1	LX20	2.5s/2.5s	1s /0.5s	5	0	9
2	LX20	2.5s/2.5s	2.5s/1s	6	1	7
3	LX20	2.5s/2.5s	1.5s/1.5s	1	2	11
Segment 2						
4	LX28	2.5s/2.5s	1s/0.5s	4	1	9
5	LX28	2.5s/2.5s	2.5s/1s	5	1	8
6	LX28	2.5s/2.5s	1.5s/1.5s	1	1	12

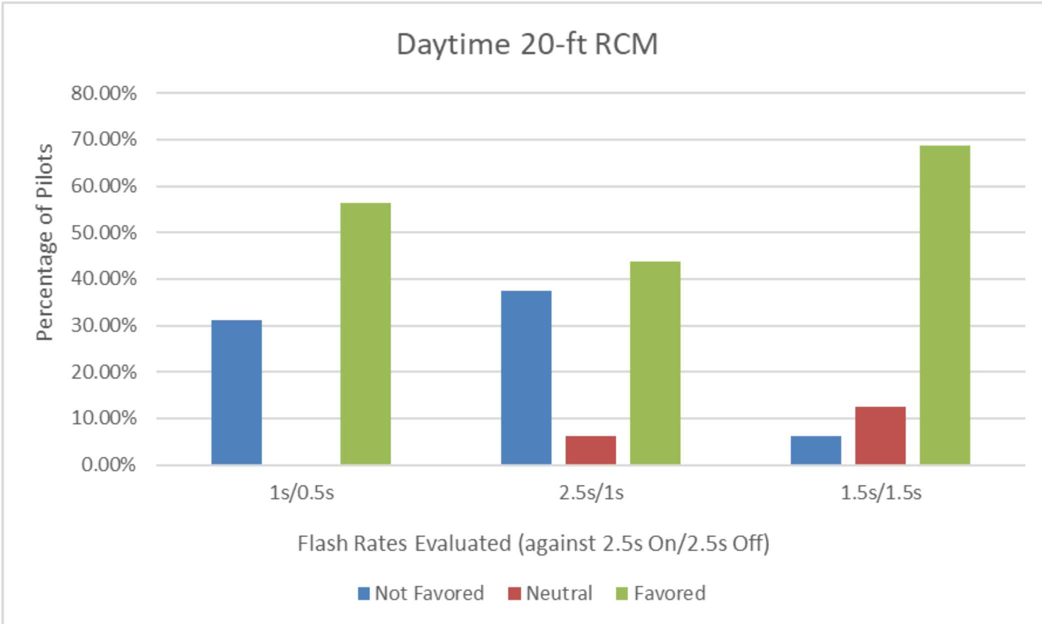

Figure 18. Flash Rate Results for 20-ft Lighted X

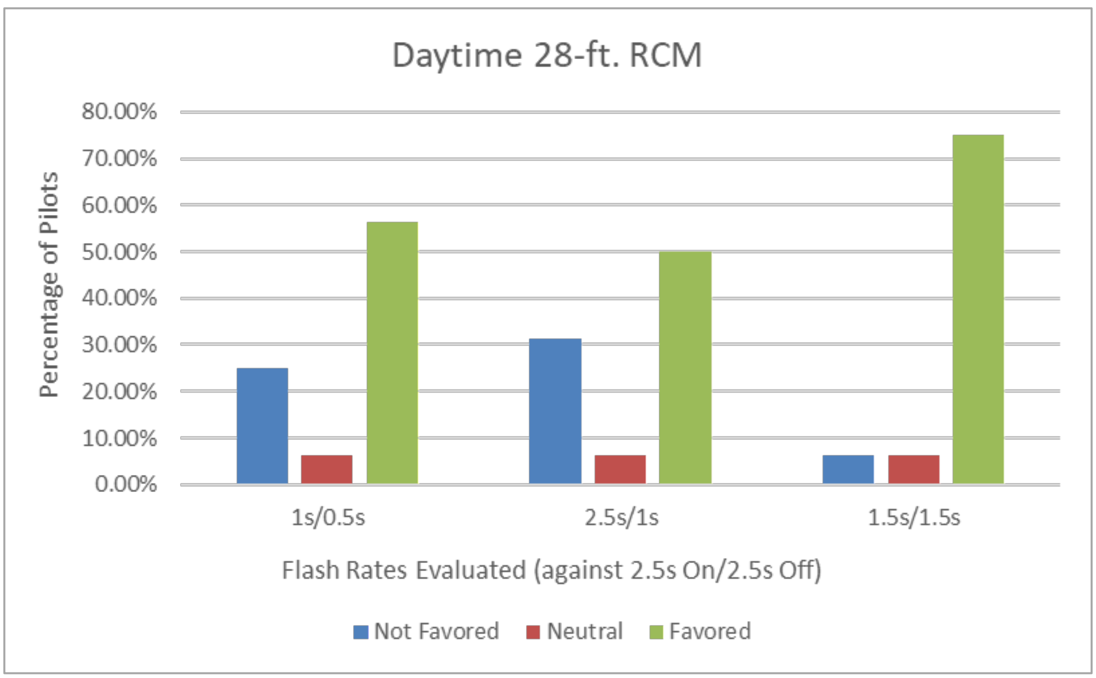

Figure 19. Flash Rate Results for 28-ft Lighted X

4.3.1.1 Synopsis of Flash Rate Results—Daytime

For LX20s, most pilots preferred a flash rate of 1.5s ON/1.5s OFF, with 11 pilots clearly stating it is better than the flash rate of 2.5s ON/2.5s OFF. Two were neutral to both flash rates. For

LX28s, also, pilots overwhelmingly preferred flash rate of 1.5s ON/1.5s OFF, with 12 clearly preferring this flash rate and one being neutral to both.

Side-by-side comparisons of LED flash rates between two LXs of the same type (e.g., an LED LX20 flashing at 1s ON/0.5s OFF compared to a LED LX20 flashing at 1.5s ON/1.5s OFF) were not possible due to limitations with equipment availability. To select a single flash rate, a flight test is recommended to compare the two most preferred flash rates from the current test.

4.3.2 Flash Rate Test Results—Nighttime

The nighttime test was conducted at 1,000 cd intensity, and the flash rate was varied for each segmented flight observation, as shown in Table 12. There were six passes to observe the LED LX at various flash rates. Figure 20 and Figure 21 show the daytime flash rate results for the 20-ft and 28-ft RCM, respectively.

Table 12. Flash Rate Results—Nighttime

Flash Rate Comparison—Nighttime (at 1,000 cd)						
#	**RCM Size**	**Left RCM (Incandescent)**	**Right RCM (LED)**	**ON/OFF interval of "X" displayed by right RCM is better than left RCM?**		
		Flash rate (On/Off)	**Flash rate (On/Off)**	**Disagree (Count)**	**Same (Count)**	**Agree (Count)**
Segment 1						
1	LX20	2.5s/2.5s	1s /0.5s	2	1	13
2	LX20	2.5s/2.5s	2.5s/1s	6	4	6
3	LX20	2.5s/2.5s	1.5s/1.5s	2	2	11
Segment 2						
4	LX28	2.5s/2.5s	1s/0.5s	4	0	12
5	LX28	2.5s/2.5s	2.5s/1s	5	3	7
6	LX28	2.5s/2.5s	1.5s/1.5s	2	3	11

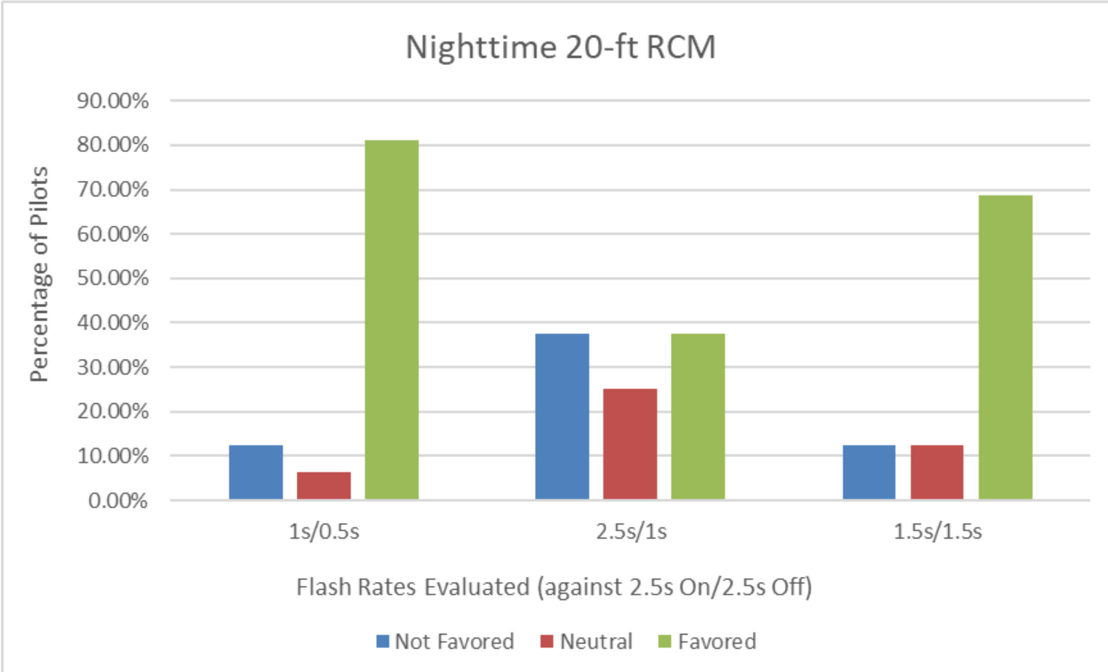

Figure 20. Flash Rate Results for 20-ft Lighted X—Nighttime

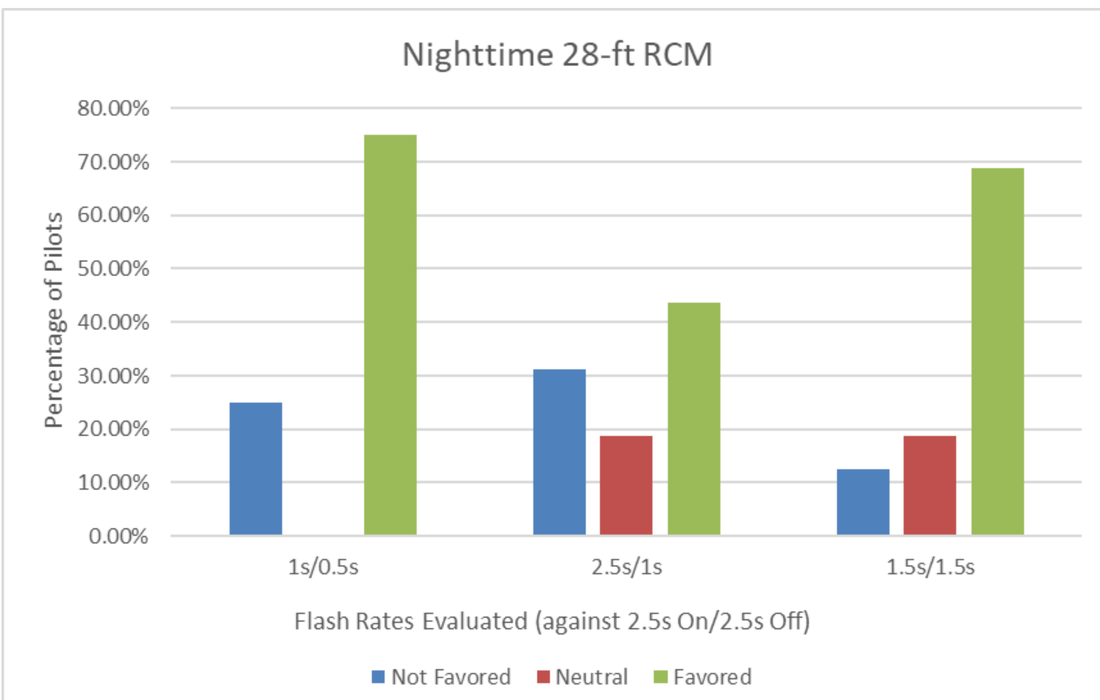

Figure 21. Flash Rate Results for 28-ft Lighted X—Nighttime

4.3.2.1 Synopsis of Flash Rate Test Results—Nighttime

The test was conducted during the nighttime at 1,000 cd intensity, and the flash rate was varied for each segmented flight observation. There were six passes at nighttime to observe the LXs at various flash rates.

For LX20s, pilots preferred flash rate of 1s ON/0.5s OFF and 1.5s ON/1.5s OFF, with 13 and 11 pilots respectively preferring these flash rates. For LX28s also, pilots overwhelmingly preferred flash rates of 1s ON/0.5s OFF and 1.5s ON/1.5s OFF, with 12 clearly preferring 1s/0.5s flash rate and 11 preferring 1.5s/1.5s. These flash rates demonstrated nighttime effectiveness for both 20- and 28-ft LXs.

Side-by-side comparisons of LED flash rates among two LXs of the same type (e.g., an LED LX20 flashing at 1s ON/0.5s OFF compared to a LED LX20 flashing at 1.5s ON/1.5s OFF were not possible due to limitations with LX equipment availability. To zero-in on a single flash rate, a comparison of these two flash rates is recommended.

Qualitatively, there were mixed views on the optimal flash rate. Consensus from pilot debriefs was that the light should stay on longer than off to make it more distinguishable and recognizable. Also, pilots felt that the warmer, amber-color tone of the incandescent lights was more distinguishable from other lights surrounding the airport. On the approach to WWD during nighttime testing, the pilots stated that the LED LXs were somewhat "washed out" by the other ambient light around the airport. There could be a correlation between the slow ramp-up and down time of incandescent LXs and pilots preferring LED LXs to stay on for longer time. Incandescent lights do not completely turn on and off immediately, so, while the incandescent LX is programmed to switch off for 2.5 seconds, it is emitting some light while it is ramping down, thus seemingly being on for longer than 2.5 seconds.

5. LIGHT OUTPUT BEHAVIOR

The difference in behavior of LED and incandescent light bulbs is shown in Figure 22.

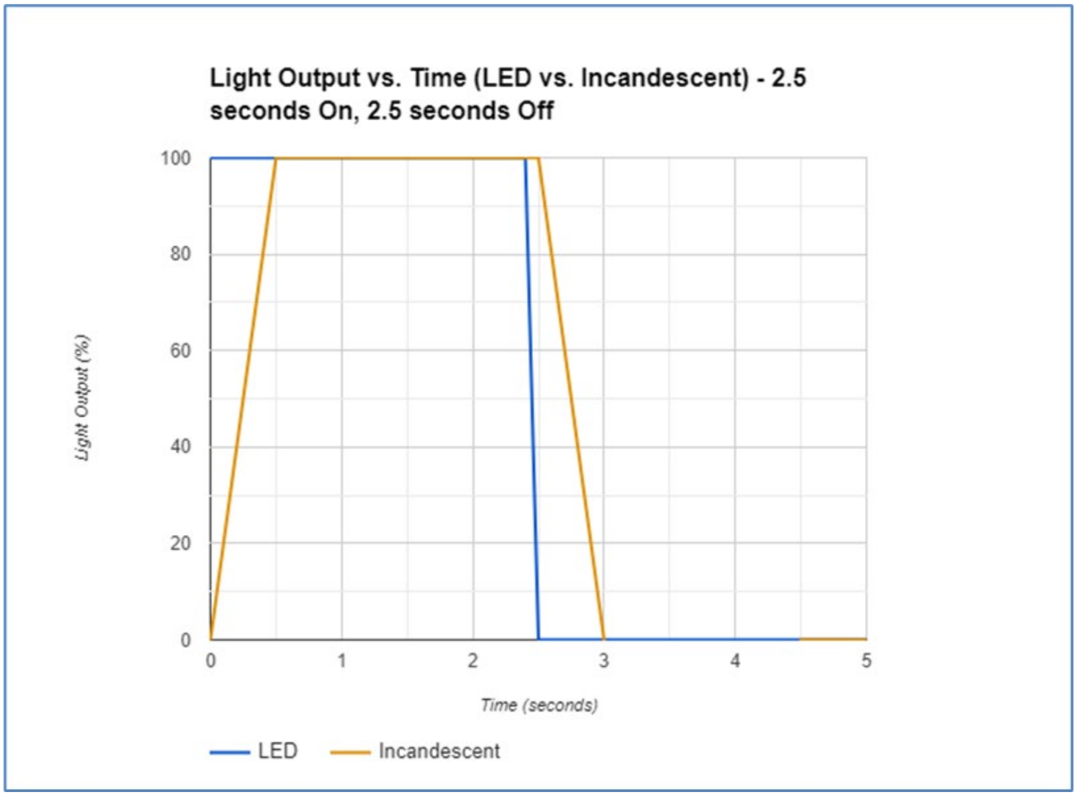

Figure 22. Light Behavior—LED versus Incandescent

Figure 22 depicts the light output of LED and incandescent bulbs in the LX over a 5-second period. The bulbs are turned on for 2.5 seconds and off for 2.5 seconds. The graph shows that LED bulbs turn on and off almost instantly, while incandescent bulbs take a longer time to reach full brightness and cool down after being turned off.

6. OBSERVER COMMENTS

Post-flight debriefs were performed at the end of each cycle to provide continuous auditing of the process, provide results, and provide contextual perspective. Although the comments do not directly have an impact on the results, they provide helpful information for follow-on testing. For example, Observer 11 provided a comment that was instructive and helpful: “In my opinion, if the flashing light was amber, it would be perfect” when describing the LED’s “whiter” optical signature compared to the incandescent. There were also several comments about having the RCM lights be a different color, such as red or orange, that could increase the distinctive requirement from ambient lights.

Because it is not feasible to include all comments from the observer response sheets, Table 13 provides a sample of the comments of interest that added value to this report.

Table 13. Selected Comments from Observers

Observer #	Test Config Context Refer to Appendix E	Comments from the Observers for Flash Rate Testing (Night) Left RCM—Incandescent, Right RCM—LED
Observer 3	NT13	Flash rate is better with right RCM.
Observer 11	NT13	In my opinion, if the flashing light in NT13 was amber it would be perfect.
Observer 12	NT13-NT15	Flash rate of right (white) was better but amber/yellow lighting would be better.
Observer 3	DT1-DT12	LED looks better closer up.
Observer 4	DT10-DT12	DT11- Right RCM ok, but Left RCM–yellow light easier to see.
Observer 5	DT9	Right RCM easier to pick up, Left RCM cleaner when visible, but dimming.
Observer 12	DT9	As we got closer to 2 miles, left became easier to see.
Observer 5	DT1-DT8	DT1-sun and some haze DT7 need faster flash rate
Observer 6	DT1-DT8	DT3-RCM faint DT4-high due to traffic in the area
Observer 12	NT1-NT6	NT2- white light is hard to distinguish. Other lights in area would be easier to spot on a lightened runway. NT3-3.0 at 500 ft best visibility. NT4-more white. NT5- amber. On first leg, don't know where to see. Got better when we figured out where to see the X.
Observer 6	NT1-NT6	NT5-Orange color easier to pick out than white NT6-need faster flash.
Observer 8	NT1-NT6	NT1-other lights blended. Copilot never saw. Difficult, not bright enough. NT6-The LX looked more like a blob. Flashing X should flash faster. More overall feeling, X was tough to see. Due also to the other surface lights.
Observer 6	NT7-NT12	NT7- Incandescent better. NT8- LED better. NT9-too bright, lost shape, could not see. NT10-shape is dim, not visible. Hard to pick out amongst many lights.
Observer 12	DT16-DT18	Initially like DT17 flash rate but closer we got I preferred the faster flash rate.
Observer 12	DT18	White is better observed from far away. As you get closer amber is easier to distinguish as an X. DT18 white is easier to observe up close.

Observer #	Test Config Context Refer to Appendix E	Comments from the Observers for Flash Rate Testing (Night) Left RCM—Incandescent, Right RCM—LED
Observer 15/16	DT16-DT18	Left color nicer. Other more visible. Best is DT16 and DT17.

7. CONCLUSIONS

The purpose of this research project was to investigate the optimal intensity (minimum and maximum), flash rate, and size of LXs to enhance conspicuity of the RCM and to validate the NIST study results. This was accomplished by conducting a two-phase testing effort that included both ground and flight testing. Although it may not have fully corroborated the results found from flight testing, the NIST study provided valuable insights into the LX testing. It is also evident that ground-based testing, while not a real-world scenario, proved to be a time-saving measure by effectively eliminating configurations unlikely to be successful during flight testing. Flight testing provided effective real-world conditions for quality discernment to create the final recommended thresholds.

FAA researchers determined the current conclusive results from Phase 2 (flight tests) with two daytime intensity values, two nighttime intensity values, one size, and at least two potential flash rates, as detailed in Table 14. All intensity and size configurations evaluated during flight testing were able to satisfy the minimum criteria of the LX shape being recognized at 1.5 NM from the runway. A preference for shorter flash rates was observed overall; and in nighttime testing, asymmetric flash rates where the lights are ON longer than they were OFF were preferred by pilots.

Table 14. Phase 2 Conclusive Results

Intensity Evaluation	
Condition	**Intensity**
Daytime	35,000 cd to 70,000 cd
Nighttime	1,000 cd to 2,000 cd
Size Evaluation	
Condition	**Size**
Daytime	28 ft
Nighttime	28 ft
Flash Rates	
Type	**ON/OFF (in seconds)**
Daytime	1.5/1.5
Nighttime	1/0.5

Through pilot questionnaires and debriefing comments, FAA researchers were able to contextualize the results of the NIST study and recommend daytime and nighttime intensities, size, and flash rates for optimal viewing of the Lighted X runway closure marker. Outside of the recommendations for intensity, size, and flash rate, researchers also determined conclusions about pilot's perception of the Lighted X and how the results differ from the NIST conclusions. Pilots still preferred the incandescent Lighted X's softer tone on the light spectrum compared to the LED's. The 28-ft LX was preferred by pilots, as mentioned in NIST study. The nighttime intensities of 500 cd and 1,000 cd were not found to be too bright by pilots, which contradicts the NIST study results. This could be because of the presence of ambient light around the airport, whereas the NIST study was conducted in a pitch-dark environment. These results show the nuance in the pilots' perception of airport lighting and the importance of both laboratory and field testing to ensure the standards for lighting are based in the real world use of these systems by the stakeholders they serve.

8. REFERENCES

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APPENDIX A—LIGHTED X CONFIGURATION DURING TESTING

The Ground Team set up four Lighted Xs (LXs).
The four LXs were spaced equally apart from each other, with the two large (28-ft) units positioned alongside the smaller (20-ft) units.

Configuration of LXs were as shown:

Incandescent 28-ft	Incandescent 20-ft	LED 28-ft	LED 20-ft

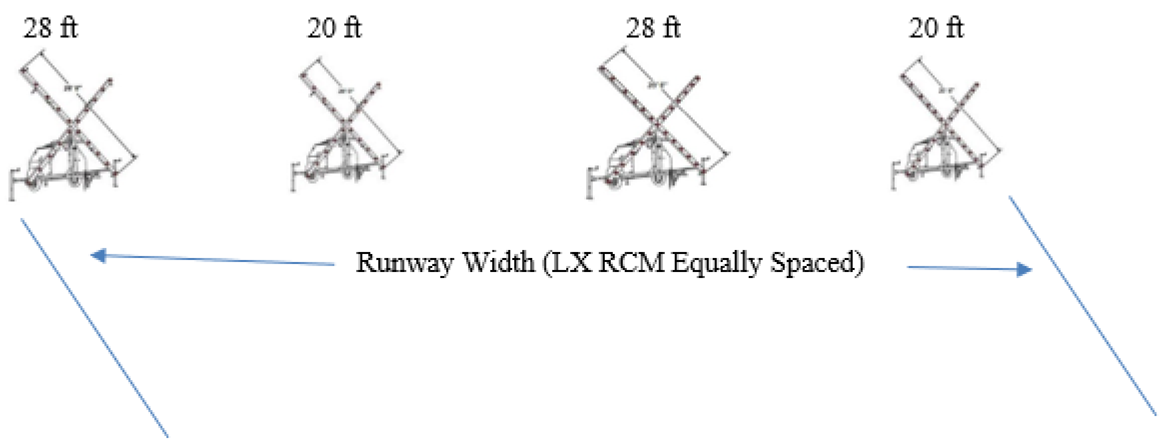

Figure A-1. Representative Placement of LXs on the Runway

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APPENDIX B—FLIGHT TESTING SCHEDULE TABLES

The following tables provide supplementary materials related to this study, such as Flight Testing Schedule, Test Configurations, Questionnaires used to collect responses from participants.

B.1 FLIGHT TESTING SCHEDULE

Table B-1. Schedule for Flight Tests (From Test Plan)

#	Day of the Week	Event	Pass/ Aircraft	Flight Duration	Test Duration	Testing Slots
Day 1	Monday	Equipment Unpacking and Setup. Fly-in Aircrafts to WWD. Pilot Briefing/Orientation		N/A	3 hours	09:00–12:00
Break (12:00–14:00)						
Day 1	Monday	Pilot Briefing/Orientation continued.		N/A	2 hours	14:00–16:00
End: Day 1						
Day 2	Tuesday	Flight Pattern Trial - Day		0.5 hour (09:30–10:00)	1 hour	09:00–10:00
Day 2	Tuesday	IE Day Session	4	1 hour (10:00–11:00)	1.5 hours	10:00–11:30
Break (11:30–14:00)						
Day 2	Tuesday	IE Day Session Continued. (if required)	4	1 hour (14:30–15:30)	2 hours	14:00–16:00
Break (16:00–18:45)						
Day 2	Tuesday	Flight Pattern Trial - Night		0.5 hour (19:00–20:00)	1 hour	18:45–19:45
Day 2	Tuesday	IE Night Session 1	4	1 hour (19:45–21:30)	1.5 hours	19:45–21:30
End Day 2						
Day 3	Wednesday	FR (Flash Rate) Day Session	6	1.5 hours (9:15–10:45)	2 hours	09:00–11:00
Break (11:00–14:00)						
Day 3	Wednesday	FR (Flash Rate) Day Session Continued. (if required)		0.5 hour (14:30–15:00)	1.5 hours	14:00–16:00
Day 3	Wednesday	SC (Size Comparison) Day Session	1	0.5 hour (15:00–15:30)	0.5 hour	14:00–16:00
Break (16:00–18:45)						
Day 3	Wednesday	IE Night Session 2	8	2 hours (19:00–21:00)	2.75 hours	18:45–21:30
End Day 3						
Day 4	Thursday	FR Night Session 2	6	1.5 hours (19:00–20:30)	1.75 hours	18:45–20:30

End Day 4
Day 5 Reserve

B.2 INTENSITY EVALUATION

LEGEND:

RCM1 – Incandescent LX20
RCM2 – LED LX20
RCM3 - Incandescent LX28
RCM4 - LED LX28
D1 – 35k cd
D2 – 70k cd
N1 – 500 cd
N2 – 1k cd
N3 – 2k cd
FR1 – Flash Rate (1s ON/0.5s OFF)
FR2 – Flash Rate (2.5s ON/1s OFF)
FR3 – Flash Rate (1.5s ON/1.5s OFF)

Table B-2. Daytime Intensity Evaluation Run Sheet

Daytime Intensity Evaluation Run Sheet		
Test ID	**Test Description**	**Comments**
DT1	Ground Team will light Incandescent LX20 at 35k cd (RCM1 at Intensity D1)	
DT2	Ground Team will light LED LX20 at 35k cd (RCM2 at Intensity D1)	
DT3	Ground Team will light Incandescent LX28 at 35k cd (RCM3 at Intensity D1)	
DT4	Ground Team will light LED LX28 at 35k cd (RCM4 at Intensity D1)	
DT5	Ground Team will light Incandescent LX20 at 70k cd (RCM1 at Intensity D2)	
DT6	Ground Team will light LED LX20 at 70k cd (RCM2 at Intensity D2)	
DT7	Ground Team will light Incandescent LX28 at 70k cd (RCM3 at Intensity D2)	
DT8	Ground Team will light LED LX28 at 70k cd (RCM4 at Intensity D2)	

Table B-3. Nighttime Intensity/Size Evaluation Run Sheet

Nighttime Intensity/Size Evaluation Run Sheet		
Test ID	**Test Description**	
NT1	Ground Team will light Incandescent LX20 at 500 cd. (RCM1 at Intensity N1)	
NT2	Ground Team will light LED LX20 at 500 cd (RCM2 at Intensity N1)	
NT3	Ground Team will light Incandescent LX28 at 500 cd (RCM3 at Intensity N1)	
NT4	Ground Team will light LED LX28 at 500 cd (RCM4 at Intensity N1)	
NT5	Ground Team will light Incandescent LX20 at 1,000 cd. (RCM1 at Intensity N2)	
NT6	Ground Team will light LED LX20 at 1,000 cd (RCM2 at Intensity N2)	
NT7	Ground Team will light Incandescent LX28 at 1,000 cd (RCM3 at Intensity N2)	
NT8	Ground Team will light LED LX28 at 1,000 cd (RCM4 at Intensity N2)	
NT9	Ground Team will light Incandescent LX20 at 2,000 cd. (RCM1 at Intensity N3)	
NT10	Ground Team will light LED LX20 at 2,000 cd (RCM2 at Intensity N3)	
NT11	Ground Team will light Incandescent LX28 at 2,000 cd. (RCM3 at Intensity N3)	
NT12	Ground Team will light LED LX28 at 2,000 cd (RCM4 at Intensity N3)	

Table B-4. Runway Closure Marker (Lighted X) Size Comparison

Section 2 Daytime RCM Size Comparison ____________		
Test ID	**Test Description**	Test Questions
DT9	Ground Team will light LED LX20 and LED LX28 at Intensity 35k cd	Which RCM conveys the RCM shape better?

Table B-5. Daytime Flash Rate Tests

<table>
<tr><th colspan="3">Flash Rate (Day)</th><th colspan="3">Runsheet</th><th>Test Number: 3</th><td rowspan="11">Intensity Value used in
test:
____

Incandescent (Record setup):

____

LED (Record setup):

____________</td></tr>
<tr><th>Test ID</th><th colspan="2">Incandescent LX (Left)</th><th colspan="3">LED (Right)</th><th>Comments</th></tr>
<tr><th colspan="7">Segment 1</th></tr>
<tr><td>DT10</td><td>LX20</td><td>2.5s ON/2.5s OFF</td><td>LX20</td><td>1s ON/0.5s OFF</td><td>FR1</td><td></td></tr>
<tr><td>DT11</td><td>LX20</td><td>2.5s ON/2.5s OFF</td><td>LX20</td><td>2.5s ON/1s OFF</td><td>FR2</td><td></td></tr>
<tr><td>DT12</td><td>LX20</td><td>2.5s ON/2.5s OFF</td><td>LX20</td><td>1.5s ON/1.5s OFF</td><td>FR3</td><td></td></tr>
<tr><th colspan="7">Segment 2</th></tr>
<tr><td>DT13</td><td>LX28</td><td>2.5s ON/2.5s OFF</td><td>LX28</td><td>1s ON/0.5s OFF</td><td>FR1</td><td></td></tr>
<tr><td>DT14</td><td>LX28</td><td>2.5s ON/2.5s OFF</td><td>LX28</td><td>2.5s ON/1s OFF</td><td>FR2</td><td></td></tr>
<tr><td>DT15</td><td>LX28</td><td>2.5s ON/2.5s OFF</td><td>LX28</td><td>1.5s ON/1.5s OFF</td><td>FR3</td><td></td></tr>
</table>

Table B-6. Nighttime Flash Rates

Flash Rate (Night)			Runsheet			Test Number: 3	Intensity Value used in test: Nighttime: __________ Incandescent (Record Intensity): _____________ LED (Record Intensity): ____________
Test ID	Incandescent LX (Left)		LED (Right)			Comments	
Segment 1							
NT13	LX20	2.5s ON/2.5s OFF	LX20	1s ON/0.5s OFF	FR1		
NT14	LX20	2.5s ON/2.5s OFF	LX20	2.5s ON/1s OFF	FR2		
NT15	LX20	2.5s ON/2.5s OFF	LX20	1.5s ON/1.5s OFF	FR3		
Segment 2							
NT16	LX28	2.5s ON/2.5s OFF	LX28	1s ON/0.5s OFF	FR1		
NT17	LX28	2.5s ON/2.5s OFF	LX28	2.5s ON/1s OFF	FR2		
NT18	LX28	2.5s ON/2.5s OFF	LX28	1.5s ON/1.5s OFF	FR3		

Table B-7. Questionnaire

Observer Information
Observer Name: ____ **Age**: _____
Contact Info (email address): ____
Observer's Primary Occupation: ____
Do you wear corrective lenses? Yes, for distance ___ **Yes,** for reading___ **Other**___ **No**___
Date/Time: ______________________
Select your role: Pilot: Co-Pilot:
Observer Number: ____________________

Table B-8. Intensity/Size Evaluation Form

Section 1

Daytime Intensity/Size Evaluation | Observer #: ____________ | Role (Pilot/Co-pilot): ________________								
Test ID	**Test Description**	**Altitude/Slant Distance when RCM is first visible (in miles)**		**Altitude/Slant Distance when RCM shape is recognizable (in miles)**		**Altitude/Slant Distance at which RCM shape becomes unrecognizable (in miles)**		**Comments (if any)**
		from aircraft GPS		**from aircraft GPS**		**from aircraft GPS**		
		Alt	**Distance**	**Alt**	**Distance**	**Alt**	**Distance**	
DT1	Ground Team will light (RCM1 at Intensity D1)							
DT2	Ground Team will light (RCM2 at Intensity D1)							
DT3	Ground Team will light (RCM3 at Intensity D1)							
DT4	Ground Team will light (RCM4 at Intensity D1)							
DT5	Ground Team will light (RCM1 at Intensity D2)							
DT6	Ground Team will light (RCM2 at Intensity D2)							
DT7	Ground Team will light (RCM3 at Intensity D2)							
DT8	Ground Team will light (RCM4 at Intensity D2)							

Section 1

Nighttime Intensity/Size Evaluation | Observer #: ____________ | Role (Pilot/Co-pilot): ________________								
Test ID	**Test Description**	**Distance when RCM is first visible (in miles)**		**Distance when RCM shape is recognizable (in miles)**		**Distance at which RCM shape becomes unrecognizable (in miles)**		**Comments (if any)**
		from aircraft GPS		**from aircraft GPS**		**from aircraft GPS**		
		Alt	Distance	Alt	Distance	Alt	Distance	
NT1	Ground Team will light (RCM1 at Intensity N1)							
NT2	Ground Team will light (RCM2 at Intensity N1)							
NT3	Ground Team will light (RCM3 at Intensity N1)							
NT4	Ground Team will light (RCM4 at Intensity N1)							
NT5	Ground Team will light (RCM1 at Intensity N2)							
NT6	Ground Team will light (RCM2 at Intensity N2)							
NT7	Ground Team will light (RCM3 at Intensity N2)							
NT8	Ground Team will light (RCM4 at Intensity N2)							
NT9	Ground Team will light (RCM1 at Intensity N3)							
NT10	Ground Team will light (RCM2 at Intensity N3)							
NT11	Ground Team will light (RCM3 at Intensity N3)							
NT12	Ground Team will light (RCM4 at Intensity N3)							

Section 2

Daytime RCM Size Comparison | Observer# ___ | Role (Pilot/Co-pilot): __________			
Test ID	**Test Description**	Test Questions	(Check one box)
DT9	Ground Team will light RCM2 and RCM4 at Intensity D1	Which RCM conveys the RCM shape better?	

Section 3

Flash Rate (**Day**)		**Observer #:** ____		**Role (Pilot/Co-pilot):** ______
Test ID	**Observation**	**Left RCM**	**Right RCM**	**Mark Your Response** (check one box)
DT10	ON/OFF interval of "X" symbol displayed by right RCM is better than left RCM?	RCM1	RCM2	Disagree Same Agree
DT11	ON/OFF interval of "X" symbol displayed by right RCM is better than left RCM?	RCM1	RCM2	Disagree Same Agree
DT12	ON/OFF interval of "X" symbol displayed by right RCM is better than left RCM?	RCM1	RCM2	☐ Disagree ☐ Same ☐ Agree

Section 3 – Segment 2

Flash Rate (Day)		**Observer #: ____**		**Role: ☐ Pilot ☐ Co-pilot**
Test ID	**Observation**	**Left RCM**	**Right RCM**	**Mark Your Response** (check one box)
DT13	ON/OFF interval of "X" symbol displayed by right RCM is better than left RCM?	RCM3	RCM4	☐ Disagree ☐ Same ☐ Agree
DT14	ON/OFF interval of "X" symbol displayed by right RCM is better than left RCM?	RCM3	RCM4	☐ Disagree ☐ Same ☐ Agree
DT15	ON/OFF interval of "X" symbol displayed by right RCM is better than left RCM?	RCM3	RCM4	☐ Disagree ☐ Same ☐ Agree

Section 3

Flash Rate (Night)		Observer Number:____		Role (Pilot/Co-pilot): ______
Test ID	Observation	Left RCM	Right RCM	Mark Your Response (check one box)
NT13	ON/OFF interval of "X" symbol displayed by right RCM is better than left RCM?	RCM1	RCM2	☐ Disagree ☐ Same ☐ Agree
NT14	ON/OFF interval of "X" symbol displayed by right RCM is better than left RCM?	RCM1	RCM2	☐ Disagree ☐ Same ☐ Agree
NT15	ON/OFF interval of "X" symbol displayed by right RCM is better than left RCM?	RCM1	RCM2	☐ Disagree ☐ Same ☐ Agree

Flash Rate (Night)		Observer #: ____		Role: ☐ Pilot ☐ Co-pilot
Test ID	**Observation**	**Left RCM**	**Right RCM**	**Mark Your Response (check one box)**
NT16	ON/OFF interval of ”X” symbol displayed by right RCM is better than left RCM?	RCM3	RCM4	☐ Disagree ☐ Same ☐ Agree
NT17	ON/OFF interval of “X”symbol displayed by right RCM is better than left RCM?	RCM3	RCM4	☐ Disagree ☐ Same ☐ Agree
NT18	ON/OFF interval of “X” symbol displayed by right RCM is better than left RCM?	RCM3	RCM4	☐ Disagree ☐ Same ☐ Agree

APPENDIX C—PILOT BRIEFING FOR FLIGHT TRIALS

Good morning and welcome. My name is __________, and I am part of the FAA Visual Guidance Research Team and your Flight Advisor. We have been contracted by the FAA to evaluate potential new runway closure marker lights.

[Introduce the research team]

In the coming days you will be taking part in flight trials here at Cape May Airport. The goal of our testing is to evaluate possible new designs for the "Lighted-X" that is used to denote a closed runway. In your flying, you might have seen a large "X" painted on the runway or held up as a sign. Although less common, you might also have seen the lighted version of that sign. This is what we will be evaluating over the coming days.

[Show Lighted-X diagram]

[1] The general procedure for flight trials is as follows: two pilots will be assigned to each of the eight aircraft. After departure, aircraft will follow one another in a sequenced series of approaches. We will not be using WWD's standard 1/19 or 10/28 runways. Instead, we will be flying low approaches to the "FAA Research Taxiway" which is oriented basically like a third RWY oriented as 5/23. So, we will refer to it as "Test RWY 23" (or "Test RWY 5" when approaching from SW) during our tests for ease of use.

[Show airport diagram (same as Lighted-X diagram)]
[If necessary, install kmz waypoint files on all iPads]

At this point, everyone should have our custom waypoints installed on their ForeFlight (or similar) EFB. Please open your EFB software. You may select either VFR sectional view, or IFR low altitude chart view. Please ensure that the custom waypoints are displayed. Notice that we've created pattern waypoints on the approaches to both RWY 5, and RWY 23. You will be using these, for the most part, like RNAV approach waypoints. No ADS-B connection is necessary at the moment—we just want to review the waypoints we'll be using for the flight trials. Notice that we've defined a northern pattern and a southern pattern. When the LX is positioned at the approach end of runway TWO THREE, it will be posted at the NORTH waypoint, and you see waypoints out at 1.5, 10, and 15 miles to the northeast, as shown. When the LX is positioned at the approach end of runway FIVE, it will be posted at the SOUTH waypoint, and you'll see waypoints out at 1.5, 10, and 15 miles to the southwest.

We suggest that you cross the initial approach fix at 2,000 feet and begin the approach via the designated approach waypoints. We also suggest an approach speed of 90KIAS and altitudes appropriate for a standard (roughly 3 degree) visual approach. However, please understand that these numbers are only suggestions. In the end, you are the PIC, and speed and altitude are at your discretion, as required for safety. Notice on your ADS-B the final waypoints (EAGLE enroute to RWY 5, and WHALE enroute to RWY 23) are about 1.5 NM from the threshold. The idea is that you break off your approach at this waypoint point and turn left into a simulated crosswind for the next approach. You can think of it as an odd, missed approach, that begins with a climbing left turn. Again, altitude is at your discretion, and you can climb on the crosswind and/or downwind as you wish.

We have assigned two pilots to each test aircraft. For reasons of experimental control and to reduce fatigue, we are asking that pilots trade off control periodically. It is not mandatory, but we advise controls hand over every 4 passes between pilots.

A set of questionnaires will be provided to you (pilots) to record your observation and input your comments (if you have any).

For the first test (intensity test), you are required to note your observation from your navigation device (iPad) at three distinct points. You will record the altitude and distance from your ForeFlight at following times:

- When you first see the RCM lights, irrespective of whether you can recognize a distinct shape.
- When you can clearly recognize the RCM shape.
- When or if RCM lights become too bright to be distinguished as a specific shape (or becomes a blur).

Also, when you land after completing a session, you are advised to write down any general observations or comments you may have under the "General Comments" section about RCMs.

The FAA Research staff consists of two teams: the GROUND team that will be managing the Lighted Xs and overseeing the technical and experimental aspects, the COMMS team (Flight Advisor) who will be communicating with the test aircraft, monitoring for "intruder" (i.e. non-test) aircraft in the area, and issuing alerts to both test and non-participating aircraft as required.

[1] All of you have two operating radios, correct? Our aim is that you transmit and receive on TEST frequency (123.45 MHz), and monitor the CTAF (122.7 MHz) on your second COMM. As required, the COMMS team (Flight Advisor) is going to broadcast messages on the CTAF advising/reminding any non-participating aircraft about the scheduled FAA test activity running at WWD airspace. Notice that we will be flying nonstandard patterns at this airport. However, the airport will remain open to traffic. We have also contacted both Dover and ACY approach and informed them of our non-standard ops. Workload permitting, they have agreed to advise incoming WWD aircraft (either VFR flight following, or IFR traffic) of our activity before they transfer them to CTAF.

[2] The general schedule is as follows: There are both daytime and nighttime sessions. We will fly the morning session, break for lunch, then fly an afternoon session. We have been informed by the FBO that 1000–1400 are the airport's busiest hours — flight arrivals peak during the lunch period.

There are many variables in any of these flight trials, and we are not exactly sure of how long the entire testing will last. We have allowed for a maximum of five days, but we suspect that, if all goes well, we will finish much earlier.

[3] Our communications and coordination procedures are as follows: each aircraft should have two functioning radios. Again, we expect you to monitor and transmit on the TEST frequency (123.45 MHz) and monitor the WWD CTAF (122.7 MHz). You are your second COMM. You can make your normal position reports on CTAF but for test-related activity (e.g., if you missed an observation or need to communicate with Flight Advisor) we would expect you to set up to transmit on the TEST frequency. What we did in pre-testing last week, and it seemed to work well, was that pilots could transition from TEST to CTAF transmit as they entered the standard pattern here.

[4] Caveats and contingencies:

Safety is paramount in what we're doing for these flight tests. If you have any concerns or notice any potential issues that could jeopardize safety, please bring them to our attention immediately. Along the same lines: notice that the COMMS team will be communicating with test aircraft, ground to air, on 123.45 MHz Please recognize that this is an advisory function only. We are not playing an ATC role, and flight patterns, altitudes, speeds, etc. are at your discretion, as required for safety.

- Our tests should not interfere with the standard traffic pattern. The prevailing winds of the day will determine what runway is experiencing more departure and arrival aircraft. We will select a flight pattern for each segment of flight testing that avoids primary runway traffic to the maximum extent possible. Please remember that both runways will be operational and approved for usage by arrival and departure aircraft.

- In this test, we will be asking you to document your findings regarding the different configurations of the X in the questionnaires that we have provided to you in your packet. Remember: This is not a competition. We want pilots to NOT be influenced by their partner in reporting their data. It is human nature, and probably more so for competitive pilot personalities, to try to "beat" your co-pilot.

But please be honest in your responses. Remember: we are not comparing pilots. We are comparing how YOU viewed configuration 1 versus configuration 2.