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Alternatives to Pyrotechnic Distress Signals; Additional Signal Evaluation

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Homeland Security

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16. Abstract (MAXIMUM 200 WORDS)

This report is the fourth in a series that details work on behalf of the Coast Guard Office of Design and Engineering Standards, Life Saving and Fire Safety Branch to develop an electronic visual distress signal characteristic. This report presents the testing of additional colors and an SOS pattern, with direct comparison to the previously-recommended, 4 Hertz, Cyan and Red-Orange, alternating, group-flashing signal and to a red, hand-held flare.

The additional testing considered three, different, White LED "colors," and a Lime LED. The research project team conducted three "pilot tests" with human subjects to compare the different colors on subjective conspicuity, before conducting a two-night, visual-search paradigm-based field experiment to quantitatively determine relative signal identification rates and response times.

This report provides the test results and analysis to support an electronic visual distress signal device performance standard that addresses Coast Guard project sponsor and stakeholders needs.

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We especially recognize the Coast Guard Auxiliarists who enthusiastically gave up personal time to serve as observers and test subjects in the field study. The project team acknowledges the behind-the-scenes efforts of the Sector Long Island Sound Auxiliary Affairs Officer and the Sector Long Island Sound Auxiliary Coordinators to insure a large number of participants.

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Finally, the project team thanks the members of the R&D Center staff for their enthusiastic participation as observers in our three pilot tests, and for assisting with logistical preparations.

EXECUTIVE SUMMARY

The Coast Guard Research & Development Center (RDC) executed a multi-year project to develop a specification for a light-emitting diode (LED) signal characteristic that could be an alternative to a pyrotechnic flare visual distress signal. The project emphasized development of a visual signal, and the early work specifically avoided evaluating signal characteristics that targeted different types of electronic/electro-optical sensors, including infrared (IR), ultraviolet (UV), or other non-visual sensors. After laboratory and field testing of numerous colors and flash patterns in 2013-2014, the project recommended a distress signal characteristic that was a group alternating, Cyan (Cy) and Red-Orange (RO) color, 4 Hertz (Hz) flashing signal at 50 candela (cd) effective intensity.

As the RDC project developed the conspicuous visual characteristic, the project sponsor, the Coast Guard's Office of Design and Engineering Standards Life Saving and Fire Safety Division (CG-ENG-4) initiated an effort with the Radio-Technical Commission for Maritime Services (RTCM) to stand up a special committee (SC-132) and develop a "standard" to incorporate the LED signal characteristic into a producible device. Such a device, once manufactured, is intended to substitute for pyrotechnic flare carriage requirements on United States (US) recreational vessels. Manufacturers were concerned about the Cyan LED initial cost and power efficacy, and the desire to include the SOS pattern. Manufacturers suggested we evaluate two colors instead of Cyan in the signal, Lime and White.

This report presents the testing of Lime and White in the 4Hz 4-3 and SOS patterns, with direct comparison to the originally-recommended, 4Hz Cy-RO signal and to a red, hand-held flare.

After three pilot tests and a two-night field experiment, the additional work concludes that the 4Hz Cy-RO 50 cd signal is still the superior characteristic for a new, LED-based distress signal, but that a RO-Cy, quick-flashing SOS pattern at 50 cd effective intensity is also acceptable. One other signal achieved a consistent level of recognition, a 4Hz RO-Lime signal, where the Lime component had an effective intensity of 100 cd (twice that of Cyan). Two other signals were comparable to a flare.

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

cd	candela
CDV	Committee Draft for Voting
CG-ENG-4	Coast Guard Office of Design and Engineering Standards, Life Saving and Fire Safety Branch
Cy	cyan
Hz	Hertz
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IR	infrared
K	Kelvin
kt	knots
L	lime
LCD	liquid crystal display
LED	light-emitting diode
M1	Method 1
M2	Method 2
MBF	minus-blue filtering
ms	milliseconds
NM	nautical miles
NVIS	night-vision imaging systems
PWM	pulse width modulation
RDC	Research & Development Center
RF	radio frequency
RO	red-orange
RT	response time
RTCM	Radio-Technical Commission for Maritime Services
US	United States
UV	ultraviolet
VDC	volts direct current
W	white
W3	white 3000K
W4	white 4000K
W5	white 5000K

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1 BACKGROUND

As this report is the fourth in a series, we respectfully direct your attention to the previous work, summarized below.

The report "Suitability of Potential Alternatives to Pyrotechnic Distress Signals" (CG-D-06-12) discusses how the Coast Guard (CG) Research and Development Center (RDC) researched available light-emitting diode (LED), flashtube, and incandescent signals, and determined that LED-devices consistently tested better than flashtube or incandescent devices. The report discussed the concept of "effective intensity," as used by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) to determine a signal's nominal range. A major development from this work showed the importance of "conspicuity," particularly signal color and temporal flash pattern, along with effective intensity, as the qualities which comprise a "good" non-pyrotechnic distress signal. The real-world condition of background lighting highlighted this need for conspicuity. Almost any signal color or flash pattern can be effective against a completely dark background, but if a searcher needs to discern a signal against shore lighting ("clutter"), a distinctive color and pattern will provide the searcher something that is identifiable and stands out. The early field testing provided one additional but important result: though an SOS pattern is presently the only approved flashing light signal for recreational boats, the present flash rate is relatively slow when compared to what literature indicates as conducive to conspicuity. Demonstration trials bore this out, as many observers said they "lost" the SOS signal because of the slow flash and extensive off-time between patterns.

After additional research, the Alternatives to Pyrotechnic Distress Signals project conducted a series of laboratory experiments designed to determine the optimal signal color and temporal pattern for identification against a variety of background lighting conditions. The laboratory work showed promise, particularly that signal patterns with a relatively quick flash rate of 2-4 Hertz (Hz), including a "modified-SOS," provided a significant amount of conspicuity against background lighting. The project culminated in a "field experiment," where the project team tested actual color and temporal patterns with human observers, at an extended range, in real-world conditions. From this field experiment, the project showed that observers considered one particular signal more conspicuous than others: a group-alternating (4-3) Cyan (Cy)/Red-Orange (RO) 4 Hz signal. To allow both identification and recognition of this signal characteristic at 6 Nautical Miles (NM), the flash needed 50 candela (cd) effective intensity. "Alternatives to Pyrotechnic Distress Signals; Laboratory and Field Studies" (CG-D-04-15) covers the material, in depth.

After RDC completed the visual-signal work, Coast Guard's Aviation Logistics Center noted that searchers using third-generation, night-vision imaging systems (NVIS) with "minus-blue" filtering (MBF) might not detect the signal. (Minus-blue filtering is an adaptation which allows NVIS use in situations where aircraft-cockpit lighting presents windscreen-reflectance issues.) Up until this point, the project's focus was a visual signal, not a signal for different types of electronic imaging or detection systems. As aircraft searches account for approximately 21% of search and rescue sorties, the project team investigated NVIS compatibility and recommended a solution that included a near-infrared LED signal, coordinated with the very-conspicuous, 4Hz Cyan and Red-Orange (Cy-RO) visual flash.

Coincident to that work, the project also found that observers indicated no difference in visual conspicuity if the duration of individual flashes in the 4-3 Cy-RO 4 Hz changed, provided the effective intensity remained the same, 50 cd. (Alternatives to Pyrotechnic Distress Signals; Supplemental Report (CG-D-17-15).

While the RDC project developed a conspicuous visual characteristic, the project sponsor, Coast Guard's Office of Engineering and Design Standards Lifesaving and Fire Safety Branch (CG-ENG-4) initiated an effort with the Radio-Technical Commission for Maritime Services (RTCM) to stand-up a special committee (SC-132) to develop a "standard" that would incorporate the LED signal characteristic into a producible device. Such a device, once manufactured, could substitute for pyrotechnic flare carriage requirements on United States (US) recreational vessels. After a one-year period of deliberation and discussion, that included the RDC project team, SC-132 did not reach approval on a Committee Draft for Voting (CDV). Manufacturers were concerned about the initial cost and power efficacy of Cyan as a signal color.

In order to move forward, the RDC project team met with CG-ENG-4 and other Coast Guard stakeholders (Offices of Search and Rescue, Boating Safety and Auxiliary, Boat, Cutter and Aviation forces) to revisit the project requirements. While retaining the need for an individual to "recognize" the signal at six nautical miles (NM), the stakeholders allowed reduction of the original six-hour signal duration requirement to two hours, but retained a two-color, visible characteristic (with a corresponding signal visible through NVIS-MBF).

RDC sought input from SC-132 participants as to potential color alternatives to the Cyan LED. Manufacturers offered two: Lime and White. Further, manufacturers expressed concern that RDC previously eliminated an "SOS" pattern, and recommended that RDC include it in a signals review.

This report moves forward and considers whether other signal characteristics, including the color Lime (not available during the earlier work) in a two-color SOS pattern, are comparable to the group-alternating (4-3) Cy-RO 4 Hz signal, and comparable to or better than a red, hand-held flare.

2 METHODOLOGY

2.1 Overall Methodology

Since the actual Research and Development Center (RDC) testing methodology in the 2014 work has stood up under scrutiny, the project team decided to conduct a full field experiment similar to that described in Section 6 of "Alternatives to Pyrotechnic Distress Signals; Laboratory and Field Studies" to determine if alternative colors or patterns as desired by the Radio-Technical Commission for Maritime Services (RTCM) Special Committee (SC-132) participants compared favorably to the conspicuity provided by the Cy-RO, and, more importantly, provided a level of conspicuity similar to or better than a handheld, red pyrotechnic flare.

The two alternative colors to Cyan are White (W) and Lime (L). For the 2014 work, the project used a 4000° Kelvin (4000K) White LED, a straightforward, "neutral" White. A project team member raised concern that we used the 4000K White without actually comparing it to a "warmer" or "cooler" White. Since the project needed new signal generators to incorporate a Lime LED cluster, we also included 3000K and 5000K, as well as the 4000K, White LED clusters.

Because of the numerous combinations possible from the three Whites, Lime, and Cyan (alternating with the Red-Orange) and two signal patterns (the 4-3 group alternating 4Hz flash or the two-color SOS), we needed to conduct a "downselect" to limit the number of signals for the full field experiment. To this end, the project planned a series of local, comparative "pilot tests." The pilot tests required a number of observers to decide which of two, simultaneously displayed signals seemed "more conspicuous" than the other.

From the pilot test results, the project team would determine which signals the project would use in the actual, 6 mile field experiment (using the same methods as the 2014 test at Eatons Neck, NY).

2.1.1 Test Ranges

2.1.1.1 Pilot Test Range

In earlier project work, we had used a local, approximate 2 NM range from Fort Trumbull, New London, CT to Eastern Point Beach, Groton, CT. We decided this would provide a good basis for side-by-side forced-choice comparisons, but needed to make sure with the separation, that the background lighting "clutter" was somewhat comparable. The distance between the two signal positions shown in Figure 1 is approximately 700 feet.

The majority of interfering lighting clutter associated with the pilot test signal location was approximately the same distance from the observers as the signals themselves. Though some light sources at Fishers Island, NY, approximately 4 miles farther away, contributed to the background lighting, the Eastern Point Beach location included high-intensity parking-lot lighting and building floodlights that were considerably "brighter" to observers than the signals themselves. Because of this, we needed to adjust the signals' intensities to account for the "background" clutter at the same distance.

The observer location at Fort Trumbull was relatively dark, and observers stood near the fort wall so as to have the southeast bastion block the high-intensity lighting from the General Dynamics facility across the Thames River from Fort Trumbull.

Figure 1. Pilot test location

2.1.1.2 Field Experiment Range

To duplicate the September 2014 field experiment conditions, and compare different signal patterns and colors to the 4 Hz Cy-R-O and flare, we used the same test configuration as in 2014: observers at Eatons Neck, New York looking to the Connecticut shore (Figure 2). As in 2014, the combination of observer and signal boat locations allowed the boats to project the signals, while the observers viewed "sparse" background lighting conditions on the Connecticut shore. As in 2014, the signal boats would drift with, and then correct for the winds and current so the signals would actually "pass through" the sparse background clutter. This would prevent an observer from always looking at an exact reference point when trying to find a signal.

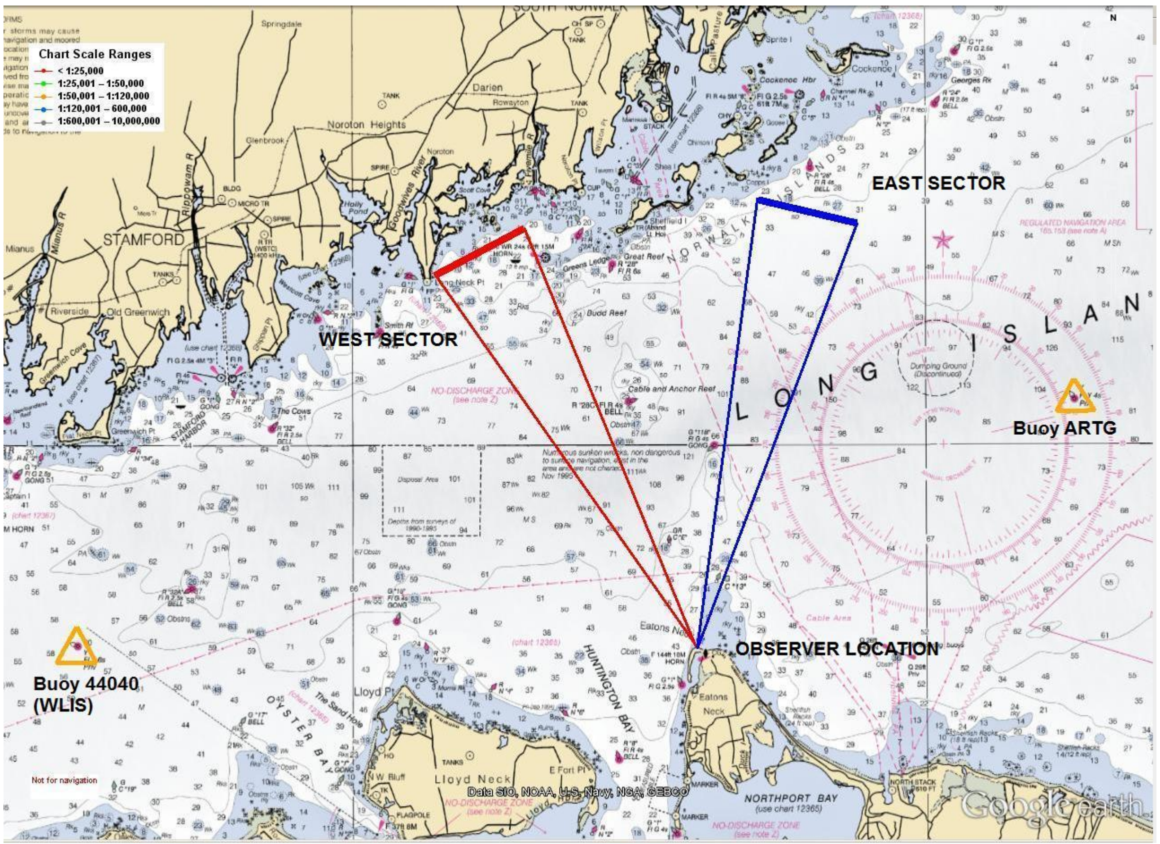

Figure 2. Field test location.

2.1.2 Signal Generators

To account for adding Lime and two additional White LEDs to the signal possibilities, and to allow a two-color SOS signal, the project had to either contract for rebuilding and reprogramming the existing devices, or build and program entirely new signal generators and signal heads. As the project had an extremely tight schedule, and had available technical skills of a recently-assigned electrical engineer, we chose to build new devices.

Figures 3 and 4 show the signal generator internal components. The red circuit card is a Texas Instruments 32-bit microcontroller, programmed to control all aspects of the signaling device including user interface via Liquid Crystal Diode display and control of the individual signal lights. The microcontroller's Pulse Width Modulation (PWM) outputs are high resolution, allowing 1000 discrete steps for fine control of the signal LEDs. Also, the microcontroller takes programming tools and techniques similar to the "Arduino" microcontroller, well established in high school and university classes.

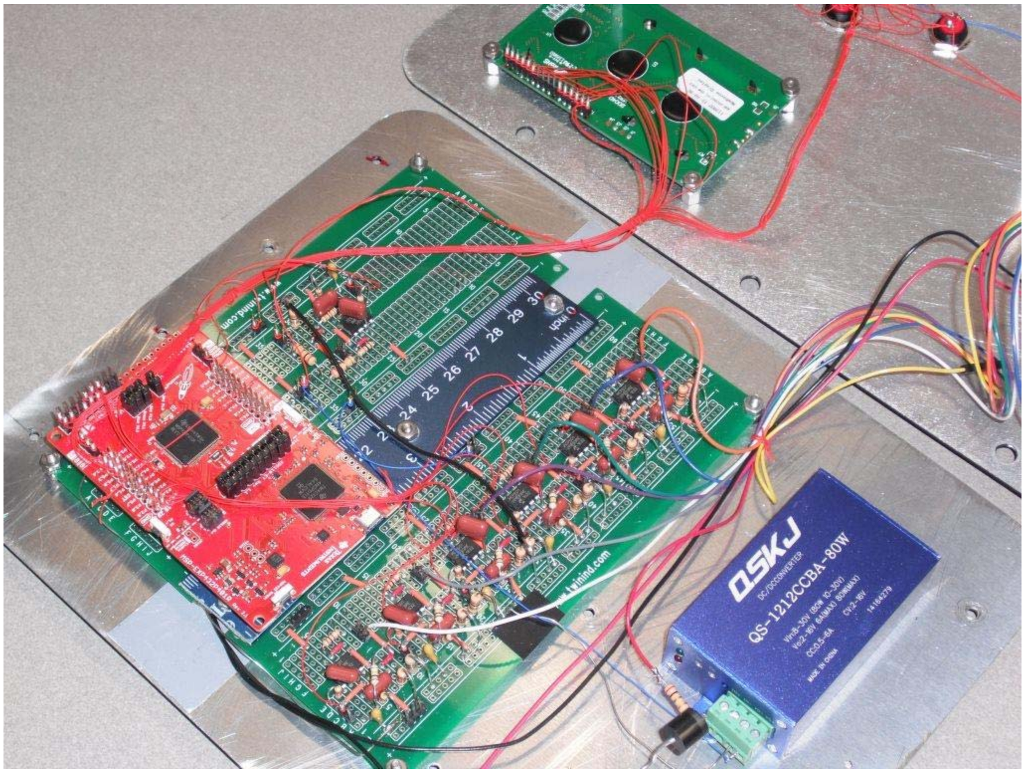

Figure 3. Signal generator circuitry.

Figure 4. Signal Generator, side view.

A dedicated, constant-current source controls each LED color. This "driver" consists of a linear operational-amplifier based constant current source with a buffer transistor. The filtered PWM from the microcontroller is compared to the voltage developed across a shunt resistor in the transistor's emitter circuit. Though not an efficient design, it allowed quick assembly and provided acceptable stability and resolution at the expense of extra current from the battery.

The project engineering team designed and constructed the signal heads from commercial components (Figure 5). The LED enclosure is an extruded aluminum heat sink with end caps and a protective transparent covering. The approximate overall dimensions are 6 x 11 inches with a 1 inch depth. The LED "stars" include 3 LEDs pre-soldered to a small aluminum based circuit board/heat sink. For each color, RDC installed 2 stars, yielding six, series connected LEDS. The Red-Orange color, with a lower maximum current rating required 4 LED stars to achieve the desired luminosity.

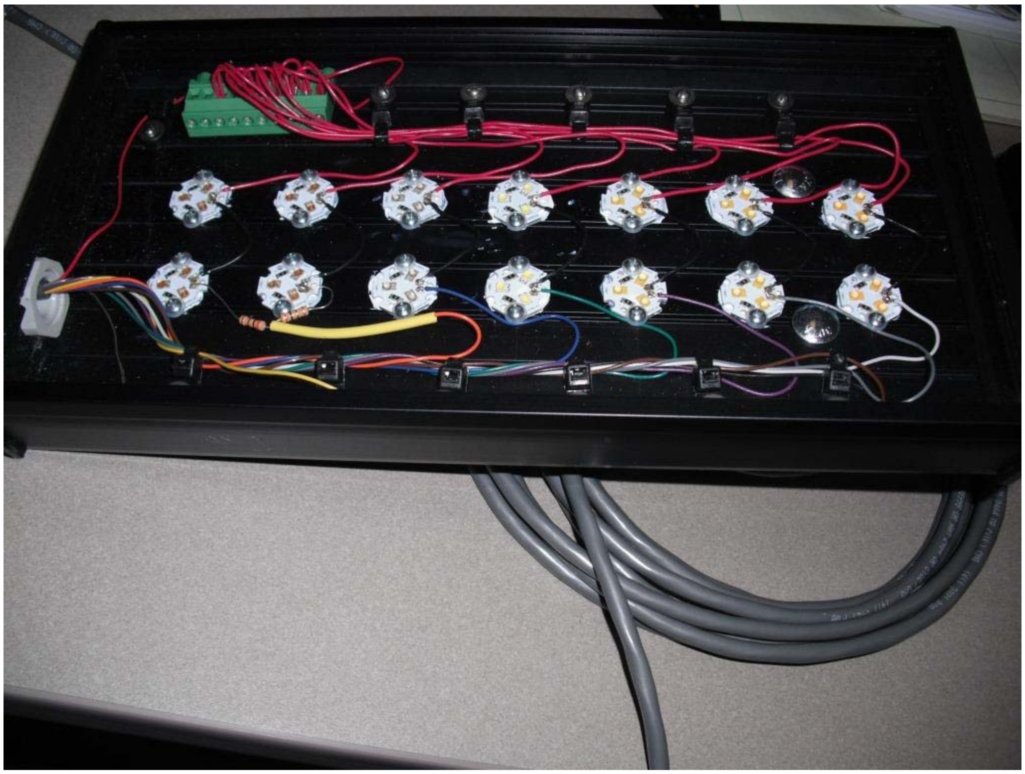

Figure 5. Signal head (without protective, transparent cover).

The system includes a 24 volt, direct current, lead acid battery pack in a carrying bag. The result is a lightweight, easy-to-install system. On the initial trials, two people easily carried all components and supporting masts to different locations.

Project engineers calibrated the signal generators in terms of luminous intensity. Luminous intensity is the amount of light a point source radiates in a given direction (expressed as the luminous flux leaving the source in that direction per unit of solid angle). They used a "zero-length" photometry range at RDC which provides a far field measurement of the light source, ensuring that it is measured as a point source. To make the measurements, they mounted the LED signal head on a test table, aligned normal (perpendicular) to the optical axis of the test range, and used the signal generator control unit to power the signal head. The engineering team *calibrated each LED color separately*.

For calibration, the signal team "drove" each color LED array at 7 or 8 intensity levels ranging from 10cd to 200cd, and used the calibration points to generate a 3rd order polynomial equation. By applying this equation to the intensity input command, the controller drives the LED at the necessary power to produce the correct luminous intensity. Additionally, the controller adjusts the level of the signals so that signals of different durations display at the same effective intensity. Once the calibrations were complete, the signal team verified luminous intensities of the test signals by measuring the individual flashes making up a signal and calculating their effective intensities. They took measurements at 10cd, 20cd, 50cd, and 100cd.

3 PILOT TESTS

The purpose of the pilot testing was to narrow down possible color and pattern combinations for a full field test in mid-May at Eatons Neck, NY. For the pilot tests, the project administered a computerized color-vision test. We did not disqualify anyone, as we wanted to see whether people with color vision deficiencies saw these signals any differently than people with normal color vision. We also had observers execute an Informed Consent Form which explained the study objective and allowed subjects to decide whether to participate. Those who elected to participate then completed a background information form giving age, boating experience, and any other known vision problems.

3.1 Pilot Test Methodology

In order to determine which of the displayed signal characteristics are more conspicuous, observers participated in "side-by-side" testing of signal pairs. On each trial, the project signal generator team at Eastern Point simultaneously displayed two, different, pre-arranged signal patterns, one to the left and one to the right (from the observers). The test team at Fort Trumbull directed the observers to study the two signals with their unaided eyes and select which appeared as more conspicuous (defined as "attention-getting", "easy to see", and "easy to differentiate from the background"). Observers then indicated their judgment with an electronic polling "key," which sent a radio-frequency signal to a nearby laptop with registration and polling software. The pilot tests were "forced choice" comparisons that prevented observers from saying the two signals were "the same," and required observers to trust their initial perceptions.

In the pilot tests, we reduced the light intensity to try to make the signal appear as "bright" as it would be at 6NM. To do this, we calculated the amount of luminous intensity required over a 2NM range to provide the same amount of luminance at the observer's eye that they would experience with the 50cd (effective) signal at 6 NM. This calculated out to approximately 5cd luminous intensity. As noted above, because the background "clutter" was at nearly the same range as the signals, their relative intensity was so bright that we needed to increase the signal output to 10 cd for the head-to-head testing. Table 1 depicts the effective intensities for the two signal generators, based on measurements in a calibration test.

Table 1. Effective intensities (in cd) for signal generators, 30 March 2017 pilot test.

Signal Effective Intensities

Signal Generator #1	East Location	30-Mar-17			
Color	Nominal 5 cd	Nominal 10 Cd	Nominal 15 cd	Nominal 20cd	Nominal 25 cd
Red-Orange	4.3	9.4	15.0	20.1	25.3
Cyan	2.6	8.3	13.4	18.2	23.2
Lime	4.7	9.5	13.5	18.5	23.6
5000K White	3.4	8.6	13.0	18.2	23.3
4000K White	4.1	8.5	13.9	19.2	23.5
3000K White	4.0	8.8	13.8	18.6	23.5

Signal Generator #3	West Location	30-Mar-17			
Color	Nominal 5 cd	Nominal 10 Cd	Nominal 15 cd	Nominal 20cd	Nominal 25 cd
Red-Orange	4.5	9.6	15.2	20.3	25.6
Cyan	2.7	8.5	13.8	18.7	24.0
Lime	4.9	9.9	14.0	19.2	24.4
5000K White	3.7	9.2	13.9	19.4	25.0
4000K White	4.2	8.5	13.9	19.2	23.6
3000K White	4.0	8.8	13.7	18.6	23.4

For all pilot testing, the vision researcher set the signal order so observers would compare all signals against each other four times. The test displayed each signal twice on the left and twice on the right, in a random manner. That way, if an observer couldn't distinguish between the two signals and always chose one on the right, that observer's answers would cancel out.

3.2 Pilot Test 1

On 30 March 2017, we looked at three different White LEDs: 4000K (W4)-as used in 2014- a "neutral" White; 3000K (W3), with a yellowish tinge; and 5000K (W5), with a bluish-signature. We compared the Whites as single-color SOS patterns, and as the 3-flash component of the 4Hz 4-3 pattern. (The 4-3 patterns included a flashing 4Hz, Red-Orange component—very conspicuous on its own, which most SC132 members accepted as a component of the original characteristic.)

Results (Table 2) show that after Red-Orange, observers considered Lime more conspicuous than any Whites, and the 5000K White (W5) the most conspicuous White.

Table 2 compares the responses to the different colored SOS signals. It shows the percentage of time observers chose one signal (in the left-hand column) over another signal (in the top row). As an example, observers indicated the Red-Orange SOS more conspicuous than the Lime SOS (100% of responses) or any

Whites (93-100%). When compared with any Whites, observers chose Lime slightly more often than W4 or W5, but significantly more often than W3. Among Whites, observers indicated W5 as significantly more conspicuous than either W3 or W4 (65% and 79% of responses, respectively.).

Table 2. Percentage of instances that observers chose one single-colored SOS signal (left column) over another single-colored SOS signal (top row).

Signals	SOS RO	SOS L	SOS W5	SOS W3	SOS W4
SOS RO	----	100%**	97%**	93%**	100%**
SOS L		----	52%	63%*	61%
SOS W5			----	65%*	79%**
SOS W3				----	59%
SOS W4					----
	N = 11	☐ = not significant		☐ p<.05*	☐ p<.01**

The 2014 work showed high conspicuity for RO, and the pilot test results confirmed this. In turn, we applied this RO conspicuity to a two-color signal. Table 3 indicates that if Whites are part of a 4 Hz signal alternating with Red-Orange, there was very little difference in the percentage of times observers chose a given signal (possibly because of the RO conspicuity). Observers did choose W5 slightly more often than either W3 or W4.

Table 3. Percentage of instances that observers chose one two-colored 4 Hz Signal (left column) over another two-colored 4 Hz Signal (top row).

Signals	4 Hz RO-W5	4 Hz RO-W3	4 Hz RO-W4
4 Hz RO-W5	----	56%	54%
4 Hz RO-W3		----	77%**
4 Hz RO-W4			----
N=11	☐ = not significant	☐ p<.05*	☐ p<.01**

Pilot Test 1 results showed W5 as the most conspicuous White LED, both as a single-color SOS and as a component in the 4Hz 4-3 signal. From here, we used W5 as the only White in subsequent tests.

3.3 Pilot Test 2

The next test on 5 April 2017 had observers determine whether any of the "best" colors from 30 March were more conspicuous than the 4Hz Cy-RO. Pilot Test 2 compared only two-color signals: SOS signals with an RO "S" component and Cy, W5 or L as the "O;" and the4Hz 4-3 signals, with W5 or L as the 3-flash component. As the results in Table 4 indicate, the observers definitely chose 4 Hz Cy-RO as most conspicuous. For our own curiosity, we wanted to know whether the color order of the 4 Hz Cy-RO (vs. 4 Hz RO-Cy) within a signal made any difference (2nd column), and the results indicated "no."

With knowledge of the observers' color-vision, we were able to determine if a color deficiency had any effect on an observer's perception of conspicuity. The data in Table 4 are from ten people with good color vision and one, slightly color-vision-deficient person. If we remove the color-deficient observer's data, the results remain rather consistent (see Table 5, below). This is important as existing laws and regulations do not require recreational mariners (nor automobile drivers) to have normal color vision.

Table 4. Percentage of time observers chose one signal (left column) over others (top row).

Signals	4Hz Cy-RO	4Hz RO-Cy	4Hz RO-W5	SOS RO-Cy	4Hz RO-L	SOS RO-W5	SOS RO-L
4Hz Cy-RO	----	54%	79%**	95%**	88%**	97%**	90%**
4Hz RO-Cy		----	81%**	84%**	90%**	93%**	95%**
4Hz RO-W5			----	50%	59%	86%**	79%**
SOS RO-Cy				----	56%	79%**	100%**
4Hz RO-L					----	93%**	95%**
SOS RO-W5						----	56%
SOS RO-L							----
	N = 11	☐ = not significant		☐ p<.05*		☐ p<.01**	

Table 5. Percentage of time observers chose one signal (left column) over others (top row, less results from a color-deficient observer.

Signals	4Hz Cy-RO	4Hz RO-Cy	4Hz RO-W5	SOS RO-Cy	4Hz RO-L	SOS RO-W5	SOS RO-L
4Hz Cy-RO	----	50%	80%**	95%**	87%**	97%**	90%**
4 Hz RO-Cy		----	80%**	82%**	90%**	92%**	95%**
4Hz RO-W5			----	50%	57%	87%**	80%**
SOS RO-Cy				----	52%	80%**	100%**
4Hz RO-L					----	97%**	95%**
SOS RO-W5						----	55%
SOS RO-L							----
	N = 10	☐ = not significant		☐ p<.05*		☐ p<.01**	

This test demonstrated 4 Hz Cy-RO and 4 Hz RO-Cy as significantly more conspicuous than any other signal. With one exception, observers considered the 4 Hz alternating-color signals superior to the SOS alternating-color signals. For example, they indicated 4 Hz RO-W5 as significantly more conspicuous than both SOS RO-W5 and SOS RO-L. Observers also indicated 4Hz RO-L as significantly more conspicuous than either SOS RO-L or SOS RO-W5. The one exception for the SOS pattern was SOS RO-Cy. Observers indicated this as equally conspicuous to the 4 Hz RO-W5 and slightly more conspicuous (though not significantly so) than the 4 Hz RO-L.

Though all observers indicated Cyan as much more conspicuous than either White or Lime, the Cyan LED takes more electrical power to project the same intensity as the White or Lime LED. Some project-team members suggested we run the White and Lime LEDs at the same power we used for Cyan. Though lab readings indicated an increase in intensity, the engineers decided to increase to a standard output rather than input current, so as not to have LED-manufacturer-specific results. A quick, project-team look at the White and Lime LEDs showed much more conspicuity at the higher intensity, so we set up the third pilot test, i.e., compare the Cy-RO to the Lime and White, with the Lime and White at two higher intensities.

3.4 Pilot Test 3

This test determined whether increasing intensity of the White and Lime signal components from Pilot Test 2 increased signal conspicuity. We planned to increase the L and W components by 1.5 times and 2.5 times the intensity of Cy. The RO and Cy components remained at the same intensity as previous pilot tests.

On 24 April 2017, we gathered a new group of observers. For this test, we wanted participants who had not seen any of our signals. Also, a light drizzle was present, and though the precipitation was slightly uncomfortable, it did not appear to affect visibility. (The project lead easily identified a vessel's masthead lights at approximately 8 NM, well beyond the approximate 2 mile test range.).

Against the 4Hz Cy-RO, we tested 4Hz RO-L (with L at 1.5 and 2.0 times the Cy intensity) and 4Hz RO-W (with W at 1.5 and 2.0 times the Cy intensity). We also tested the 4Hz RO-Wx2 against the 4Hz RO-Lx2, and the 4Hz RO-Wx1.5 against the 4Hz RO-Lx1.5. Observers compared each combination four times, with a given signal appearing twice on the left and twice on the right.

Table 6 shows that observers still picked Cy-RO as more conspicuous than RO-Lx2, but not by much, and definitely indicated Cy-RO as significantly more conspicuous than the RO-Wx2. Cy-RO was also significantly more conspicuous than RO-W 1.5x and RO-L 1.5x.

Table 6. Percentage of time observers chose one signal (left column) over others (top row).

Signals	4Hz Cy-RO	4HzRO Lx2	4HzRO Lx1.5	4HzRO Wx2	4HzRO Wx1.5
4Hz Cy-RO	-----------	56%	76%**	65%*	68%**
4HzRO Lx2		---------------		53%	
4HzRO Lx1.5			----		50%
	N=15	☐ = not significant		☐ p<.05*	☐ p<.01**

We also considered whether removing color vision deficient observers from the results had any effect on the signal rankings. Table 7 shows almost identical results as Table 6.

Table 7. Percentage of time observers chose one signal (left column) over others (top row), less results from color-deficient observers.

Signals	4Hz Cy-RO	4HzRO Lx2	4HzRO Lx1.5	4HzRO Wx2	4HzRO Wx1.5
4Hz Cy-RO	-----------	56%	75%**	63%*	68%**
4HzRO Lx2		---------------		59%	
4HzRO Lx1.5			----		50%
	N=11	☐ = not significant		☐ p<.05*	☐ p<.01**

3.5 Pilot Test Conclusions

Based on the pilot test results, it still appeared that 4 Hz Cy-RO provided the greatest conspicuity, significantly so for all signals except the 4Hz RO-Lx2. It also appeared that the 4 Hz pattern is significantly better than the SOS pattern. Also, the side-by-side tests did indicate the 5000K white provides greater conspicuity than the other two White LEDs.

Note: With these results, we planned for the 6NM field experiment. As field experiment plans included a "pre-test" to check operations, communications, and equipment, the project team decided to conduct an informal comparison of all signals, including the lime and white at the 1.5 x intensity. In the pre-test, the opinion of project team and two volunteer observers indicated the 1.5 x intensity Lime and White signals did not appear as conspicuous as the other signals.

The resultant signals for the field experiment were: 4Hz Cy-RO, 4Hz RO-L, 4Hz RO-W, SOS RO-Cy, SOS RO-L, SOS RO-W. All the RO and Cy components would be at 50cd effective intensity, while the L and W would be at 100cd effective intensity.

4 FIELD EXPERIMENT

This field test included two separate nights of observer trials on 15-16 May 2017. The test used a visual search paradigm. For most trials, the experimenters displayed a single signal from one of two boats. The observers were to determine if the “left” boat or “right” boat displayed the signal. If neither boat displayed a signal (a “null” trial), the observers were to indicate “no signal displayed.” Each night's test series included 72 "trials," including 8 observations each of 7 different signals (56 trials) and 16 "null" trials (i.e., trials that had no signal). We were fortunate to have 28 observers (“subjects”) participate in the testing on the first night, and 25 observers on the second night. All but three were members of the Coast Guard Auxiliary, and we sincerely appreciate their willing participation.

4.1 Signals

The experiment included signals that resulted from the 3 pilot tests in March and April 2017, in addition to the 4Hz, group alternating Cyan/Red-Orange signal from the 2014 test and a red-hand held flare. The temporal nature of the signal patterns is detailed below in Table 8.

Table 8. Field experiment signal patterns.

Signal Patterns	
Temporal Pattern	**Actual signal characteristic in milliseconds (eclipse duration)**
4 Hz Cyan/Red-Orange 4-3 group alt	Cyan: 125 (125) 125 (125) 125 (125) 125 (250) Red-orange: 125 (125) 125 (125) 125 (250) …
4 Hz Red-Orange/Lime 4-3 group alt	Red-orange: 125 (125) 125 (125) 125 (125) 125 (250) Lime: 125 (125) 125 (125) 125 (250) …
4 Hz Red-Orange/ White 4-3 group alt	Red-orange: 125 (125) 125 (125) 125 (125) 125 (250) White: 125 (125) 125 (125) 125 (250) …
SOS Red-Orange/Cyan	Red-orange: 125 (125) 125 (125) 125 (125) Cyan: 375 (125) 375 (125) 375 (125) Red-orange: 125 (125) 125 (125) 125 (500) …
SOS Red-Orange/Lime	Red-orange: 125 (125) 125 (125) 125 (125) Cyan: 375 (125) 375 (125) 375 (125) Red-orange: 125 (125) 125 (125) 125 (500) …
SOS Red-Orange/White	Red-orange: 125 (125) 125 (125) 125 (125) Cyan: 375 (125) 375 (125) 375 (125) Red-orange: 125 (125) 125 (125) 125 (500) …
Red Hand-held Flare	Red: > 5 min

From the pilot tests, the project found that the only time White and Lime, used in conjunction with Red-Orange, provided comparable conspicuity to the Cyan/Red-Orange combination, was when we increased the effective intensity of Lime and White to approximately twice the effective intensity of Cyan. Since the effective intensity of the Cyan/Red-Orange baseline signal is 50 candela (cd) for both colors, we increased the effective intensity of the Lime and White signal components to approximately 100 cd, leaving the Red-Orange at 50 cd. The table of signal intensities (Table 9) indicates the actual (measured) intensities needed to achieve approximately 100 cd effective intensity. Note that for the different signal durations, the amount of measured intensity changes to maintain the desired effective intensity.

Table 9. Field experiment signal intensities.

Signal Intensities			
Signal Generator #1	BOAT: West		
Color	Signal Duration (ms)	Measured Intensity (cd)	Effective Intensity (cd)
Red-Orange	125	137	52
Cyan	125	127	49
	375	74	48
White	125	265	102
	375	154	101
Lime	125	257	99
	375	150	98
Red Flare	>300000	not measured	>500
Signal Generator # 3	BOAT: East		
Color	Signal Duration (ms)	Measured Intensity (cd)	Effective Intensity (cd)
Red-Orange	125	135	52
Cyan	125	125	48
	375	71	46
White	125	255	98
	375	146	95
Lime	125	253	97
	375	149	97
Red Flare	>300000	not measured	>500

4.2 Procedures

The bulk of the experimental procedures followed CG-D-05-14. As a quick overview, we stationed two boats in Long Island Sound, approximately 45 degrees apart, 6 NM away from observers at CG Station Eatons Neck shore. On any given trial, if a boat displayed a signal, the observers needed to respond (within 30 seconds) whether they saw the signal to the left or right. They could also respond that they did not see a signal. In some cases, observers never made any response within the 30-sec trial window, what we call a "non-response." For most trials, there was, in fact, a signal displayed (by one of the two boats). On some trials, the boats displayed no signal (a "null" trial), and the observers needed to determine that no signal was present.

4.3 Results Analysis and Description

The 2014 work (CG-D-04-15) used the following evaluation metrics:

1) Correct vs. incorrect: if the experimenters displayed a signal, did the subject correctly identify which side it was on. Or, if the experimenters did not display a signal, did the subject correctly respond that no signal was present. If a subject did not respond on a trial, we noted that separately as a "no response."
2) Response time (RT): the elapsed time between the signal initiation and subject's correct response.

After review of the 2014 results and subsequent analysis and discussion, the project's operations research statistician determined that the "correct vs. incorrect" metric caused some individuals' responses to have a greater effect on average percent-correct and average response time. When comparing the percent of times a subject correctly identified the side (left or right) on which a signal appeared, i.e., the percent correct, the 2014 analysis discarded non-responses. The proportion was the number of correct identifications divided by the number of correct plus incorrect responses for a particular signal. This method presented an issue: a subject could potentially respond correctly one time for a particular signal, and then fail to respond for the other seven trials of that same signal and receive a 100% correct score.

A subject's average percent correct for each of the seven signals was the basis for the differences between the percent correct for different signals. The 2014 analysis used these differences to determine if one signal was statistically different than another using the Wilcoxon Signed-Rank test.

To maintain consistency with the 2014 work, this report includes the 2014 methodology (Method 1, M1), but also uses the number of correct responses divided by the total number of trials where the boats presented a given signal, i.e., 8 planned trials (Method 2, M2). As in 2014, the analysis used the differences between the percent correct for the different signals to determine if one signal was statistically more conspicuous than another using the Wilcoxon Signed-Rank test.

Similar to the issue with analyzing the percent correct, when analyzing response times, using the 2014 methodology, a subject could potentially only correctly identify a particular signal once while correctly identifying another, eight times. This would result in an average response time from a sample of 8 being compared to a single observation.

To compare the response times for two particular signals, both methods use the average time a subject took to respond to a particular signal, generated only from the subject's correct identifications of the signal. To offset the potential "one out of eight" bias, Method 2 only uses the responses from subjects who correctly identified at least 5 of 8 presentations of a given signal. If the observer did not identify the signal on the correct side, or did not respond, that response time was not included in the average signal response time for the subject. If a subject did not correctly identify a signal at least 5 out of 8 times, the average response time for that subject was not included in the analysis for that particular signal.

The Method 2 analysis then used the average response time (for each subject who had at least 5 of 8 correct responses) for each signal as the basis for the differences between response times for different signals. As in Method 1, the analysis used the Wilcoxon Signed-Rank test to determine if one signal yielded a statistically different response than another.

Though the 2014 analysis used a Friedman nonparametric test for repeated measures design (Siegel, 1956) to determine whether there were any significant differences among the entire set of data analyzed within a test (for example, whether mean RT to any of the eight signals is significantly different from the rest), we did not use this test here, and used the Wilcoxon Signed-Rank test to compare all differences.

4.4 Field Experiment Execution and Results

4.4.1 Field Experiment Test 1

The afternoon of 15 May featured relatively high winds (approximately 15-20 knots (kt)) that caused a visible layer of spray that obscured visibility near the surface of the water. Though the project team at Eatons Neck could clearly see landmarks and buildings at Port Chester, NY, and at Stamford, Norwalk and

Bridgeport, CT, the particulates that obscured visibility on the surface of Long Island Sound caused the team to consider test delay. Approximately one hour before sunset, the winds abated and the spray subsided. Visibility at the surface improved to the point where the project team decided to go forward with the first night's testing. The project intended the signal vessels to station themselves approximately 6 NM from Eatons Neck Point. As it turned out, the East boat was slightly beyond 6 NM, while the West boat was less than 6 NM. For the duration of the test, the boats maintained station generally in their assigned sectors, maneuvering to account for surface-current set, approximately 5.5 – 6.3 NM from the observers at Eatons Neck.

Throughout the evening, observers at Eatons Neck could see landmarks 15-20 miles distant. However, the project team could not say for certain that visibility between the observers and the signal vessels was in excess of 10 NM. The East signal vessel reported visibility at 6 NM for the duration of the test, and the West signal vessel reported that two navigation buoys within 3.5 NM as not "sharp" in appearance. However, both vessels reported that more-distant, higher elevation "reference landmarks" were "sharp" from the beginning through the end of the test. (Appendix A includes vessel observations and vessel distances to Eatons Neck Point.)

The project team began signal familiarity demonstrations and "practice" trials at approximately 2030 local time and began the actual Test 1 observation trials at approximately 2130. The series of trials finished at approximately 2320. The signal teams and observers did not experience any signal system abnormalities, except that on three occasions, the signal team on the West vessel encountered difficulties in activating the pyrotechnic flare.

Table 10 includes Test 1 results. As in CG-D-05-14, the left half of the table ranks the signals by the average percent correct, while the right half ranks the signals by the average response time. The table includes both "Method 1" analysis results and "Method 2" results (as discussed earlier) to indicate the differences that result when "no response" is counted with "incorrect response" as in Method 2.

Table 10. Field Experiment Test 1, Results summary.

Test 1 - Comparison by % Correct and Mean Response Time (RT) (seconds)-15 May 2017									
Signal	Mean Correct (1)	**Mean Correct (2)**	Mean RT (2)	No Response	Signal	Mean Correct (2)	Mean RT (1)	**Mean RT (2)**	No Response
4Hz Cy-RO	89%	**83%**	10.89	6%	SOS RO-L	77%	11.52	**10.75**	8%
SOS RO-Cy	83%	**79%**	11.11	6%	4Hz Cy-RO	83%	11.28	**10.89**	6%
SOS RO-L	82%	**77%**	10.75	8%	4Hz RO-W	72%	11.30	**11.00**	6%
4Hz RO-L	80%	**76%**	11.48	6%	SOS RO-Cy	79%	11.61	**11.11**	6%
4Hz RO-W	77%	**72%**	11.00	6%	4Hz RO-L	76%	12.34	**11.48**	6%
SOS RO-W	77%	**72%**	11.82	8%	SOS RO-W	72%	11.89	**11.82**	8%
Flare*	~~34%~~	**~~31%~~**	~~17.59~~	~~13%~~	Flare*	~~31%~~	~~19.17~~	**~~17.59~~**	~~13%~~

(1) - Analysis using Method 1 (same as 2014)
(2) - Analysis using Method 2
* Three of eight flares did not activate properly; flare data are not used in Test 1 analysis

For Test 1, we note that the mean correct values for the flare are much lower than the remainder of the signals and the mean response times are significantly higher than the remainder of the signals. Also, the number of "no responses" to the flare are approximately double the number of "no responses" for the other signals. As each boat displayed the flare four times, two or three miscues on one vessel severely impacted the test results. Table 10 reports the flare results with strikethrough, as we cannot use these in any valid analysis. *The reader cannot assume that all the signals are significantly better than the flare from Test 1 results.*

Tables 11 and 12 are the Wilcoxon analyses for the percent correct and response times respectively, using Method 2. The Wilcoxon analyses indicate whether we can state that responses are significantly different, or one signal "better" than another, beyond random chance, based on Wilcoxon head-to-head "victories," i.e., significant differences. This resulted in some of the signals appearing higher in the order despite having a lower average (e.g., in Table 12, SOS RO-L has a faster RT, but has no Wilcoxon "victories," thus ranking below 4Hz Cy-RO and SOS RO-Cy).

Table 11. Field Experiment Test 1, Wilcoxon analysis for percent correct.

Wilcoxon Analysis - AccuraCy (% correct) Statistical Comparison Day 1 Method 2								
Signals	**% corr**	4HzCy-RO	SOS RO-Cy	SOS RO-L	4Hz RO-L	4Hz RO-W	SOS RO-W	Flare
4HzCy RO	83%	-------	22.5*	14**	25*	8.5**	16.5**	n/a
SOS RO-Cy	79%		-------	59.5	80	33.5*	35*	n/a
SOS RO-L	77%			-------	91	66.5	61.5	n/a
4Hz RO-L	76%				-------	83	56	n/a
4Hz RO-W	72%					-------	81	n/a
SOS RO- W	72%						-------	n/a
Flare	~~31%~~							-------
N varied 15 to 28		not significant		p < 0.1	p < 0.05*	p < 0.01**		

Table 12. Field Experiment Test 1, Wilcoxon analysis for response time.

Wilcoxon Analysis - Response time (RT) Statistical Comparison Day 1 Method 2								
Signals	**Avg RT**	4Hz Cy-RO	SOS RO-Cy	4Hz RO-W	SOS RO-L	SOS RO-W	4Hz RO-L	Flare
4HzCy-RO	10.89	-------	132	132	70.5	34*	57*	n/a
SOS RO-Cy	11.11		-------	133	99	49*	78	n/a
4HzRO-W	11.00			-------	102	63	76	n/a
SOS RO-L	10.75				-------	70	68	n/a
SOS RO-W	11.82					-------	67	n/a
4Hz RO-L	11.48						-------	n/a
Flare	~~17.59~~							-------
N varied 4 to 24		not significant		p < 0.1	p < 0.05*	p < 0.01**		

Because of the flare activation issues, we do not consider comparisons against the flare in Test 1. Table 11 shows that observers correctly identified the 4Hz Cy-RO 83% of the time, and the correct response rate is significantly higher than the % correct to any other signal. The SOS RO-Cy shows a statistically greater percent correct than either the 4Hz RO-W or the SOS RO-W. Though not as significant, the SOS RO-L shows a statistically better % correct when compared to the 4Hz RO-W, also.

Table 12 indicates the 4Hz Cy-RO response times were statistically faster than the SOS RO-W and 4Hz RO-L response times; the SOS RO-Cy also shows a statistically better response time than the SOS RO-W.

In Test 1, the 4Hz Cy-RO signal shows the largest number (6) of significant differences with other signals, followed by the SOS RO-Cy (3).

4.4.2 Field Experiment Test 2

For the second test on 16 May 2017, the project team originally stationed the signal boats at 5.5 – 6 NM from the Eatons Neck. At approximately 2030, the project lead called for the signal demonstration. At that time, neither the observers nor the shore test team could locate and identify any of the signals. The test director climbed to a higher elevation, and even with binoculars, could barely discern signals from either boat. The test team gradually moved the signal boats closer to the observers until the test team lead and observers could regularly see signal display from both vessels.

With signal boats at 4.6 to 4.8 NM from the observers, the test team conducted signal and position familiarization as in Test 1, and then ran through the “practice” trials. Test 2 actually began at approximately 2245. Throughout Test 2, the signal boats remained on station between 4.3 and 4.8 NM from the observers. The test lead occasionally repositioned the vessels to make sure background lighting clutter stayed relatively consistent. Test 2 completed at approximately 2350.

Test 2 occurred in somewhat challenging atmospheric conditions. Though the test team and observers ashore could not regularly identify the signals until the signal boats moved closer to shore, the weather observers aboard the signal vessels reported visibility as “better” than the previous night during Test 1. For Test 1, the West boat observer noted the two buoys appeared “fuzzy” throughout the test, but that both buoys appeared “sharp” during Test 2. During both tests, the more-distant landmarks with greater elevation all appeared “sharp.” In Test 2, the shore test team noted the rather dominant presence of the pyrotechnic flare when activated from either the East or the West signal boats, more so than during the “good” activations of Test 1.

From this, we assume that surface-level atmospherics on 16 May 2017 were somewhat different than conditions on 15 May for Test 1, with a resulting attenuation on the light signals, but not necessarily of the much-higher-intensity hand-held flare.

Table 13 provides Test 2 summary results. Notwithstanding the flare activation issues in Test 1, the overall percent correct in Test 2 is approximately the same as in Test 1, but the number of “No Responses” is much lower than in Test 1. From the summary results, the mean response time spread is greater in Test 2 than in Test 1. All experiment conditions need to be the same to combine the data sets from Test 1 and Test 2. As noted, atmospherics and vessel positions were not the same, so we consider Test 1 and Test 2 as two, completely separate and different tests. Specifically, we cannot combine the individual data sets for analysis.

Table 13. Field Experiment Test 2, Results summary.

Test 2 - Comparison by % Correct and Mean Response Time (RT) (seconds)-16 May 2017									
Signal	Mean Correct (1)	**Mean Correct (2)**	Mean RT (2)	No Response	Signal	Mean Correct (2)	Mean RT (1)	**Mean RT (2)**	No Response
4Hz RO-L	78%	**78%**	10.22	2%	4Hz Cy-RO	77%	10.06	**9.86**	4%
SOS RO-W	78%	**77%**	13.27	2%	4Hz RO-L	78%	10.25	**10.22**	2%
4Hz Cy-RO	79%	**77%**	9.86	4%	SOS RO-Cy	74%	10.63	**10.30**	3%
Flare	79%	**77%**	12.92	4%	4Hz RO-W	75%	10.66	**10.99**	3%
4Hz RO-W	77%	**75%**	10.99	3%	SOS RO-L	72%	11.71	**11.96**	4%
SOS RO-Cy	76%	**74%**	10.3	3%	Flare	77%	12.41	**12.92**	4%
SOS RO-L	74%	**72%**	11.96	4%	SOS RO-W	77%	12.82	**13.27**	2%

(1) - Analysis using method 1 (same as 2014)
(2) - Analysis using method 2

Tables 14 and 15 provide the Test 2 Wilcoxon analysis for percent correct and response time, respectively. In Table 14, there are no statistically significant differences in percent correct between any of the signals, though the SOS RO-W and SOS RO-L comparison "trends" toward a difference, but not at the generally-accepted 5% probability cutoff.

Table 14. Field Experiment Test 2, Wilcoxon analysis for percent correct.

Wilcoxon Analysis - Accuracy (% correct) Statistical Comparison Day 2 Method 2								
Signals	**% corr**	4Hz RO-L	SOS RO-W	Flare	4Hz Cy-RO	4Hz RO-W	SOS RO-CY	SOS RO-L
4Hz RO-L	78%	-------	41	28.5	116	51	45.5	60.5
SOS RO-W	77%		-------	41.5	70	41	46	29
Flare	77%			-------	71.5	52.5	69.5	72.5
4Hz Cy-RO	77%				-------	70	88	61.5
4Hz RO-W	75%					-------	74.5	79.5
SOS RO-CY	74%						-------	91
SOS RO-L	72%							-------
N varied 13 to 22	not significant		p < 0.1	p < 0.05*	p < 0.01**			

Table 15 does indicate significant differences in response times. Three signals (4 Hz Cy-RO, 4Hz RO-L, and SOS RO-Cy) had significantly faster RTs than the flare. Four signals had statistically faster response times to SOS RO-W: 4 Hz Cy-RO, 4Hz RO-L, SOS RO-Cy, and 4Hz RO-W. Of final note, the 4 Hz Cy-RO also had statistically faster response times than the SOS RO-L.

Table 15. Field Experiment Test 2, Wilcoxon analysis for response time.

Wilcoxon Analysis - Response time (RT) Statistical Comparison Day 2 Method 2								
Signals	**Avg RT**	4Hz Cy-RO	4Hz RO-L	SOS RO-CY	4Hz RO-W	SOS RO-L	SOS RO-W	Flare
4Hz Cy-RO	9.86	-------	74	59	56	29*	8**	22**
4Hz RO-L	10.22		-------	74	62	36	11**	41*
SOS RO CY	10.30			-------	52	50	19**	24*
4Hz RO-W	10.99				-------	54	28*	57
SOS RO-L	11.96					-------	61	36
SOS RO-W	13.27						-------	84
Flare	12.92							-------
N varied 16 to 20	not significant		p < 0.1	p < 0.05*	p < 0.01**			

5 CONCLUSIONS

This one field experiment actually included two completely separate tests under separate conditions: the apparent visibility was different; the distance of signals to observers was different; and observer experience was different (e.g., by the start of the second night, all observers had experience seeing a flare at a distance and had familiarity with the LED signals). As stated above, we cannot combine the two separate data sets to yield a single answer. On the other hand, we can present the combined analysis results of the two separate tests and look for commonality.

Table 16 takes the Wilcoxon analysis results, i.e., any significant differences between signals (from Tables 11, 12, 14, and 15), and groups them for each signal, over both tests, for both percent correct and response time.

Table 16. Combined Wilcoxon analysis.

	4Hz Cy-RO				SOS RO CY				4Hz RO-L				4Hz RO-W				SOS RO-L				SOS RO-W				Flare				# of Diff
	Test1		Test 2		Test1		Test 2		Test1		Test 2		Test1		Test 2		Test1		Test 2		Test1		Test 2		Test1		Test 2		
	%	RT	%	RT	%	RT	%	RT	%	RT	%	RT	%	RT	%	RT	%	RT	%	RT	%	RT	%	RT	%	RT	%	RT	
4Hz Cy-RO																													10
SOS RO CY																													5
4Hz RO-L																													2
4Hz RO-W																													1
SOS RO-L																													0
SOS RO-W																													0
Flare																													0

The far right-hand column indicates the total number of significant differences for each signal. Two signals achieved significantly better scores in both Test 1 and Test 2: 4Hz Cy-RO (top row) in Test 1, had significantly better percent correct scores over all other signals, and significantly better response times over two other signals in Test 1 (lighter shading). 4Hz Cy-RO had significantly better response times over two signals (and the flare) in Test 2 (darker shading). The SOS RO-Cy (second row) had significantly better percent correct scores over two signals, and significantly better response time over one other signal in Test 1 (lighter shading), while having significantly better response times over one other signal (and the flare) in Test 2 (darker shading). The 4 Hz RO-L (third row) had a significantly better response time over one other signal (and the flare) in Test 2. 4 Hz RO-W (fourth row) had one significantly better response time in Test 2, *but not better than the flare*. Conversely, the SOS RO-W (sixth signal across the top) had significantly worse scores in both tests (against 4 other signals in Test 2), while the flare showed significantly worse performance in three Test 2 comparisons.

From these two tests, in conjunction with the results of this year's pilot testing, and the 2014 testing, the results indicate that the two most conspicuous signals are the 4Hz Cy-RO and the SOS RO-Cy, with all signal components at 50cd effective intensity. The 4Hz RO-L (with the Lime component at 100cd effective intensity) also showed significantly better performance than two other signals. The 4Hz RO-W, better than one other signal, and the SOS RO-L, with the L or W components at 100 cd effective intensity, may be adequate to provide a level of conspicuity comparable to a red hand-flare. The SOS RO-W did not compare well against any other signal.

Note: The temporal pattern of the SOS is fixed, and results in specific luminous intensities to achieve the desired *effective* intensities (50 cd for CY, and 100 cd for L and W). Appendix B includes a pictorial depiction of the 4Hz and SOS signals showing the required luminous intensity.

6 RECOMMENDATIONS

For the most conspicuous visual signal, the project recommends the 4 Hz group alternating (4-3) Cyan and Red-Orange 50 candela effective intensity characteristic. This characteristic continues to demonstrate greater conspicuity than all other signals tested.

Understanding that this project's Coast Guard sponsor and stakeholders need to (1) weigh manufacturers' ability to field a marketable product; and (2) the existing, generally-accepted constructs in mariner awareness and public education, as an alternative to the "best" signal the project recommends two additional visual characteristics, an SOS Red-Orange and Cyan 50 candela effective intensity signal, and a 4 Hz group alternating (4-3) Red-Orange and Lime signal where the Lime component has 100 candela effective intensity.

As further alternatives that can provide an *adequate* solution, i.e., comparable to a flare, the project includes a 4 Hz group alternating (4-3) Red-Orange and White signal where the White component has 100 candela effective intensity and an SOS Red-Orange and Lime, where the Lime component has 100 candela effective intensity signal.

Note: Appendix B graphically presents the recommended signal-patterns and includes individual component timing and minimum required luminous intensity to produce the appropriate characteristic.

Finally, the project recommends *not* adopting an SOS Red-Orange and White, even where the White component has 100 candela effective-intensity.

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APPENDIX A. ADDITIONAL FIELD TEST DATA

A.1 Test 1 – Monday 15 May 2017

A.1.1 Signal Vessel Distance to Observers at Eatons Neck

Table A-1. Test 1 signal distances (NM) 15 May.

Test 1 - 15 May 2017 - Signal Distance from Observers							
	East Boat-Distance				West Boat-Distance		
EDT	**Vsl Lat**	**Vsl Lon**	**Dist**	**EDT**	**Vsl Lat**	**Vsl Lon**	**Dist**
2030	41.053 N	73.364 W	**6.2**	2030	41.039 N	73.445 W	**5.5**
2045	41.054 N	73.365 W	**6.3**	2045	41.037 N	73.444 W	**5.5**
2100	41.053 N	73.368 W	**6.2**	2100	41.037 N	73.445 W	**5.5**
2115	41.053 N	73.368 W	**6.2**	2115	41.038 N	73.445 W	**5.5**
2130	41.051 N	73.369 W	**6.1**	2130	41.037 N	73.443 W	**5.4**
2145	41.051 N	73.373 W	**6.0**	2145	41.038 N	73.447 W	**5.6**
2200	41.051 N	73.372 W	**6.0**	2200	41.038 N	73.443 W	**5.5**
2215	41.051 N	73.368 W	**6.1**	2215	41.038 N	73.440 W	**5.4**
2230	41.049 N	73.366 W	**6.0**	2230	41.039 N	73.448 W	**5.6**
2245	41.047 N	73.370 W	**5.8**	2245	41.039 N	73.444 W	**5.5**
2300	41.045 N	73.369 W	**5.7**	2300	41.038 N	73.445 W	**5.5**
2315	41.044 N	73.371 W	**5.6**	2315	41.038 N	73.442 W	**5.4**
2330	41.026 N	73.384 W	**4.5**	2330	41.038 N	73.441 W	**5.4**

A.1.2 Signal Vessel Weather Logs

Table A-2. Test 1 signal vessel weather logs 15 May.

DATE: 15 May 2017				BOAT: EAST			CG 45733				RECORDER: JD						
	WIND			SEAS				AIR			VISIBILITY						
TIME	SPEED	DIR	GUSTS	HEIGHT	DIR	BREAKING	SPRAY	TEMP	REL HUM	DEW	ESTIMATE	11B	28 C	"A"	"B"	"C"	"D"
2000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2015	10	0	—	< 1	180	—	—	55	50	—	6	O	S	S	S	S	S
2030	10	0	—	< 1	180	—	—	50	50	—	6	F	S	S	S	S	S
2045	10	0	—	< 1	180	—	—	50	50	—	6	F	S	S	S	S	S
2100	< 10	0	—	< 1	180	—	—	47	50	—	6	S	S	S	S	S	S
2115	< 10	0	—	< 1	180	—	—	45	50	—	6	S	S	S	S	S	S
2130	10	0	—	< 1	180	—	—	45	50	—	6	S	S	S	S	S	S
2145	10	0	—	< 1	180	—	—	45	50	—	6	S	S	S	S	S	S
2200	10	0	—	< 1	180	—	—	45	50	—	6	S	S	S	S	S	S
2215	< 10	0	—	< 1	180	—	—	45	—	—	6	S	S	S	S	S	S
2230	< 10	0	—	< 1	180	—	—	45	—	—	6	S	S	S	S	S	S
2245	< 10	0	—	< 1	180	—	—	45	—	—	6	S	S	S	S	S	S
2300	< 10	0	—	< 1	180	—	—	45	—	—	6	S	S	S	S	S	S

DATE: 15 MAY 2017				BOAT: WEST			CG 49410				RECORDER: MH						
	WIND			SEAS				AIR			VISIBILITY						
TIME	SPEED	DIR	GUSTS	HEIGHT	DIR	BREAKING	SPRAY	TEMP	REL HUM	DEW	ESTIMATE	11B	28 C	"A"	"B"	"C"	"D"
2000	10	320	—	2	330	—	—	62	DAMP	—	—					S	S
2015	8-10	320	—	1	330	—	—	61	DAMP	—	—	F	F	F	S	S	S
2030	1.9	250	4.1	< 1	250	—	—	61	DAMP	—	—	F	F	S	S	S	S
2045	10	275	15.1	< 1	300	—	—	61	DAMP	—	—	F	F	S	S	S	S
2100	12	275	15.0	< 1	300	—	—	61	DAMP	—	—	F	F	S	S	S	S
2115	6.2	280	8.1	< 1	295	—	—	61	DAMP	—	—	F	F	S	S	S	S
2130	6.1	270	7.0	< 1	290	—	—	60.5	DAMP	—	—	F	F	S	S	S	S
2145	3.7	270	6.1	< 1	290	—	—	60.5	DAMP	—	—	F	F	S	S	S	S
2200	2.6	275	3.5	< 1	280	—	—	60	DRY	—	—	F	F	S	S	S	S
2215	5.5	285	8.1	< 1	280	—	—	59.5	DRY	—	—	F	F	S	S	S	S
2230	2.5	290	2.7	< 1	280	—	—	59	DRY	—	—	F	F	S	S	S	S
2245	3	290	3.8	< 1	290	—	—	58.5	DRY	—	—	F	F	S	S	S	S
2300	1.4	285	2.2	< 1	285	—	—	58.5	DRY	—	—	F	F	S	S	S	S

Wind Speed / gusts - knots	Temperature - Degrees F
Sea Height - feet	Relative humidity - percent
Degrees magnetic	

VISIBILITY		
Points of Reference		Appearance
11B - Grn LBB	B - Greens Ledge Light	S - Sharp
28 C - Red LBB	C - Eatons Neck Light	F - Fuzzy
A - Northport Platform	D - Northport Stacks	O- Obscured

A.2 Test 2 – Tuesday 16 May 2017

A.2.1 Signal Vessel Distance to Observers at Eatons Neck

Table A-3. Test 2 signal distances (NM) 16 May.

Test 2 - 16 May 2017 - Signal Distance from Observers							
	East Boat				West Boat		
EDT	**Vsl Lat**	**Vsl Lon**	**Dist**	**EDT**	**Vsl Lat**	**Vsl Lon**	**Dist**
2030	41.050 N	73.372 W	**6.0**	2030	41.039 N	73.445 W	**5.6**
2045	41.052 N	73.370 W	**6.1**	2045	41.039 N	73.445 W	**5.6**
2100	41.052 N	73.369 W	**6.1**	2100	41.039 N	73.444 W	**5.6**
2115	41.044 N	73.369 W	**5.6**	2115	41.039 N	73.444 W	**5.6**
2130	41.034 N	73.371 W	**5.0**	2130	41.037 N	73.440 W	**5.4**
2145	41.032 N	73.370 W	**4.9**	2145	41.036 N	73.437 W	**5.3**
2200	41.033 N	73.366 W	**5.0**	2200	41.033 N	73.435 W	**5.1**
2215	41.035 N	73.369 W	**5.1**	2215	41.032 N	73.432 W	**5.0**
2230	41.026 N	73.371 W	**4.6**	2230	41.031 N	73.428 W	**4.8**
2245	41.027 N	73.368 W	**4.6**	2245	41.030 N	73.426 W	**4.8**
2300	41.025 N	73.385 W	**4.3**	2300	41.027 N	73.430 W	**4.6**
2315	41.026 N	73.383 W	**4.4**	2315	41.026 N	73.428 W	**4.6**
2330	41.027 N	73.380 W	**4.5**	2330	41.026 N	73.426 W	**4.5**
2345	41.028 N	73.378 W	**4.6**	2345	41.026 N	73.424 W	**4.5**

A.2.2 Signal Vessel Weather Logs

Table A-4. Test 2 signal vessel weather logs 16 May.

DATE: 16 May 2017				BOAT: EAST				CG 45733			RECORDER: JD						
	WIND			SEAS				AIR			VISIBILITY						
TIME	SPEED	DIR	GUSTS	HEIGHT	DIR	BREAKING	SPRAY	TEMP	REL HUM	DEW	ESTIMATE	11B	28 C	"A"	"B"	"C"	"D"
2000	< 5	205	0	0	0	—	—	64.4	62	—	6	—	—	S	S	S	S
2015	< 5	205	0	0	0	—	—	64.4	61	—	6	—	—	S	S	S	S
2030	0	0	0	0	0	—	—	64.2	61	—	6	S	S	S	S	S	S
2045	< 5	270	0	0	0	—	—	64.2	61	—	6	S	S	S	S	S	S
2100	0	0	0	0	45	—	—	64.2	60	—	6	S	S	S	S	S	S
2115	0	0	0	0	45	—	—	64.0	60	—	6	S	S	S	S	S	S
2130	0	0	0	0	45	—	—	64.0	60	—	6	S	S	S	S	S	S
2145	0	0	0	0	45	—	—	64.0	60	—	6	S	S	S	S	S	S
2200	0	0	0	0	0	—	—	63.9	60	—	6	S	S	S	S	S	S
2215	0	0	0	0	0	—	—	63.9	60	—	6	S	S	S	S	S	S
2230	0	0	0	0	0	—	—	63.7	60	—	6	S	S	S	S	S	S
2245	0	0	0	0	45	—	—	63.7	59	—	6	S	S	S	S	S	S
2300	0	0	0	0	0	—	—	63.5	59	—	6	S	S	S	S	S	S

DATE: 16 MAY 2107				BOAT: WEST				CG 49410			RECORDER: MH						
	WIND			SEAS				AIR			VISIBILITY						
TIME	SPEED	DIR	GUSTS	HEIGHT	DIR	BREAKING	SPRAY	TEMP	REL HUM	DEW	ESTIMATE	11B	28 C	"A"	"B"	"C"	"D"
2000	U/W	310	U/W	0	—	N	N	65.5	DRY	—	—	S	S	S	S	S	S
2015	0.3	308	0.9	0	—	N	N	62.5	DRY	—	—	F	F	S	S	S	S
2030	0.5	305	1.2	0	—	N	N	62.5	DRY	—	—	F	F	S	S	S	S
2045	0.2	302	0.8	0	—	N	N	62.5	DRY	—	—	F	S	S	S	S	S
2100	0.2	300	0.5	0	—	N	N	62.0	DRY	—	—	S	S	S	S	S	S
2115	1.9	294	3.2	0	—	N	N	61.9	DRY	—	—	S	S	S	S	S	S
2130	2.2	278	2.4	0	—	N	N	61.9	DRY	—	—	S	S	S	S	S	S
2145	0.3	267	0.7	0	—	N	N	61.9	DRY	—	—	S	S	S	S	S	S
2200	1.2	258	1.8	0	—	N	N	61.8	DRY	—	—	S	S	S	S	S	S
2215	0.6	267	1.2	0	—	N	N	61.0	DRY	—	—	S	S	S	S	S	S
2230	0.2	261	0.4	0	—	N	N	61.0	DRY	—	—	S	S	S	S	S	S
2245	0.1	254	0.3	0	—	N	N	60.8	DRY	—	—	S	S	S	S	S	S
2300	2	296	2.2	0	—	N	N	60.5	DAMP	—	—	S	S	S	S	S	S

Wind Speed / gusts - knots	Temperature - Degrees F
Sea Height - feet	Relative humidity - percent
Degrees magnetic	

VISIBILITY		
Points of Reference		Appearance
11B - Grn LBB	B - Greens Ledge Light	S - Sharp
28 C - Red LBB	C - Eatons Neck Light	F -Fuzzy
A - Northport Platform	D - Northport Stacks	O- Obscured

APPENDIX B. GRAPHIC PRESENTATION OF RECOMMENDED SIGNAL CHARACTERISTICS

Figure B-1. Recommended signal characteristics.

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