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EVALUATION OF 5-YEAR DAYBOARD MATERIALS

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16. Abstract

The U. S. Coast Guard Research and Development Center evaluation of 5-year dayboard systems consisted of a material search/evaluation, a life cycle cost benefit study, accelerated weathering of candidate materials, field deployment of a limited number of full-size dayboards, and a detection and color recognition field test conducted with 1/2-inch diameter plugs of the candidate materials on both light and dark backgrounds. Materials evaluated are the current fluorescent elastromeric film, a nonfluorescent elastromeric film, epoxy paint, Surlyn foam, Lumasite acrylic, and Modulite (fiberglass embedment). Results of the detection and color recognition field test found no candidate material had higher nor lower measured distances than the fluorescent material, on both light and dark backgrounds. The nonfluorescent film, Surlyn foam, and Modulite materials all appear to provide detection and color recognition distances within 10 percent of those for the current system and were found to be acceptable lower cost replacements for the current system.

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Dayboard, Aids to Navigation, Detection and Color Recognition, Substrate, Backing, Accelerated Weathering

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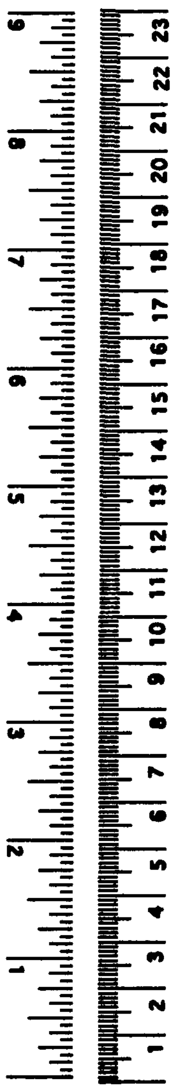
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

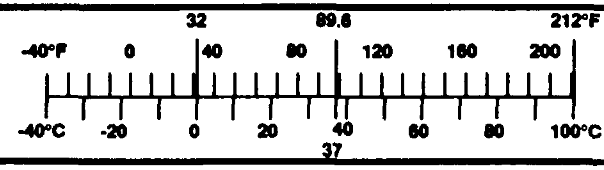
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	* 2.5	centimeters	cm
ft	feet	30.0	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* 1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10.286.



Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	4.23	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35.32	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

INTRODUCTION

1. Background

This report documents the United States Coast Guard Research and Development (R&D) Center evaluation of candidate replacement dayboard systems. It provides information to assist the U.S. Coast Guard in designing a dayboard that, after 5 years of weathering, has detection and color recognition distances that are not substantially shorter than the currently used fluorescent film that has been exposed to 1 year of weathering (nominal performance of the present system). The evaluation was conducted by the Navigation Systems Branch of the R&D Center.

Since 1962, the U.S. Coast Guard has evaluated dayboard systems in an attempt to identify a cost-effective way of providing adequate dayboard signals to mariners. The current dayboard system employs fluorescent elastomeric film on a backing that is typically made of plywood. Fluorescent film has been used because of its superior detection and color recognition ranges (when new); however, this fluorescent material degrades with environmental exposure and requires replacement every 1 to 2 years.

For this evaluation, the detection and color recognition performances of candidate dayboard systems were measured for a 1/2-inch diameter plug of each color material to facilitate the field test setup. The use of 1/2-inch plugs made it possible to conduct the detection and color recognition field test on a 500-foot field rather than requiring miles of unobscured space for full-sized dayboards. Test observers are considered to have been alerted to the general location of the samples on a narrow background. The results presented can only be used in a comparative evaluation of the relative performance of each candidate material with respect to the currently used fluorescent vinyl dayboard system.

2. Dayboard Materials

After a detailed technical evaluation of potential materials and a life cycle cost benefit analysis, five dayboard systems were considered to be viable candidates for replacing the current dayboard system. Table 1 provides a description of the five unweathered candidate materials and the currently used fluorescent vinyl material (also unweathered). Table 1 also provides Commission on Illumination (CIE) coordinates (x and y) and luminance (Y) measurements for the CIE 1964 supplementary standard 10-degree colorimetric observer for unweathered materials.

3. Accelerated Weathering

The materials included in the evaluation were subjected to an accelerated weathering process. This process provides energy to the material surface that is equivalent to the energy it would receive in a proportionate time of fixed angle exposure in a Florida marine environment. Table 2 describes the accelerated weathering test cycle parameters.

Each candidate material was exposed to this test cycle for 3000 hours (an approximation of 5-years of natural weathering), and the fluorescent vinyl reference was exposed for 600 hours (an approximation of 1-year of natural weathering).

Table 1. Unweathered Dayboard Materials

Project Reference	Type	Color	CIE Coordinates		
			Y	x	y
R1	3M fluorescent film	Red	26.65	.64	.33
R2	Fasign nonfluorescent film	Red	17.84	.60	.33
R3	Painted FRP	Red	20.95	.57	.38
R4	Surlyn foam	Red	21.01	.56	.35
R5	Pre-colored acrylic	Red	13.64	.62	.35
R6	Modulite	Red	15.85	.57	.33
G1	3M fluorescent film	Green	52.38	.31	.63
G2	Fasign nonfluorescent film	Green	34.20	.37	.58
G3	Painted FRP	Green	30.66	.34	.56
G4	Surlyn foam	Green	39.59	.36	.55
G5	Pre-colored acrylic	Green	21.24	.37	.52
G6	Modulite	Green	28.05	.36	.53

Table 2. Accelerated Weathering Test Specifications

Exposure device	CI-65 #5 serial C3B-1493
Light source	Controlled irradiance Xenon arc
Filter combination	Quartz inner/Borosilicate "S" outer
Irradiance level	0.55 ± 0.01 W/m^2 @ 340 nm
Exposure cycle	40 minutes light only 20 minutes light plus front spray 60 minutes light only 60 minutes dark w/back spray
Black panel temperature	70 ± 3 deg. C light/38 ± 3 deg. C dark
Dry bulb	47 ± 2 deg. C light/38 ± 4 deg. C dark
Relative humidity	$50\pm5\%$ light/$95\pm5\%$ dark
Spray water	Deionized

4. Field Test for Detection and Color Recognition Distances

Two field tests were conducted to obtain detection and color recognition distance measurements for the samples. Distance measurements were obtained for 1/2-inch diameter material samples. These samples were viewed against 4- by 4-foot light and dark grey background boards. These boards were divided into nine equal squares with 1/2-inch holes cut in the center of each. Test observers walked toward a background board and notified a data recorder when a sample became visible in any square of the particular board being examined. The data recorder was also notified when the color of the material was determined.

In the first field test analysis, distance measurements for unweathered candidate materials were compared to distance measurements for reference material that had been exposed to 300 hours of accelerated weathering. In the second field test analysis, candidate material samples were exposed to the full 3000 hours of accelerated weathering. The distance measurements for these samples were then compared to distance measurements for reference material that had been exposed to 600 hours of accelerated weathering.

The analysis of the field test data was conducted using the Student t-test. This analysis method helped determine, within a 5-percent significance level, which materials had longer, shorter, or equivalent detection and color recognition distances when compared to the reference material.

RESULTS AND CONCLUSIONS

1. Results

a. At the completion of 3000 hours of accelerated weathering, all of the candidate materials had experienced changes in color and physical appearance. No material failed completely; however, the sprayed acrylic coating on the Surlyn foam (R4/G4) crystalized and separated from the foam material creating a white scaling effect, and the epoxy paint (R3/G3) became brittle and separated from the FRP backing very easily.

b. When a candidate material had detection or color recognition distances that differed from the reference material (longer or shorter) while being viewed against a light background board, a corresponding difference for the dark background board could not be found.

c. When distance measurements for each material were combined over light and dark backgrounds, all but the acrylic material were within 10 percent of reference material distances. Extrapolation of the test data to full-size dayboard distances indicated that a 3-foot fluorescent vinyl dayboard which is seen at approximately 3.3 nautical miles, could be expected to be seen at approximately 3 nautical miles when replaced with the same size nonfluorescent candidate dayboard material.

d. A number of full-size dayboards were installed by field units in the First and Seventh U.S. Coast Guard Districts. General comments from field unit personnel indicated that:

- the lack of familiarity with the foam material presented some problems (surface preparation for application of retroreflective tape increased installation time and compression of material while bolted to support structures required use of locknuts to keep the boards secure);

- the FRP and foam materials tend to clog drill bits when bolt holes are being drilled;
- the acrylic material tends to break in moderate to high winds; and
- The light weight of candidate materials makes them easier to handle than the present system materials.

2. Conclusions

a. The paint/FRP dayboard system has volatile organic compounds in the formulation of the paint and after weathering, had a tendency to separate from the backing material if chipped or cracked. In the field evaluation, several acrylic dayboards broke in moderate to high winds, and another broke when caught in a fishing trawler's rigging. This substrate also had the shortest overall detection and color recognition distances. These systems should not be considered for replacing the current dayboard system.

b. The comments made by field units about the materials used in the field evaluation indicate that minor installation problems exist with the material compression and drill bit clogging. These problems can be resolved by preparing for the new materials as follows.

- Compression of the foam material can be prevented by using a compression sleeve as per manufacturer recommendations.
- Drill bit clogging can be prevented by using a hole punch, smaller diameter hole saw, or nonclogging drill bit.

b. The foam, Modulite, and nonfluorescent film/FRP appear to be viable replacement dayboard systems. However, questions about full-size dayboard performance for the Modulite and foam should be resolved prior to definitive selection of a replacement dayboard system.

c. In order to maintain the visual signal presented by the 1-year weathered fluorescent vinyl material for 5 years, the recommended candidate dayboard systems would require a 10-percent increase in size. The lighter weight of these systems would minimize any additional handling problems. However, the relatively close placement of aids to navigation in the field minimizes the loss of 10-percent distance performance, and increased board size is not recommended.

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CHAPTER 1
INTRODUCTION

1.1 SCOPE AND OBJECTIVES

This report documents the United States Coast Guard Research and Development (R&D) Center evaluation of candidate replacement dayboard systems. It provides information to assist the U.S. Coast Guard in designing dayboards with a 5-year field life. These dayboards must, after exposure to 5 years of weathering, maintain detection and color recognition distances that are not substantially shorter than those for the currently used fluorescent film samples that have been exposed to 1 year of weathering (nominal performance of the present system). A series of five preliminary reports have provided information regarding each phase of the dayboard systems' evaluation.

The first report (reference 1) detailed the advantages and disadvantages of using several possible dayboard systems and recommended systems that should be tested further. The second report (reference 2) provided a life cycle cost analysis of the candidate dayboard systems. The third report (reference 3) described the field test procedures that were used to compare detection and color recognition distances of tested materials. These materials included unweathered samples of the alternative dayboard systems as well as currently used fluorescent dayboard material that underwent accelerated weathering for an equivalent of 6 months. The fourth report (reference 4) provided a detailed description of the accelerated weathering process. This fourth report presented observations made while the dayboard systems being evaluated were subjected to the equivalent of 5 years of accelerated weathering. The fifth report (reference 5) summarized the results of the detection and color recognition distance analyses for 1-year equivalent weathered fluorescent dayboard material and 5-year equivalent weathered samples of alternative dayboard systems.

This evaluation of 5-year field life dayboard systems has been conducted by the R&D Center Navigation Systems Branch. The project objectives were to (1) identify potential 5-year dayboard systems, (2) conduct field test evaluations of weathered and unweathered materials, and (3) provide recommendations as to which system(s) could best replace the currently used dayboard system.

1.2 THE DAYBOARD SYSTEM

For the purposes of this evaluation, navigation signs used for marking marine channel boundaries and providing daytime navigation ranges are termed dayboards. The current dayboard is constructed of A/C exterior plywood and fluorescent elastomeric film. The U.S. Coast Guard currently has 38,634 dayboards, totaling 576,742 square feet (ft^2) of material, installed throughout its aids to navigation system (see reference 2, table 1-1). This equates to an average of approximately 15 ft^2 per dayboard.

1.2.1 Substrate Material

Fluorescent film has been used for more than 20 years because, when new, it provides significantly longer detection and color recognition distances than nonfluorescent materials. Fluorescent materials have longer detection and color recognition distances because they are able to convert invisible ultraviolet radiation into visible light, thereby effectively increasing material luminance. However, ultraviolet radiation also causes a degradation of the fluorescent material making it necessary to replace the current dayboard system within 2 years.

1.2.2 Backing Material

The U.S. Coast Guard has used A/C exterior plywood (3/8- or 1/2-inch) as a backing material because it is rigid, easy to work with, mounts easily using simple hardware, and does not pose a hazard to the environment. Depending on location, this grade of plywood has a service life of 2 to 3 years. In practice, U.S. Coast Guard units use a lower-grade plywood in areas where dayboards are often damaged by collisions or flooding and a higher-grade plywood for larger dayboards and range boards. Mounting dayboards typically requires bolting the dayboard to an existing support structure.

1.3 FUNCTIONAL REQUIREMENTS FOR A REPLACEMENT DAYBOARD

Increasing the lifetime of dayboards should result in significant savings in personnel, ship, and material costs. Alternative dayboard systems should be easily constructed and mounted with readily available materials, not pose a hazard to the environment, and after 5 years of weathering should provide a visual signal that is not substantially worse than the visual signal provided by current dayboard system material that had been exposed to 1 year of weathering.

1.3.1 Substrate Function Requirements

Substrates are materials containing color pigments or dyes that are intended to present a specific visual signal to an observer. The shape and color of the dayboards are selected in accordance with chapter 5 of reference 6.

1.3.1.1 Substrate Material. Primary evaluation criteria for substrate materials include estimated life in a marine environment, potential effect on the environment, cost and availability, and ease of handling. The substrates used in this evaluation were selected because of their ability to resist physical degradation and minimize the loss of color and luminance normally associated with extended weathering. Table 1-1 provides a summary of the advantages and disadvantages of using several of the substrates examined during the earlier phases of this evaluation.

1.3.1.2 Substrate Color. The International Association of Lighthouse Authorities (IALA) has published a document that recommends surface colors for use as visual signals on aids to navigation (reference 7). Figure 1-1 depicts the 1931 Standard Observer Chromaticity diagram overlaid with regions that represent the IALA-recommended surface colors. These regions are recommended because they present distinct visual signals and are commercially-available colors.

Chromaticity coordinates for materials should fall within the suggested regions to provide optimum conspicuity and color definition. Colors chosen from nonadjacent regions provide sufficient contrast to minimize the possibility of perceiving a visual signal that is different than the signal actually being provided. Luminance, though not shown, is a measure of a color's reflectivity, and it is directly related to what may be expected in detection and color recognition distances. Luminance will be discussed in more detail later in this document.

Table 1-1. Advantages and Disadvantages of Dayboard Substrates

Potential Substrate	Advantages	Disadvantages
Hi-Bild polyurethane or epoxy paints systems	High performance Excellent color retention Long life	High volatile organic compound (VOC) content Harmful vapors May lose gloss High quality assurance (QA) required
Polane high solids enamel	Excellent performance Wide range of colors	High VOC Harmful vapors No good on wood
Instant set elastomer polyurethane	100-percent solids Developed for buoys Long life	Harmful vapors Need topcoat for color
Diaflex-topcoat	Excellent weathering Field tested on buoys	R&D for customer color
Sprayed metalized coatings	15-year life	Cannot be colored
Elastomeric vinyl film (non-fluorescent)	Customer colors available 24,000 ft^2 in field testing "Best" available colors Highest Munsell value Familiar product to personnel	No Coast Guard QA
Fiberglass reinforced plastic (FRP) (Polyplate)	Engineered for sign industry Extensive testing as backing Weather resistant Long life: 10-year warranty	Bright colors unavailable
Surlyn foam (Softlite)	Excellent documentation Meets CG buoy specification Tested by Woods Hole Custom dayboard colors 113 dayboards tested by the R&D Center Combined substrate & backing	R&D for custom color
Acrylic sheeting (LumaSite)	Engineered for sign industry Combined substrate & backing Long life: 7-year warranty Custom dayboard colors	Sparse test data May irritate skin R&D for custom color
Fabrics	Brightly colored, lightweight, disposable	Very short life Needs frame

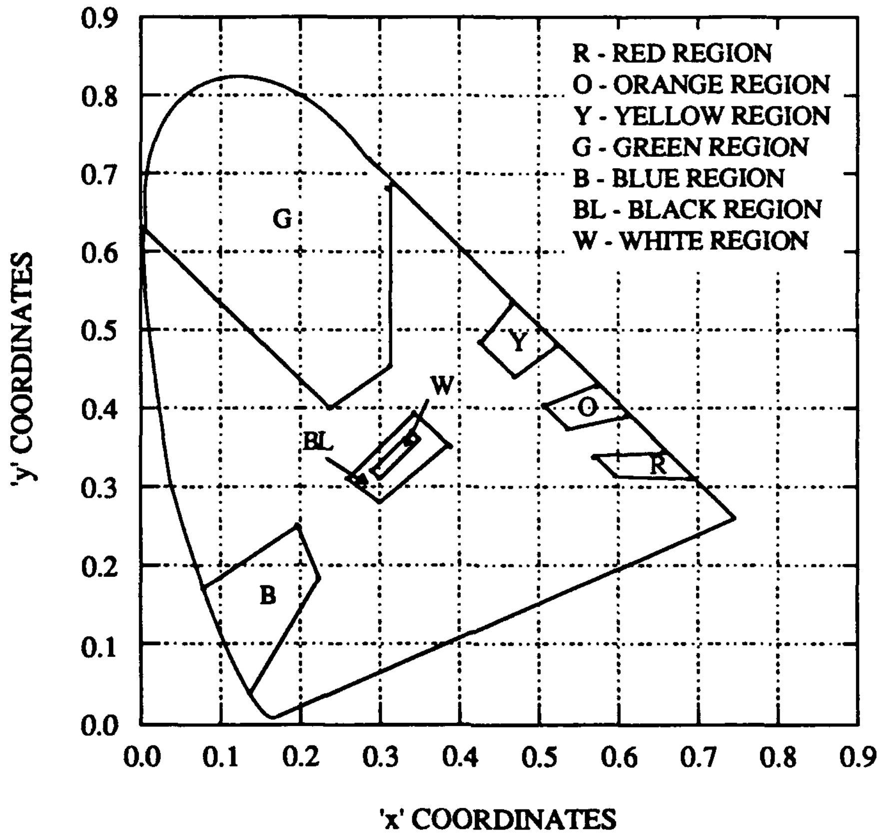

Figure 1-1. Chromaticity Regions Recommended by IALA for Ordinary Colors

The U.S. Coast Guard uses red and green as colors for aids to navigation. Manufacturers of alternative dayboard materials have found that they cannot produce a nonfluorescent color that has a luminance equivalent to a fluorescent material within the same IALA-recommended red or green color region. Recommendation 3 in reference 7 provides the option of choosing colors for aids to navigation that are not within the IALA recommended regions, provided consideration is given to minimizing confusion between the colors chosen. The requirement to provide luminance equivalent to the fluorescent vinyl was accepted as justification, for the purposes of this evaluation, to use materials that plotted outside the borders of the IALA-recommended regions. The materials and colors used in this evaluation were chosen because they provided a red or green visual signal with a luminance having detection and color recognition distances similar to those obtained from fluorescent vinyl material.

1.3.2 Backing Functional Requirements

The dayboard backing material must be sturdy enough to withstand environmental forces when fastened rigidly to a support structure. Other requirements include a 5-year field life, low cost, ready availability, easy of handling, and environmental safety. Table 1-2 provides a summary of the advantages and disadvantages of using several of the backing materials examined during the earlier phases of this evaluation.

1.4 SELECTION OF DAYBOARD SYSTEMS

1.4.1 Life Cycle Cost Benefit Analysis

The dayboard systems that were considered to be viable alternatives to the current dayboard system at the conclusion of the technical evaluation were subjected to a detailed life cycle cost benefit analysis. Reference 2 should be consulted for details of this analysis. The "Economic Analysis Handbook," NAVFAC P-442 was used to provide guidelines for this analysis.

The life cycle cost analysis was conducted using the following assumptions.

- The U.S. Coast Guard will continue to construct dayboards in the present manner, thereby eliminating consideration of costs or savings associated with altering this part of the system.

- The Coast Guard will be required to visit each dayboard site every 2 years. These visits will minimize potential savings attributed to decreased maintenance requirements. New dayboards would be installed at the rate of 50-percent in the first year, 50-percent in the second year, and approximately 2.5-percent each consecutive year through the end of the expected dayboard service life. The 2.5-percent yearly replacement accounts for expected failures from severe environmental factors (e.g., flooding) and human destruction (e.g., theft).

- The 10-percent discount rate for government expenditure specified in NAVFAC P-442 applies.

Table 1-2. Advantages and Disadvantages of Dayboard Backings

Potential Backing	Advantages	Disadvantages
Marine grade plywood	Strong 5-year life Simple preparation Extensive field use Can be reused	Long term life is not as great as metals
Aluminum	Very strong Resists corrosion Previously tested Very long life	Generates hazardous waste Unstable pricing High shipping costs
Galvanized steel	Very strong Very long life Resists corrosion	Hard to handle Unstable pricing High shipping costs
Fiberglass reinforced plastic (FRP) "Polyplate"	Engineered for sign industry Extensive field tests since 1977 Weather resistant Long life: 10-year warranty Stable pricing Lightweight - 1 lb/ft^2. Tested by Coast Guard	Tendency to fracture May irritate skin Possible sole source procurement
Surlyn foam (Softlite)	Excellent documentation Meets CG Buoy Specification Tested by Woods Hole Lightweight - easy to handle and install 113 dayboards tested by the R&D Center Combined substrate & backing	Possible sole source procurement
Acrylic sheeting (LumaSite)	Engineered for sign industry Combined substrate & backing Long life: 7-year warranty Custom dayboard colors	Sparse test data May irritate skin Possibility of shattering
Fiberboard	Used in highway signs for 6 years Pre-primed Compatible with films or paints Low price alternative to high density overlaid plywood	Limited test data for marine environment

Costs for backing, substrate, retroreflective borders and numbering, labor, and overhead were included in the figures for total system costs. A summary of the life cycle costs is presented in table 1-3. The Net Present Value (NPV) is calculated at a 10-percent discount rate for the years 1992 to 2001; that is, it represents the system costs over the next 10 years in todays dollars. NPV is normalized to the present system for easy comparison between systems.

Table 1-3. 1990 Estimated Life Cycle Costs of Dayboard Systems

System	Estimated Field Life (years)	Total System Costs ($)	Net Present Value ($)	Normalized Value $\left(\frac{NPV}{NPV_{present\ system}}\right)$
1. FRP/Film	5	1,933,969	3,027,716	.496338
2. Fiberboard/Film	5	2,089,366	3,259,149	.534277
3. Plywood/Film	5	2,541,768	3,932,911	.644728
4. Fiberboard/Paint	6	2,851,095	4,393,590	.720248
5. FRP/Paint	5	3,108,283	4,776,622	.783039
6. Acrylic	5	3,305,064	4,917,407	.806118
7. Aluminum/Film	5	3,231,874	4,960,686	.813213
8. Plywood/Paint	6	3,372,706	5,170,427	.847596
9. Surlyn Foam/Film	5	3,485,517	5,177,841	.848812
10. Surlyn Foam	6	3,813,583	5,651,314	.926429
11. Aluminum/Paint	6	3,832,115	5,678,062	.930814
12. Present System	2	1,937,711	6,100,101	1.000000
13. Polyurethane	6	5,039,510	7,420,603	1.216472

1.4.2 Dayboard Systems Evaluated

After a detailed technical evaluation and a cost analysis study, the following four candidate dayboard systems were considered optimum choices for further evaluation.

1. Nonfluorescent elastomeric film applied to an FRP backing,
2. Surlyn foam produced at varying densities to form substrate and backing layers,
3. Paint substrate on FRP backing, and
4. Precolored acrylic sheeting (acts as both substrate and backing).

A material known as Modulite was added to the evaluation after the initial material selection and field test of unweathered candidate materials. Modulite is a fiberglass embedment material comprising paper saturated with a colored ink and embedded within a fiberglass layup. Table 1-4 provides a description of the 12 unweathered dayboard material samples evaluated. Commission on Illumination (CIE) coordinates (x,y) and luminance measurements (Y) for the 1964 supplementary 10-degree colorimetric observer are included for new materials.

The four original unweathered candidate dayboard materials were included in a field test to compare their detectability and color recognition ability to the present fluorescent vinyl system that had been exposed to 300 hours of accelerated weathering. A description of the field test can be found in section 1.5. Accelerated weathering is described in section 1.6.

The four original candidate systems were then exposed to 3000 hours of accelerated weathering that approximated a 5 year exposure to a Florida marine environment. When these materials reached 600 hours of weathering, the Modulite material was added to the weathering machine. The weathering process for the Modulite material was completed approximately 1 month after the other materials.

When the accelerated weathering of the original candidate materials was complete, they were included in a field test that compared their detection and color recognition distances to material of the present fluorescent vinyl system that had undergone a weathering process that was equivalent to approximately 1 year of southern marine exposure. A second phase of this field test was conducted when the Modulite material had completed 3000 hours of accelerated weathering.

Table 1-4. Unweathered Dayboard Materials

Project Reference	Type	Color	CIE Coordinates		
			Y	x	y
R1	3M fluorescent film	Red	26.65	.64	.33
R2	Fasign nonfluorescent film	Red	17.84	.60	.33
R3	Painted FRP	Red	20.95	.57	.38
R4	Surlyn foam	Red	21.01	.56	.35
R5	Pre-colored acrylic	Red	13.64	.62	.35
R6	Modulite	Red	15.85	.57	.33
G1	3M fluorescent film	Green	52.38	.31	.63
G2	Fasign nonfluorescent film	Green	34.20	.37	.58
G3	Painted FRP	Green	30.66	.34	.56
G4	Surlyn foam	Green	39.59	.36	.55
G5	Pre-colored acrylic	Green	21.24	.37	.52
G6	Modulite	Green	28.05	.36	.53

1.5 FIELD TEST DESCRIPTION

Two field tests were performed to compare candidate dayboard material detection and color recognition distances to detection and color recognition distances of the currently used fluorescent vinyl material.

The first field test was conducted in the late Summer/early Fall of 1990. Unweathered samples of the four original candidate dayboard materials were tested and compared to currently used fluorescent vinyl material that had been weathered for the equivalent of 6 months. The Modulite material had not yet been identified as a candidate dayboard system.

The second field test was conducted in the late Summer/early Fall of 1991. This test was conducted in two phases. The first phase included samples of the four original candidate dayboard materials that were weathered for the equivalent of 5 years. These were compared to fluorescent vinyl material that had been weathered for the equivalent of 1 year. The second phase provided the same comparison, but 5-year equivalent weathered Modulite material was added to the list of candidate systems. Data analyses were conducted on the combined phase 1 and phase 2 data set.

1.5.1 Field Test Apparatus

Two uniform color backgrounds were used in the evaluation of the dayboard material detection and color recognition distances. A light grey (Munsell coordinates 7.5 PB 8/2) and a dark grey (Munsell coordinates 2.5 PB 4/2) were chosen to represent the light and dark background that is typical of the natural ocean environment (reference 8). Four, 4-by-4 foot background boards were fabricated; two in each color. Each board was divided into nine equal squares using 2-inch duct tape in a contrasting color. A 1/2-inch diameter hole was drilled in the center of each square. Half-inch diameter plugs were made with test sample material attached to the ends for insertion into the background boards. Half-inch diameter plugs were also made with ends painted in the background colors for use as blanks.

1.5.2 Field Test Procedure

The four background boards were set on stands so that the bottom edge of each board was approximately 3 feet from the ground. Figure 1-2 depicts the field setup. Each pair of like-colored background boards had one each of the color material plugs placed randomly in the predrilled holes. Each hole not filled with a sample plug was filled with the appropriately colored blank plug. Thus, all dayboard materials were viewed against both background colors as the test subjects completed a set of "walk-through" detection and color recognition runs against the four test boards. All of the plugs were mounted flush with the board surface to minimize shadowing.

Data were collected in both sunny and overcast conditions between 1000 and 1500 local time. Test observers started 465 feet from the boards to prevent them from detecting any of the samples. Each observer was assigned a background board and instructed to begin walking slowly forward, stopping periodically to view the boards. When a test observer detected a color sample in any of the nine squares of the current board, and again when they could recognize the color (red or green), an accompanying data recorder was notified. The test observers were encouraged not to report detection or color recognition until they were reasonably sure of their call. When notified of a detection, and when a color was reported, data recorders logged the distance in feet. If an observer reported a color incorrectly, then later changed the color, the nearer distance was used and a color reversal was recorded. When the observer and recorder were sure of the number, placement, and color of each sample on the board, the testing procedure was repeated until all four boards were completed. On completion of a session consisting of all four boards, the positions of the colored and background pegs were switched and a new session was begun.

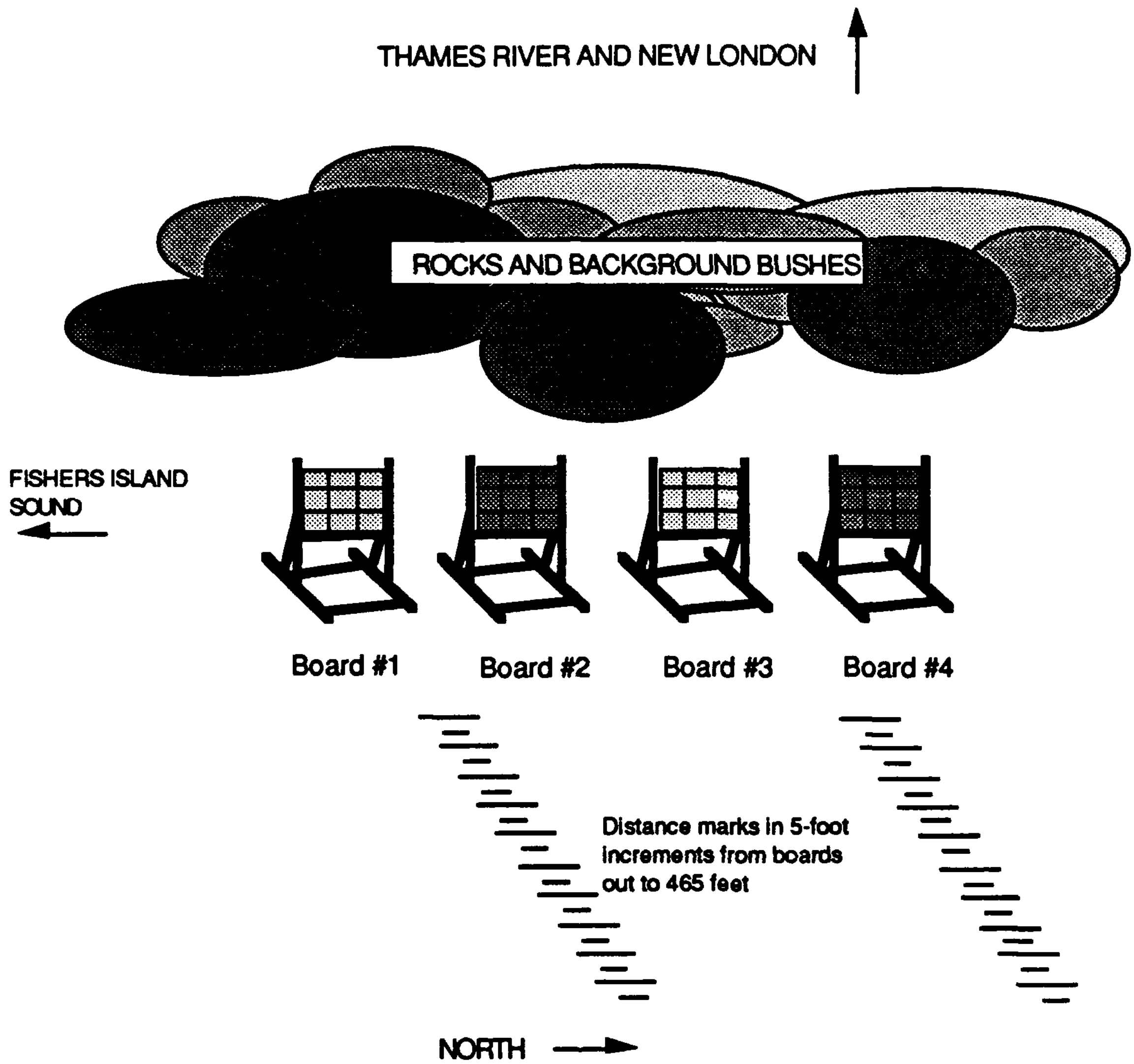

Figure 1-2. Field Experiment Setup

1.5.3 Field Test Analysis Procedures

Results from the field tests were analyzed using the methods described in reference 8, section 3-2.1, "To determine whether the average performance of a new product differed from the standard." This analysis method was essentially the use of a Student t-test, and a brief description of the reference 9 procedures was given in references 3 and 5. SYSTAT, a commercially available software package, was used to analyze the data and prepare graphs. Detailed analyses of field test results are presented in references 3 and 5. A summary of the results is presented in section 2.2 of this report.

1.6 ACCELERATED WEATHERING DESCRIPTION

Accelerated weathering simulates the effects of natural weathering on material samples in a shorter time span. The accelerated weathering process was performed with an Atlas weatherometer using a controlled irradiance xenon arc lamp and a water spray as described in SAEJ1960. Table 1-5 describes the accelerated weathering parameters for this test.

The test cycle was used to expose the material samples to conditions approximating an equivalent of 5 years, fixed-angle exposure in a Florida marine environment. Accelerated weathering can only approximate natural weathering. To establish equivalent time periods, relative performance has been measured for samples weathered in a laboratory versus samples weathered naturally. It is possible that the actual color of a material sample exposed to an accelerated weathering process will not be identical to that of a similar material sample exposed to a natural weathering process. However, a Spearman Rank Correlation for the colorfastness of materials would not be expected to show any rank reversals. For example, if sample 2 faded faster than sample 1 in natural weather, the same should be expected in similar samples subjected to equivalent accelerated weathering. Further discussion of the validity of accelerated weathering and the procedures used for this evaluation are presented in reference 4.

Table 1-5. Accelerated Weathering Test Specifications

Exposure device	CI-65 #5 serial C3B-1493
Light source	Controlled irradiance Xenon arc
Filter combination	Quartz inner/Borosilicate "S" outer
Irradiance level	0.55 ± 0.01 W/m^2 @ 340 nm
Exposure cycle	40 minutes light only 20 minutes light plus front spray 60 minutes light only 60 minutes dark w/back spray
Black panel temperature	70 ± 3 deg. C light/38 ± 3 deg. C dark
Dry bulb	47 ± 2 deg. C light/38 ± 4 deg. C dark
Relative humidity	50 ± 5% light/95 ± 5% dark
Spray water	Deionized

During the accelerated weathering of the material samples, CIE (1964, 10-degree observer) tristimulus coordinates (X, Y, and Z) were recorded for new material and at 6-month equivalent intervals through the 5-year simulated exposure. The Surlyn foam material developed a white scaling that might have affected its tristimulus coordinate readings. The scaling is believed to be the result of a clear acrylic spray that was added to the surface of the foam to enhance its luminance. The heat generated during the accelerated weathering may have caused this sprayed surface to crystalize and separate from the foam.

The results of the accelerated weathering process are presented in detail in reference 4. Table 1-6 provides a description of the 12 weathered dayboard materials evaluated after completion of the 3000 hours of accelerated weathering (approximating 5-years of natural weathering). CIE coordinates (x,y) and luminance measurements (Y) for the 1964 supplementary 10-degree colorimetric observer are included for these materials. No material used during this evaluation failed during accelerated weathering, and all of the candidate materials were recommended for inclusion in the second field test. The painted FRP material is the only material that showed signs of becoming brittle with extended weathering. Once the painted surface was chipped or cracked, the paint surrounding this area tended to continue to flake or peel.

Table 1-6. Five-Year Weathered Dayboard Materials

Project Reference	Type	Color	CIE Coordinates		
			Y	x	y
R1	3M fluorescent film	Red	27.40	.57	.38
R2	Fasign nonfluorescent film	Red	18.02	.52	.32
R3	Painted FRP	Red	27.60	.49	.38
R4	Surlyn foam	Red	28.58	.45	.34
R5	Pre-colored acrylic	Red	11.82	.58	.35
R6	Modulite	Red	26.63	.49	.39
G1	3M fluorescent film	Green	37.35	.24	.44
G2	Fasign nonfluorescent film	Green	31.95	.33	.52
G3	Painted FRP	Green	31.74	.34	.50
G4	Surlyn foam	Green	42.02	.33	.45
G5	Pre-colored acrylic	Green	24.49	.33	.46
G6	Modulite	Green	27.87	.36	.49

1.7 FULL-SIZE FIELD DEPLOYMENT

Full-size dayboards were constructed of the four original candidate dayboard systems. These dayboards were shipped to selected Coast Guard commands for installation in the field. Comments on ease of installation, durability, and perceived replacement worth were solicited. Section 2.4 summarizes these comments.

CHAPTER 2
EVALUATION RESULTS

2.1 INTRODUCTION

This chapter summarizes the results of the data analyses for the field test data as described in chapter 1 and provides comparative measurements for full-size dayboards of the same materials. Two major discussions of results are presented in this chapter. Section 2.2 provides a summary analyses of candidate dayboard performance during the two detection and color recognition field tests; and section 2.3 provides detailed information regarding size, performance, distance, and costs for full-size dayboard systems.

2.2 DETECTION AND COLOR RECOGNITION FIELD TEST RESULTS

Table 2-1 provides the average detection and color recognition distances achieved during each field test. The top half of the table provides the distances measured during the detection and color recognition field test with unweathered candidate materials conducted in 1990. The lower half of the table provides the distances measured during the detection and color recognition field test with 5-year weathered candidate materials conducted in 1991. Both phases of the 1991 field test were combined for data analysis.

Background color and luminance are major factors in determining which material will have longer detection and color recognition distances. Therefore, average detection and color recognition distances are provided for each background color and for the combined light and dark background conditions. The materials that had longer detection and/or color recognition distances on one color background board typically had shorter detection and/or color recognition distances on the other background board.

Table 2-2 provides a summary of t-statistic results. The t-statistic may be used to determine whether the performance of a candidate material is different than that of the reference material at a chosen confidence level. The annotations of "better" and "worse" are subjectively determined through examination of the differences in mean values.

Tables 2-1 and 2-2 show that no candidate material had shorter detection and color recognition distances than the reference on both light and dark backgrounds. As materials weathered and faded, detection and color recognition distances typically decreased on the light background but increased on the dark background. The result is that there are typically only minor changes in overall distances from unweathered materials to the 5-year weathered materials. The acrylic material experienced the largest negative shift of any material and has distances after 5 years of weathering that are substantially below those for the reference material.

Table 2-1. Detection and Color Recognition Field Test Summary

	Material ID	DARK BACKGROUND		LIGHT BACKGROUND		ALL DATA		
		Detection Distance (ft)	Color Recognition Distance (ft)	Detection Distance (ft)	Color Recognition Distance (ft)	Total # Observations	Detection Distance (ft)	Color Recognition Distance (ft)
1990 Field Test with Unweathered Candidate Materials	R1 (FV)	284	255	265	192	120	274	223
	R2 (NFV)	260	229	303	220	120	282	224
	R3 (Paint)	211	185	316	190	120	265	187
	R4 (Foam)	227	205	294	206	120	261	206
	R5 (Acrylic)	214	188	312	206	120	264	198
	G1 (FV)	322	264	247	181	115	285	223
	G2 ((NFV)	318	254	232	171	115	275	213
	G3 (Paint)	281	227	261	176	115	271	201
	G4 (Foam)	335	254	255	177	115	295	216
	G5 (Acrylic)	271	215	279	176	115	275	196
1991 Field Test with Weathered Candidate Materials	R1 (FV)	293	254	264	200	139	278	227
	R2 ((NFV)	223	203	286	220	121	252	209
	R3 (Paint)	259	229	269	198	119	262	211
	R4 (Foam)	252	220	274	201	125	261	209
	R5 (Acrylic)	197	171	294	210	122	243	189
	R6 (Modulite)	255	219	276	202	91	262	207
	G1 (FV)	281	252	252	199	139	266	225
	G2 ((NFV)	266	234	264	200	121	265	217
	G3 (Paint)	262	228	264	195	119	259	209
	G4(Foam)	296	265	235	192	125	263	226
	G5 (Acrylic)	213	182	276	196	122	241	186
	G6 (Modulite)	266	231	276	190	91	269	208

Table 2-2. Summary of Detection and Color Recognition Distance Analyses

Background	Material	1990 Field Test With Unweathered Candidate Materials — Candidate Material Performance Relative to the Reference*		1991 Field Test With Weathered Candidate Materials — Candidate Material Performance Relative to the Reference*	
		Detection	Color Recognition	Detection	Color Recognition
Dark	G2 (NFV)	No Difference	Worse	Worse	Worse
Dark	G3 (FRP)	Worse	Worse	Worse	Worse
Dark	G4 (Foam)	Better	No Difference	Better	Better
Dark	G5 (Acrylic)	Worse	Worse	Worse	Worse
Dark	G6 (Modulite)	N/A	N/A	Worse	Worse
Light	G2 (NFV)	No Difference	Worse	Better	No Difference
Light	G3 (FRP)	No Difference	No Difference	No Difference	No Difference
Light	G4 (Foam)	No Difference	No Difference	Worse	No Difference
Light	G5 (Acrylic)	Better	No Difference	Better	No Difference
Light	G6 (Modulite)	N/A	N/A	Better	Worse
Dark	R2 (NFV)	Worse	Worse	Worse	Worse
Dark	R3 (FRP)	Worse	Worse	Worse	Worse
Dark	R4 (Foam)	Worse	Worse	Worse	Worse
Dark	R5 (Acrylic)	Worse	Worse	Worse	Worse
Dark	R6 (Modulite)	N/A	N/A	Worse	Worse
Light	R2 (NFV)	Better	Better	Better	Better
Light	R3 (FRP)	Better	No Difference	No Difference	No Difference
Light	R4 (Foam)	Better	Better	Better	No Difference
Light	R5 (Acrylic)	Better	Better	Better	Better
Light	R6 (Modulite)	N/A	N/A	No Difference	No Difference

* These results are based on the t-test results presented in references 3 and 5. As noted earlier, the t-test supports acceptance or rejection of the null hypothesis. The terms Better, Worse, and No Difference are a subjective evaluation based on the μ_{diff} and t-value.

2.3 FULL-SIZE DAYBOARD ESTIMATES

For this evaluation, the detection and color recognition performances of candidate dayboard systems were measured for a 1/2-inch diameter plug of each color material to facilitate the field test setup. The use of 1/2-inch plugs made it possible to conduct the detection and color recognition field test on a 500-foot field rather than requiring miles of unobscured space for full-sized dayboards. Test observers are considered to have been alerted to the general location of the samples on a narrow background. The results presented can only be used in a comparative evaluation of the relative performance of each candidate material with respect to the currently used fluorescent vinyl dayboard system.

As materials weathered, no consistent trend in the degradation of distance measurements resulted. Estimates for reduced field life of full size dayboards of the candidate systems cannot be made. Based on the data collected during this study, the options that should be considered are accepting a small reduction in the signal provided to the mariner or increasing the size of the dayboard.

2.3.1 Procedure for Estimating Full-Size Dayboard Performance

The results of the field test can be extrapolated for full-size dayboards by assuming a proportional increase in detection distance. Mandler (reference 10) successfully used this approximation in earlier dayboard experiments. The extrapolated results presented can only be used in a comparative evaluation of the relative performance of each candidate material with respect to the currently used fluorescent vinyl dayboard system and are generally greater than distances that may be expected in actual use. Figure 2-1 graphically presents the relationship between detection distances and dayboard size. The actual relationship is defined in the following equation:

$$\frac{\text{1/2 height (sample)}}{\text{average distance}} = \frac{\text{1/2 height (full-size dayboard)}}{\text{estimated distance}}$$

The relationship assumes a constant angle of illumination and a perfectly clear atmosphere. The angle of the sun between a time of day from 1000 to 1400 was nearly constant for the test setup orientation, and the assumption of a clear atmosphere is adequate for a comparative analysis. The use of 1/2-inch plugs in the field test means that the full-size dayboards referenced here have a round area of the given diameter.

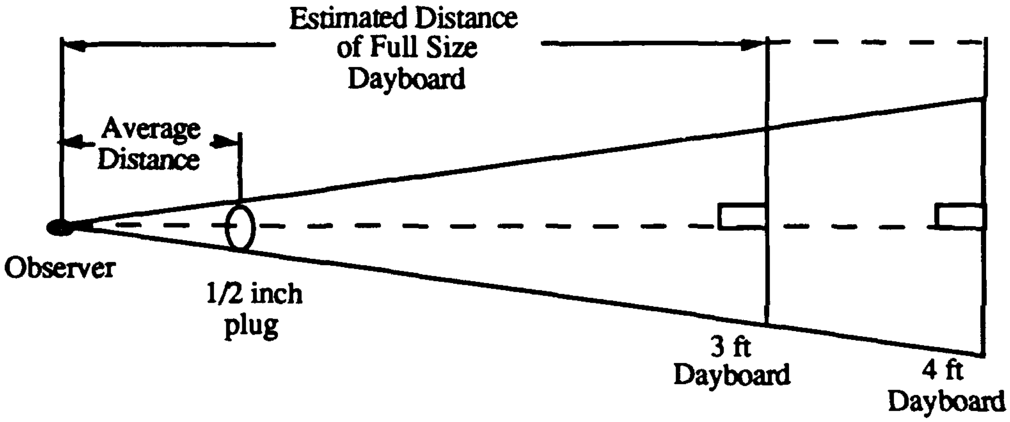

Figure 2-1. Representation of Full-Size Dayboard Distance Estimation Model

2.3.2 Full-Size Dayboard Estimated Performance

The equation in section 2.3.1 can be solved for the recommended height of a dayboard to be visible at a desired distance, or it can be solved for the distance at which a given size dayboard is estimated to be first visible. Appendix A provides estimated detection and color recognition distances for full-size dayboards. These distances are calculated for 3-, 4-, 6-, and 8-foot dayboards. Also shown in appendix A are the estimated sizes of candidate material dayboards needed to maintain the signal presented by a 1-year weathered, 3- to 8-foot fluorescent dayboard for a 5-year life span.

Full-size dayboard distances are provided for light, dark, and overall background conditions. As is truc in the field test data, the candidate materials typically had shorter distances than the reference material against the dark background and longer distances than the reference material against the light background. Dayboards are expected to be viewed against both light and dark backgrounds; therefore, the data for overall background conditions will be used for this discussion.

2.3.2.1 Comparison of Extrapolated Distances to Estimated Nominal Ranges. Figure 2-2 presents bar graphs of the estimated detection distances for full-size dayboards in overall background conditions. It is included here for the sole purpose of confirming the reasonableness of the distances extrapolated from the detection and color recognition field test data. The graph presents the extrapolated distances for 3-, 4-, 6-, and 8-foot dayboards. The horizontal lines at various levels represent the estimated nominal visual range of detection for an

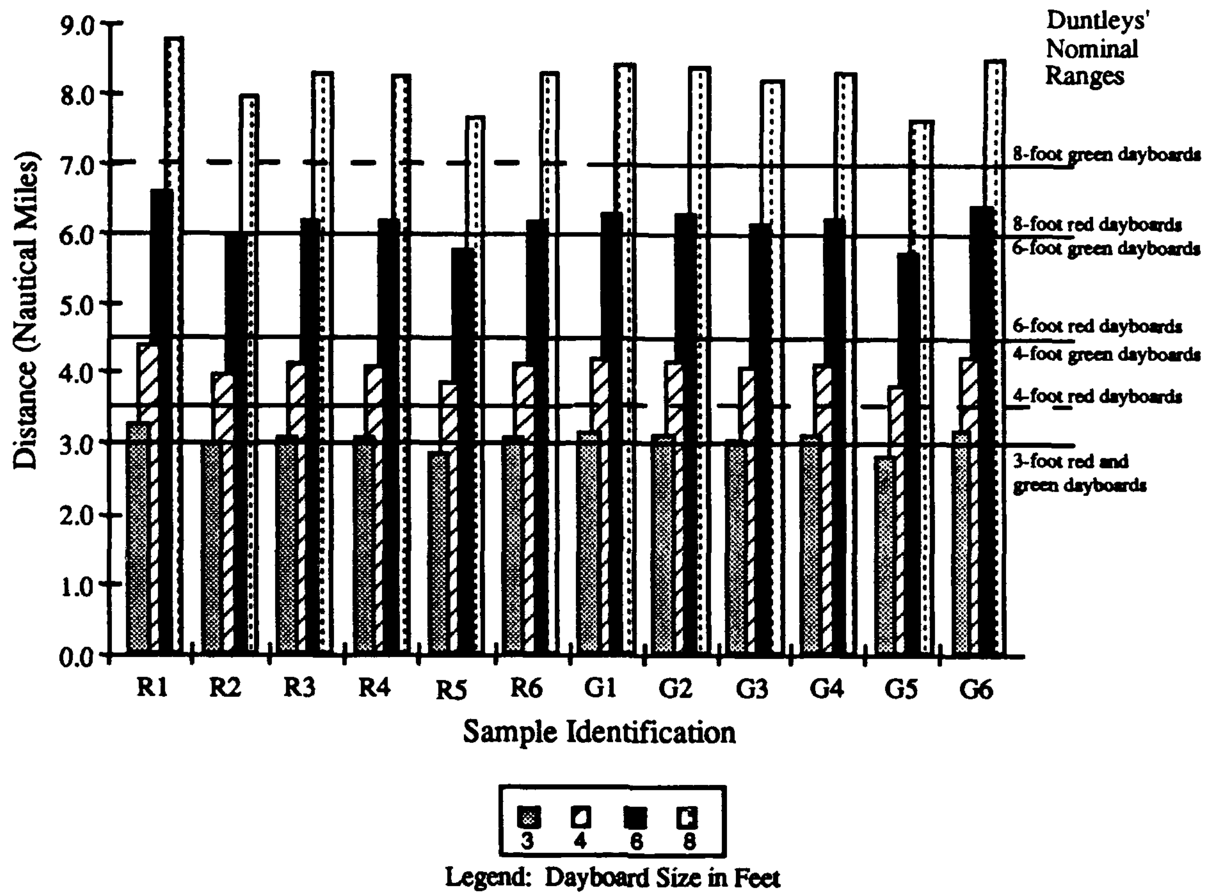

Figure 2-2. Detection Distances Calculated for Full-Size Dayboards

estimated contrast for an average green and red. These ranges were obtained by using a 10-mile visibility (approximate visual horizon from 50-foot bridge height) and an approximated average contrast value as inputs to Duntley's Nomogram shown in CG-250-35A, 'Performance Characteristics of Buoys.' Extrapolated detection distances for the candidate dayboard materials are all within 10-percent of the nominal range and indicate that the extrapolated distances for candidate materials are reasonable. Errors introduced by the use of an alerted test observer and errors inherent to extrapolating beyond measured results account for differences between the candidate dayboard material distances and Duntleys' nominal ranges shown in figure 2-2.

2.3.2.2 Comparison of Extrapolated Candidate Material Distances to Extrapolated Reference Material Distances. Figure 2-3 presents bar graphs of the estimated detection distances for full-size candidate material dayboards in overall background conditions The graph presents the extrapolated distances for 3-, 4-, 6-, and 8-foot dayboards. The horizontal lines at various levels represent the estimated average detection distances for full-size candidate material dayboards. Where the horizontal line is solid, the label on the right hand side of the graph applies to the materials listed beneath it. Where the horizontal line is dashed, it does not apply to the materials beneath it. Figure 2-3 shows that the Lumasite acrylic (G5/R5) clearly had the shortest detection distances of any of the candidate materials, and is the only material to perform more than 10-percent worse than the reference (G1/R1).

2.4 FIELD EVALUATION COMMENTS

Three full-size dayboards of each original candidate dayboard system were built and installed by U.S. Coast Guard personnel. Aids to Navigation Team (ANT) Key West, FL, in the Seventh District and ANT Long Island Sound and ANT South Portland, ME, in the First District provided comments on installation and durability of these boards. Dayboards were mounted on H-beams, concrete piles, and dayboard brackets with good southerly exposure. Table 2-3 summarizes the comments provided by the ANT units.

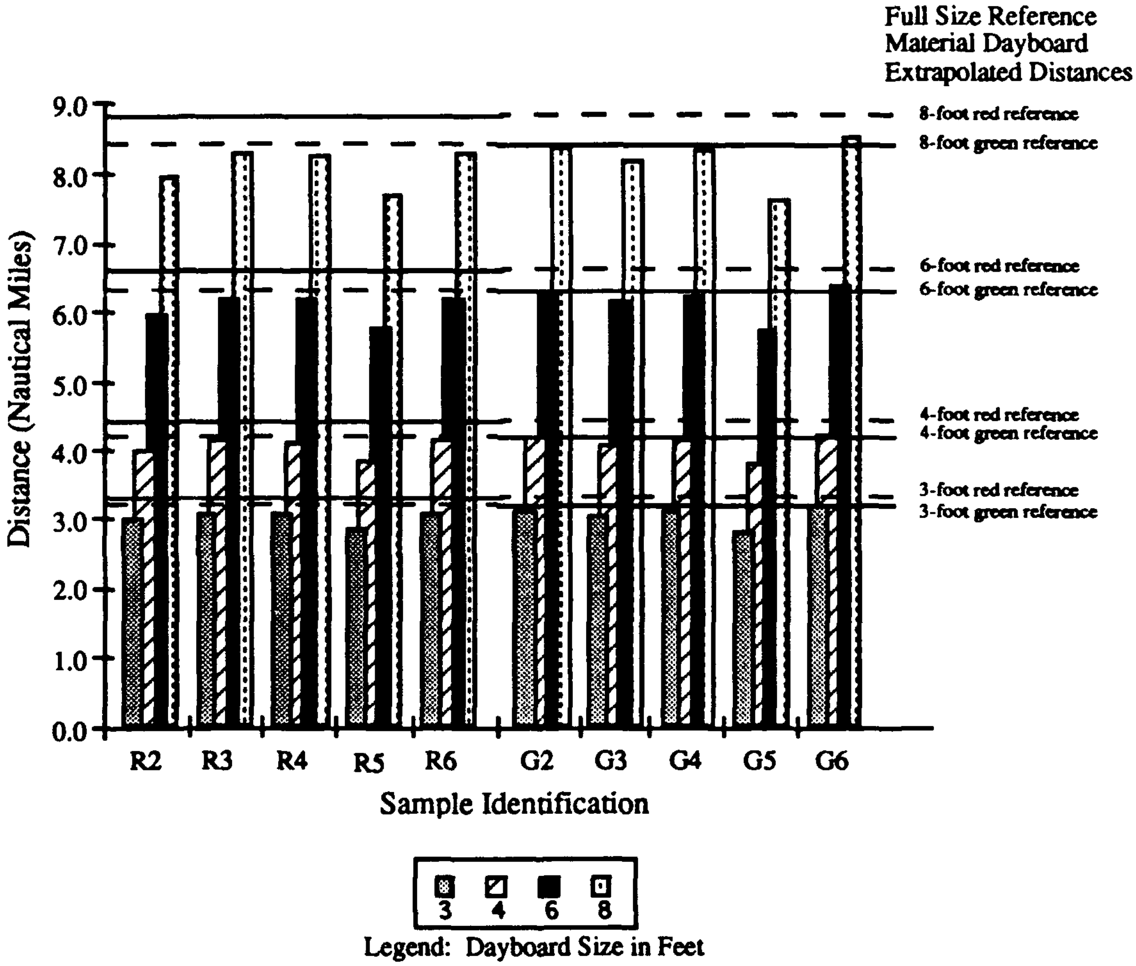

Figure 2-3. Detection Distances Calculated for Full-Size Candidate Dayboard Systems

Table 2-3. Field Unit Comments on Candidate Dayboard Installation and Durability

Aids to Navigation Team	Comments
ANT Key West, FL	Surlyn Foam - Retro numbers (both 3M and Reflexite) do not stick very well. The TR's appear to be pre-faded, but the SG color is a good match. Foam compresses when hardware tightened and nuts eventually back off the bolt, so nylon lock nuts must be used. FRP with epoxy paint - care must be taken when mounting on H-beams and concrete so as not to crack board when tightening hardware. TR's color is a good match. Lumasite Acrylic - same mounting problems as FRP. The life expectancy of a dayboard in Key West is approximately 6 months due to the sun's intensity. The failure of one board (lumasite) was due to a collision with the rigging of a fishing trawler. Overall, the colors seem to be holding up well and the boards are much easier to work with due to their light weight.
ANT Long Island Sound	Lumasite dayboard at light #14 in Norwalk failed in a storm less than 7 months after installation. Maximum sustained winds in that storm were less than 40 knots. Missing/not found. Lumasite and FRP dayboards were said to be too flimsy, and the lack of rigidity caused them to warp when mounted. When this happens, the retroreflective tape does not reflect in the proper direction. Surlyn Foam - TR's color appears faded even when brand new. Drill bit gets clogged with foam when drilling mounting holes resulting in increased mounting time.
ANT South Portland, ME	FRP boards appear dull and faded (both colors). The reduction in mounting time due to the light weight of the test dayboards is significantly offset by the Lumasite and Surlyn Foam clogging the drill bit when mounting holes are being drilled. One Lumasite board failed in 20-knot winds, and BMC Ramp stated that they would not withstand a windstorm of much intensity. An improved mounting bracket was seen as a possible solution. Color photos of the Portland area installations are on file at D1 OAN (Gene Negretti), and the following message tr ıffic pertains to these dayboards: R261400Z APR 91, R261401Z APR 91, and R231900Z MAY 91.

CHAPTER 3
CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

The following conclusions are based on the quantitative analysis and qualitative comments provided in chapters 1 and 2.

3.1.1 Painted FRP

The Volatile Organic Compound (VOC) component of the paint substrate and the ease with which chipped paint separated from the backing decrease the value of this substrate. Detection and color recognition distances obtained for this substrate are not large enough to warrant selection of this material to replace the current system.

3.1.2 Lumasite Acrylic

The Lumasite acrylic dayboard system had physical mounting or performance problems at each ANT unit. An improved mounting bracket could be developed to provide a solution to this problem. However, this material had shorter detection and color recognition distances than those of the other candidate materials. No benefit would be gained from further investigation of this dayboard system.

3.1.3 Surlyn Foam

Each ANT unit noted that drill bit clogging would increase mounting time; however, the light weight of the foam material made it easier to work with than the present system. Other differences noted for this system range from the different procedures required to attach the retroreflective numbering or border to the differences in color appearance from the present system.

The white surface scaling that occurred during accelerated weathering with these material samples is not expected to occur when weathered in a natural environment.

The Surlyn foam dayboard system had detection and color recognition distances that were consistently among the longest for all candidate systems evaluated.

Although the Surlyn foam material displayed good detection and color recognition distances and is easy to work with, the surface scaling, difference in handling, and preliminary cost estimate must be considered. Prior to arriving at a final decision regarding this material, full-size dayboards should be exposed to a full 5-year analysis to determine whether the surface scaling occurs during natural exposure.

3.1.4 Modulite

The Modulite material was added to the list of candidate materials after the other four materials had begun accelerated weathering. Full-size deployment was not done, field unit comments are not available, and cost benefit figures have not been compiled in this report.

This material had detection distances that were among the longest for all systems. The color recognition distances for this material were not as long as most candidate samples, but they were within 10-percent of the reference material. Prior to arriving at a final decision regarding this material, full-size dayboards should be constructed and field unit comments solicited. A life cycle cost benefit analysis should also be completed.

3.1.5 FRP with Nonfluorescent Film

The FRP backing was noted by all ANT units as clogging drill bits, not being rigid, or cracking as it was tightened in a bracket. Possible solutions to these problems include forming a supporting bracket system or replacing the FRP backing with marine grade plywood.

The nonfluorescent vinyl film had color recognition distances that were among the longest for all of the dayboard systems. Detection distances for the green samples were equivalent to those for the reference material, but the distances for the red samples were 10-percent shorter than those for the reference material.

The significant life cycle cost savings (roughly 50-percent over the current system) and field unit familiarity with elastomeric films, coupled with the results of the field tests, indicate this system is a viable option for replacing the current system. If the backing material were to be replaced, cost savings over the Net Present Value of the current system for the ten years estimated in table 1-3 would decrease from roughly $3,072,385 to $2,167,190. Prior to arriving at a final decision regarding this material, the backing material concerns should be addressed.

3.2 RECOMMENDATIONS

1. The paint/FRP and acrylic dayboard systems evaluated should not be considered for replacing the current dayboard system.

2. The foam, Modulite, and nonfluorescent film/FRP appear to be viable replacement dayboard systems. Questions about full-size dayboard performance, however, should be resolved before making a definitive selection of a replacement dayboard system.

3. In order to maintain the visual signal presented by the 1-year weathered fluorescent vinyl material for 5 years, the recommended candidate dayboard systems would require a 10-percent increase in size. The lighter weight of these systems would minimize any additional handling problems. However, the relatively close placement of aids to navigation in the field minimizes the loss of less than 10-percent distance performance, and increased board size is not recommended.

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DATA APPENDIX

APPENDIX A

Estimated Performance of Full Size Dayboards

The data presented were extrapolated from detection and color recognition performances of color samples that were measured for a 1/2-inch diameter plug of each color sample to facilitate the field test setup. The results were extrapolated for full-size dayboards by assuming a proportional increase in detection distance. Figure A-1 graphically presents the relationship between detection distances and dayboard size. The actual relationship is defined in the following equation:

$$\frac{\text{1/2 height (sample)}}{\text{average distance}} = \frac{\text{1/2 height (full-size dayboard)}}{\text{estimated distance}}$$

The relationship assumes a constant angle of illumination and a perfectly clear atmosphere. The angle of the sun between a time of day from 1000 to 1400 was nearly constant for the test setup orientation, and the assumption of a clear atmosphere is adequate for a comparative analysis.

Calculated distances are presented for 3-, 4-, 6-, and 8-foot dayboards. Also shown in the appendix are the estimated sizes of candidate material dayboards needed to maintain the signal presented by the 3- to 8-foot fluorescent dayboards. The use of 1/2-inch plugs in the field test means that the full-size dayboards referenced here have a round area of the given diameter.

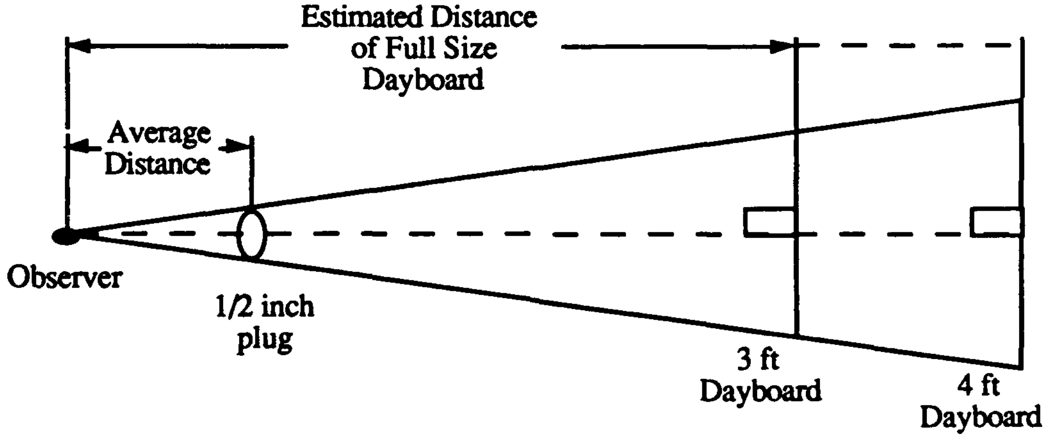

Figure A-1. Representation of Full-Size Dayboard Distance Estimation Model

3 FOOT SQUARE BOARDS

	DARK BACKGROUND		LIGHT BACKGROUND		ALL DATA	
	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE
R1	3.4	3.0	3.1	2.3	3.2	2.6
R2	3.1	2.7	3.6	2.6	3.3	2.7
R3	2.5	2.2	3.7	2.3	3.1	2.2
R4	2.7	2.4	3.5	2.4	3.1	2.4
R5	2.5	2.2	3.7	2.4	3.1	2.3
G1	3.8	3.1	2.9	2.1	3.4	2.6
G2	3.8	3.0	2.8	2.0	3.3	2.5
G3	3.3	2.7	3.1	2.1	3.2	2.4
G4	4.0	3.0	3.0	2.1	3.5	2.6
G5	3.2	2.5	3.3	2.1	3.3	2.3

3 FOOT SQUARE BOARDS

	DARK BACKGROUND		LIGHT BACKGROUND		**ALL DATA**	
	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE	**DETECTION DISTANCE**	**RECOGNITION DISTANCE**
R1	3.5	3.0	3.1	2.4	**3.3**	**2.7**
R2	2.6	2.4	3.4	2.6	**3.0**	**2.5**
R3	3.1	2.7	3.2	2.3	**3.1**	**2.5**
R4	3.0	2.6	3.2	2.4	**3.1**	**2.5**
R5	2.3	2.0	3.5	2.5	**2.9**	**2.2**
R6	3.0	2.6	3.3	2.4	**3.1**	**2.5**
G1	3.3	3.0	3.0	2.4	**3.2**	**2.7**
G2	3.2	2.8	3.1	2.4	**3.1**	**2.6**
G3	3.1	2.7	3.1	2.3	**3.1**	**2.5**
G4	3.5	3.1	2.8	2.3	**3.1**	**2.7**
G5	2.5	2.2	3.3	2.3	**2.9**	**2.2**
G6	3.2	2.7	3.3	2.3	**3.2**	**2.5**

SIZE DAYBOARD TO MAINTAIN SIGNAL OF 3 FOOT 1 YEAR WXED DAYBOARD

R1	3.0	3.0	3.0	3.0	**3.0**	**3.0**
R2	3.9	3.8	2.8	2.7	**3.3**	**3.3**
R3	3.4	3.3	2.9	3.0	**3.2**	**3.2**
R4	3.5	3.5	2.9	3.0	**3.2**	**3.3**
R5	4.5	4.5	2.7	2.9	**3.4**	**3.6**
R6	3.4	3.5	2.9	3.0	**3.2**	**3.3**
G1	3.0	3.0	3.0	3.0	**3.0**	**3.0**
G2	3.2	3.2	2.9	3.0	**3.0**	**3.1**
G3	3.2	3.3	2.9	3.1	**3.1**	**3.2**
G4	2.8	2.9	3.2	3.1	**3.0**	**3.0**
G5	4.0	4.2	2.7	3.0	**3.3**	**3.6**
G6	3.2	3.3	2.7	3.1	**3.0**	**3.2**

4 FOOT SQUARE BOARDS

	DARK BACKGROUND		LIGHT BACKGROUND		ALL DATA	
	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE
R1	4.5	4.0	4.2	3.0	4.3	3.5
R2	4.1	3.6	4.8	3.5	4.5	3.5
R3	3.3	2.9	5.0	3.0	4.2	3.0
R4	3.6	3.2	4.6	3.3	4.1	3.3
R5	3.4	3.0	4.9	3.3	4.2	3.1
G1	5.1	4.2	3.9	2.9	4.5	3.5
G2	5.0	4.0	3.7	2.7	4.3	3.4
G3	4.4	3.6	4.1	2.8	4.3	3.2
G4	5.3	4.0	4.0	2.8	4.7	3.4
G5	4.3	3.4	4.4	2.8	4.3	3.1

4 FOOT SQUARE BOARDS

	DARK BACKGROUND		LIGHT BACKGROUND		**ALL DATA**	
	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE	**DETECTION DISTANCE**	**RECOGNITION DISTANCE**
R1	4.6	4.0	4.2	3.2	**4.4**	**3.6**
R2	3.5	3.2	4.5	3.5	**4.0**	**3.3**
R3	4.1	3.6	4.3	3.1	**4.1**	**3.3**
R4	4.0	3.5	4.3	3.2	**4.1**	**3.3**
R5	3.1	2.7	4.6	3.3	**3.8**	**3.0**
R6	4.0	3.5	4.4	3.2	**4.1**	**3.3**
G1	4.4	4.0	4.0	3.1	**4.2**	**3.6**
G2	4.2	3.7	4.2	3.2	**4.2**	**3.4**
G3	4.1	3.6	4.2	3.1	**4.1**	**3.3**
G4	4.7	4.2	3.7	3.0	**4.2**	**3.6**
G5	3.4	2.9	4.4	3.1	**3.8**	**2.9**
G6	4.2	3.7	4.4	3.0	**4.3**	**3.3**

SIZE DAYBOARD TO MAINTAIN SIGNAL OF 4 FOOT 1 YEAR WXED DAYBOARD

R1	4.0	4.0	4.0	4.0	**4.0**	**4.0**
R2	5.3	5.0	3.7	3.6	**4.4**	**4.3**
R3	4.5	4.4	3.9	4.0	**4.2**	**4.3**
R4	4.7	4.6	3.9	4.0	**4.3**	**4.3**
R5	5.9	5.9	3.6	3.8	**4.6**	**4.8**
R6	4.6	4.6	3.8	4.0	**4.2**	**4.4**
G1	4.0	4.0	4.0	4.0	**4.0**	**4.0**
G2	4.2	4.3	3.8	4.0	**4.0**	**4.1**
G3	4.3	4.4	3.8	4.1	**4.1**	**4.3**
G4	3.8	3.8	4.3	4.1	**4.0**	**4.0**
G5	5.3	5.5	3.7	4.1	**4.4**	**4.8**
G6	4.2	4.4	3.7	4.2	**4.0**	**4.3**

6 FOOT SQUARE BOARDS

	DARK BACKGROUND		LIGHT BACKGROUND		ALL DATA	
	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE
R1	6.7	6.0	6.3	4.6	6.5	5.3
R2	6.2	5.4	7.2	5.2	6.7	5.3
R3	5.0	4.4	7.5	4.5	6.3	4.4
R4	5.4	4.9	7.0	4.9	6.2	4.9
R5	5.1	4.5	7.4	4.9	6.3	4.7
G1	7.6	6.3	5.9	4.3	6.8	5.3
G2	7.5	6.0	5.5	4.1	6.5	5.1
G3	6.7	5.4	6.2	4.2	6.4	4.8
G4	7.9	6.0	6.0	4.2	7.0	5.1
G5	6.4	5.1	6.6	4.2	6.5	4.6

6 FOOT SQUARE BOARDS

	DARK BACKGROUND		LIGHT BACKGROUND		**ALL DATA**	
	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE	**DETECTION DISTANCE**	**RECOGNITION DISTANCE**
R1	6.9	6.0	6.3	4.7	**6.6**	**5.4**
R2	5.3	4.8	6.8	5.2	**6.0**	**5.0**
R3	6.1	5.4	6.4	4.7	**6.2**	**5.0**
R4	6.0	5.2	6.5	4.8	**6.2**	**5.0**
R5	4.7	4.1	7.0	5.0	**5.8**	**4.5**
R6	6.0	5.2	6.5	4.8	**6.2**	**4.9**
G1	6.7	6.0	6.0	4.7	**6.3**	**5.3**
G2	6.3	5.5	6.3	4.7	**6.3**	**5.1**
G3	6.2	5.4	6.3	4.6	**6.1**	**5.0**
G4	7.0	6.3	5.6	4.6	**6.2**	**5.4**
G5	5.1	4.3	6.5	4.6	**5.7**	**4.4**
G6	6.3	5.5	6.5	4.5	**6.4**	**4.9**

SIZE DAYBOARD TO MAINTAIN SIGNAL OF 6 FOOT 1 YEAR WXED DAYBOARD

R1	6.0	6.0	6.0	6.0	**6.0**	**6.0**
R2	7.9	7.5	5.5	5.5	**6.6**	**6.5**
R3	6.8	6.7	5.9	6.1	**6.4**	**6.5**
R4	7.0	6.9	5.8	6.0	**6.4**	**6.5**
R5	8.9	8.9	5.4	5.7	**6.9**	**7.2**
R6	6.9	7.0	5.7	5.9	**6.4**	**6.6**
G1	6.0	6.0	6.0	6.0	**6.0**	**6.0**
G2	6.3	6.5	5.7	6.0	**6.0**	**6.2**
G3	6.4	6.6	5.7	6.1	**6.2**	**6.5**
G4	5.7	5.7	6.4	6.2	**6.1**	**6.0**
G5	7.9	8.3	5.5	6.1	**6.6**	**7.3**
G6	6.3	6.5	5.5	6.3	**5.9**	**6.5**

8 FOOT SQUARE BOARDS

	DARK BACKGROUND		LIGHT BACKGROUND		ALL DATA	
	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE
R1	9.0	8.1	8.4	6.1	8.7	7.1
R2	8.2	7.2	9.6	7.0	8.9	7.1
R3	6.7	5.8	10.0	6.0	8.4	5.9
R4	7.2	6.5	9.3	6.5	8.3	6.5
R5	6.8	5.9	9.9	6.5	8.3	6.3
G1	10.2	8.3	7.8	5.7	9.0	7.1
G2	10.1	8.0	7.3	5.4	8.7	6.7
G3	8.9	7.2	8.3	5.6	8.6	6.4
G4	10.6	8.0	8.1	5.6	9.3	6.8
G5	8.6	6.8	8.8	5.6	8.7	6.2

8 FOOT SQUARE BOARDS

	DARK BACKGROUND		LIGHT BACKGROUND		**ALL DATA**	
	DETECTION DISTANCE	RECOGNITION DISTANCE	DETECTION DISTANCE	RECOGNITION DISTANCE	**DETECTION DISTANCE**	**RECOGNITION DISTANCE**
R1	9.3	8.0	8.3	6.3	**8.8**	**7.2**
R2	7.1	6.4	9.0	7.0	**8.0**	**6.6**
R3	8.2	7.2	8.5	6.3	**8.3**	**6.7**
R4	8.0	7.0	8.7	6.4	**8.3**	**6.6**
R5	6.2	5.4	9.3	6.6	**7.7**	**6.0**
R6	8.1	6.9	8.7	6.4	**8.3**	**6.5**
G1	8.9	8.0	8.0	6.3	**8.4**	**7.1**
G2	8.4	7.4	8.3	6.3	**8.4**	**6.9**
G3	8.3	7.2	8.3	6.2	**8.2**	**6.6**
G4	9.4	8.4	7.4	6.1	**8.3**	**7.1**
G5	6.7	5.8	8.7	6.2	**7.6**	**5.9**
G6	8.4	7.3	8.7	6.0	**8.5**	**6.6**

SIZE DAYBOARD TO MAINTAIN SIGNAL OF 8 FOOT 1 YEAR WXED DAYBOARD

R1	8.0	8.0	8.0	8.0	8.0	8.0
R2	10.5	10.0	7.4	7.3	8.8	8.7
R3	9.1	8.9	7.9	8.1	8.5	8.6
R4	9.3	9.2	7.7	8.0	8.5	8.7
R5	11.9	11.9	7.2	7.6	9.2	9.6
R6	9.2	9.3	7.7	7.9	8.5	8.8
G1	8.0	8.0	8.0	8.0	8.0	8.0
G2	8.5	8.6	7.6	8.0	8.0	8.3
G3	8.6	8.8	7.6	8.2	8.2	8.6
G4	7.6	7.6	8.6	8.3	8.1	8.0
G5	10.6	11.1	7.3	8.1	8.8	9.7
G6	8.5	8.7	7.3	8.4	7.9	8.7