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FIELD STUDY OF DETECTABILITY OF COLORED TARGETS AT SEA

by

Human Engineering Branch

Bureau of Medicine and Surgery, Navy Department
Project NM 002 014.09.03

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Medical Research Laboratory Report No. 265

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Color Vision Report No. 31

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Released by

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26 May 1955

THIS REPORT CONCERNS .

the relative delectability at sea of colors in the red through yellow range, including fluorescents and standard paints. Orange and scarlet fluorescent paints were found to be outstandingly detectable

IT IS FOR THE USE OF .....

offices concerned with the procurement and manufacture of life- saving equipment, ditching and survival gear, and for writers of air- sea rescue manuals.

ITS APPLICATION FOR THE SUBMARINE FORCE .....

will be in the procurement of more visible gear which will benefit sea and air-sea rescue. The results may also be utilized in increasing the delectability of floats, buoys, safety gear, test materials, and re- coverable equipment.

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ABSTRACT

Air-to-sea sightings of various colored targets were made in fair weather. Observers were stationed in an aircraft flying at 700 feet altitude in an established search pattern. Targets were aluminum spheres painted with different test colors as follows: 16 ordinary paints of varying brightnesses and saturations in the yellow through red range, including certain Army-Navy standard colors; black and white; and four fluorescent paints. Tar- gets were presented singly, and the distance at which each was detected was recorded.

Colors which were detected at the greatest dis- tances were the yellow-red and orange-red fluorescents; next in detectability were ordinary paints of high bright- ness and/or saturation.

The effects of certain operational and observa- tional variables are discussed. The data may be used as guides in selecting colors for survival gear and in es- tablishing rescue search patterns.

FIELD STUDY OF DETECTABILITY OF COLORED TARGETS AT SEA

INTRODUCTION

In spite of numerous attempts to improve the detection of sur-vivors at sea by electronic devices, chief reliance must still be placed on visual detection. Survival gear must be of some color, and the color is a trifling part of the cost. If one color could be demonstrated to be more effective than another in promoting detection in a majority of situations, the research involved would be amply justified.

Laboratory studies by Malone, Sexton and Farnsworth (1,2) in- dicated the superior visibility of orange-reds at small subtense. This was confirmed in a limited air-sea test by Malone (3). The Medical Research Laboratory did not at first investigate the use of fluorescents because of their instability, but Malone's study, as well as tests by Whtttingham and Ellis (4) demonstrated the superiority of fluorescents over the matte yellow which is in common use.

Field experiments proved to be complex. In the initial ap- proaches at Medical Research Laboratory, attempts were made to sim-plify observations by holding certain color factors constant. When brightness contrasts were held to a minimum, the previous studies of this Laboratory showed that an orange-red (scarlet) was the most con- spicuous hue when seen at detection distances (visually speaking, at "small subtense"). When brightness contrasts varied, maximum de- tectability was found for colors lighter than the background. However, hue can be controlled whereas brightness contrast

can be only partially predetermined. Depending upon the state of the weather and the angle

of observation, a dark target may be more conspicuous than a light, and vice versa. It can be shown theoretically that with an overcast sky of uniform brightness with perfectly smooth water, a white target would be invisible and a dark target would show up at maximum contrast at a search angle of incidence to the sea. On the other hand, it can be shown that with a clear sky and sunshine a dark object would be inconspicuous and a white object would exhibit maximum contrast.

Some other simplifications were made by treating a uniform background without motion. Actually the search area is an expanse ex-hibiting wave movements, light flicker, mowing cloud shadows, natural objects such as seagulls and fish and floating objects such as flotsam and buoys. Some of these considerations are outlined in a paragraph by Hartridge (5).

"During the 1939-45 war many Allied aircraft came down in the North Sea. These aircraft were fitted with rubber dinghies, so that their crews could re-main afloat until rescue could be effected. At first the fabric of which the dinghies were made had a bright lemon-yellow colour, but it was frequently found, even under good atmospheric conditions, that the position of a dinghy could not be detected by aircraft fly-ing overhead, and experiment showed that this failure was due to the colour of the fabric. Yellow test objects, particularly on a blue ground, are found to appear white when they are a long distance away. The dinghies, having apparently become white in colour, could easily be mis-taken for a collection of seabirds, or even flecks of foam. When other colours were tested it was soon found that the best one of all is a bright orange-red. This keeps its colour far better than yellow when seen at a distance, and renders objects easily distinguishable.

A Coast Guard experiment (6) emphasized the important in-fluence of the background conditions:

"Surveying the lifejacket visibility problem, the situation sums up as follows:

Daylight: The Indian orange jacket can be seen about the same distance as a white jacket when whitecaps are not present and about twice as far when whitecaps are preset.

Night; Without searchlights, visibility of any color is so low that probability of detection is extremely small, With searchlights giving predominately bluish light (carbon arc, mercury vapor) visibility of various colors is of the same order with white slightly more visible. With tung-sten searchlights the white jacket will be slightly more visible under no whitecap conditions and orange jacket considerably more visible when whitecaps are present."

While there is no doubt that the result of laboratory and field studies is to prove the superiority of scarlet over any other color when brightness contrasts are at a minimum it is the combination of hue with brightness which makes a target more or less visible under actual search conditions. These conditions involve the background, the mete-rological conditions including the color and state of the sea, the angle of the sun, the angle of the observer in relation to the illumination and to the part of the sea being searched, and the light conditions which range through a variety of conditions from full sunlight to heavy over-cast. Discovery is further modified by the type of target used, by ob-server expectation and search method. It therefore appeared necessary to run a rather extensive study which would embrace as many of these variables as possible. The operational resources of the Laboratory during the period alloted to this study limited the observations to fair weather, usually with calm seas and clear sky, which are the conditions that favor the conspicuity of light objects. Therefore only a portion of the operational variables were sampled and conclusions

which are drawn from the data presented in this report must taken as applying with certainty only to fair weather

No study reported heretofore on this subject has approached the completeness of the experimental plan or the number of observa- tions reported in this study . In spite of this, the number of variables was so great that statistically reliable differences were seldom ob-tained. This indicates how little confidence may be placed in studies of more limited extent, less systematically organized and sparsely sampling the great variety of conditions which are found outdoors at

One of the contributions of this study is the data on actual dis-tances--and ranges of distances--at which targets were sighted These figures should supply information for the refinement of air-sea search and rescue manuals

EQUIPMENT AND METHODS

Targets

Two types of targets were used: spherical balls of uniform size, and a few stock items of standard survival equipment.

Spherical targets were selected for the principal part of the test so that the area and shape of exposure to the observers would show the least change with motion of the sea and with angle of view. The balls were 34 inches in diameter--a size roughly intermediate between that of a large life raft and that of an aviator's helmet

The colors applied to the spheres were selected from the fol-lowing ranges:

(a) The yellow-red to red range of hues on either side of 7.5 red (Munsell notation). This hue range had been found maximally ef-fective in previous tests.

(b) A series of reds of approximately the same hue but varying in saturation from near neutral to the most vivid obtainable. This se-ries was included in the hope of isolating the effect of chroma (satura-tion) upon noticeability.

(c) A complete range of values (brightness) from black to white, to isolate the effects of brightness contrasts.

(d) Standard military colors which have been specified for Air-Sea rescue material: Life Boat Yellow, International Orange, and Scar-let.

(e) Proprietary red, orange and yellow outdoor paints. These were included in order to test the detection distances of commercially obtainable colors of highest saturation.

(f) Commercially available fluorescent pigments from yellow to red. These were not included until near the close of the study be-cause up to that time no fluorescents had been reported for which rea-sonable performance could be expected.

It was possible to make up interlocking series so that no more than 22 colors were required altogether. Perfect counterbalancing of the design could not be obtained, however.

A list of the colors will be found in Table 1. The first column gives the color designation which will be used throughout this report, and the second column gives alternative designations for several colors. Most of the specifications are given in Munsell notations (hue, value/ chroma) and are accurate to the nearest scale unit, as determined by visual comparison. The nearest matches to certain standard colors are also shown. Life Boat Yellow was obtained by matching several representative samples from

standard equipment. The four fluorescent

colors were obtained from Switzer Brothers, Inc., and are available in paints of extended stability. The color matching and painting were carried out by the Illustrations Unit of this Laboratory under the direc-tion of Mr. John P. Verges.

The spheres were repainted from time to time during the course of the experiment, but at the expiration date of the longest period of ex-posure, they were again compared with Munsell standards. In column 3 will be found the best match after exposure.

The last three columns of Table 1 present the CIE* x,y coordin-ates and reflectance values for the colors, calculated for Illuminant C. These CIE locations are plotted in Figure 1. For the ordinary colors, these specifications were obtained from spectrophotometric measure-ments. The values for the fluorescent colors are by courtesy of Switzer Brothers, Inc., who have developed special techniques for such measure-ments. Their data are in good agreement with visual estimates. Some variability must be expected in the specifications for fluorescents, due to different application techniques. The following limits were provided:

Fire Orange	Luminance factor	:	35% minimum
	Excitation purity	:	85% minimum
	Dominant wavelength	:	608-612 mμ
Arc Yellow	Luminance factor	:	75% minimum
	Excitation purity	:	85% m/n/mum
	Dominant wavelength	:	588-590 mμ
Neon Red	Luminance factor	:	28% minimum
	Excitation purity	:	60% minimum
	Dominant wavelength	:	492.7c-434c mμ
Saturn Yellow	Luminance factor	:	85% minimum
	Excitation purity	:	78% minimum
	Dominant wavelength	:	566-568 mμ

* Commission Internationale d'Eciairage

Table I. Specifications of the 22 colors tested. Colors applied to spheres for air to water sightings.

Designation	Alternative designation	Designation after exposure	CIE specifications x	y	Y(%R)
du Pont 6478	5 R 4/14	5 R 4/14	.525	.316	12
5 R 4/10		7.5 R 5/8	.476	.320	13
5 R 5/10		5 R 6/10	.460	.321	18
7.5 R 6/8		10 R 6/8	.428	.331	31
7.5 R 7/7		2.5 YR 7/4	.382	.327	44
7.5 R 4/8		7.5 R 5/8	.462	.336	16
du Pont 5546	International Orange, "Scarlet" 7.5 R 5/12	7.5 R 5/12	.533	.348	21
7.5 R 5/10		7.5 R 6/8	.486	.347	22
7.5 R 6/10			.451	.342	29
10 R 6/8		2.5 YR 7/6	.427	.349	37
10 R 4/10		10 R 5/8	.459	.353	15
10 R 5/8		10 R 5/8	.455	.357	22
10 R 6/10		2.5 YR 6/8	.465	.365	30
10 R 7/8		2.5 YR 7/6	.417	.353	43
du Pont 24534	5 Y 8/10	5 Y 8/8	.432	.461	66
Life Boat Yellow	10 YR 7/10	2.5 Y 7/10	.452	.424	46
White	10 Y 9/1		.323	.336	79
Black			.301	.315	05
Fire Orange	Fluorescents		.633	.330	40
Arc Yellow			.554	.419	80
Neon Red			.565	.273	34

Saturn Yellow		.405	.535	97

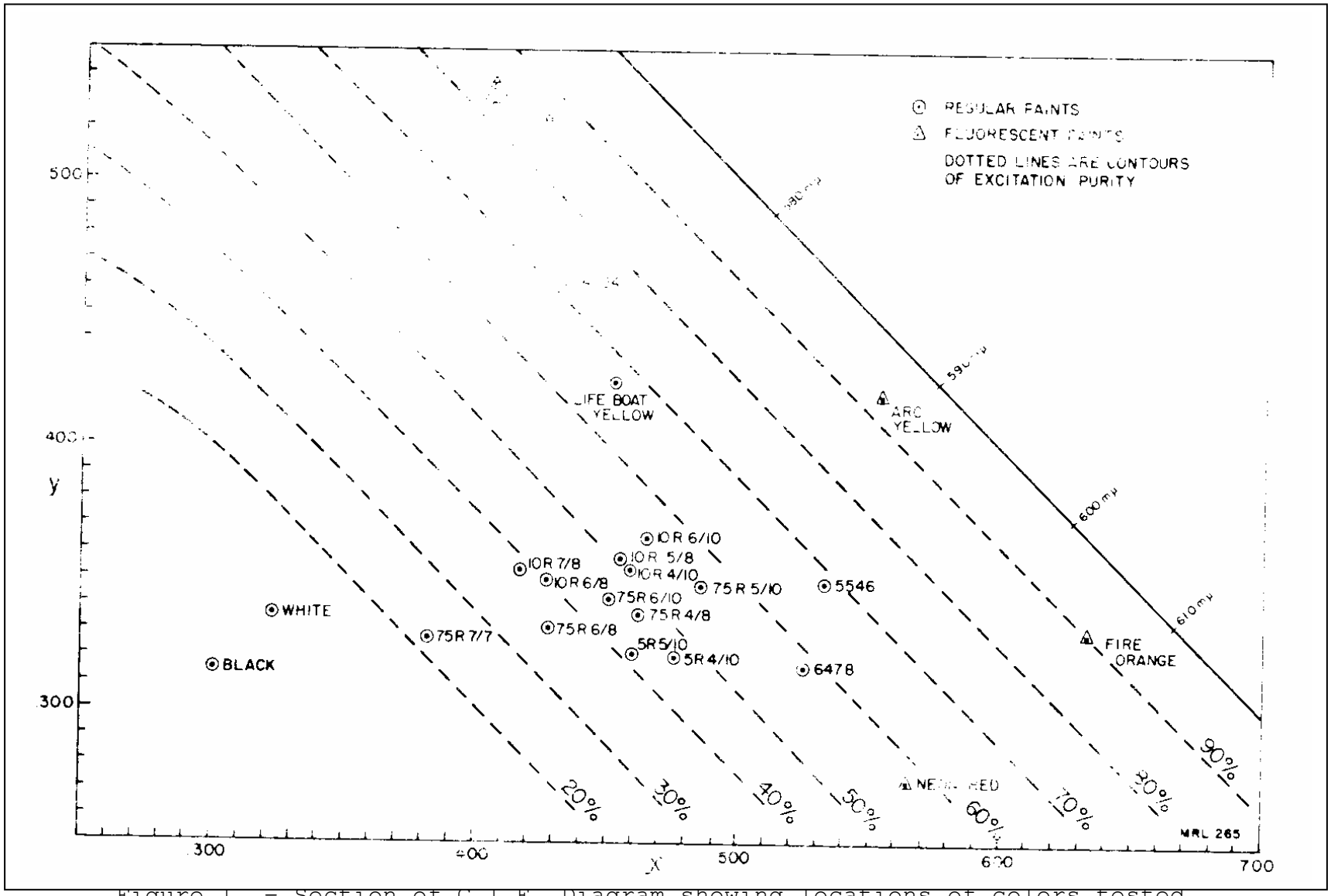

Figure 1. - Section of C.I.E. Diagram showing locations of colors tested.

The life rafts and dummies used as additional targets are de- scribed in Table II. They ware used in their original stock colors. Targets and equipment were supplied by the Aeronautical Medical Equipment Laboratory of Philadelphia through the cooperation of CDR E. M. Wurzel and Mr. Fred Brown.

Method of performing observations

A P4Y-2 (BuNo. 59810) aircraft was assigned by Chief, Bureau of Aeronautics for use by the laboratory for performing flights in making observations of the targets. The aircraft was operated by a flight crew attached to the Naval Aircraft Torpedo Unit, Naval Air Station, Quonset Point, Rhode Island. The Naval Air Station is approxi-mately fifty miles northeast of the Submarine Base. The observers from the laboratory boarded the plane at the Trumbull Airport, Groton, Connecticut,

The laboratory was provided a tug by the Operations Officer, Submarine Base, to convey and maneuver the targets in Long Island Sound, the site of flight operations.

In performing the flights, the aircraft was operated at an alti-tude of approximately 700 feet and a speed of 160 knots. The pilot was successful in maintaining the altitude and speed constant for all practi-cal considerations. The pattern of the flight is presented in Figure 2.

The flights were conducted during January to May, 1954. Pre-liminary flights were made during November and December, 1953, in order to orient the flight crew and the

observers and to synchronize operations with the crew on the tug.

Table II. Description of life rafts and dummies used as targets in air to water sightings.

Target	Official description	Dimensions	Colors
Large raft	Life Raft Mark 7 (7-place); Spec. Mil-R-5567 (AER); Stock no. R83R15570	Length: 144"; Width: 68"; Water level ht.: 18 1/2 to 22 1/2" Diam. of tube: 16".	Life Boat Yellow
Medium raft	Life Raft, Mark 4 (4-place); Spec. Mil-R-5567 (AER); Stock no. R83R15530.	Length: 110"; Width: 60"; Water level ht.: 18 1/2 to 22 1/2; Diam. of tube: 15 1/4".	Life Boat Yellow with gray or fluorescent tarpaulin in center.
Small raft	Para-Raft Kit, PK-2 (Single place); Spec. 23K3 (AER) - 1; Stock no. R83K709970.	Length: 64 1/2"; Width: 28 to 36"; Water level ht.: 7 to 12" Diam. of tube: 6 to 9 3/4".	Life Boat Yellow
Dummy		Length across shoulders of life jacket: 16"; Diam. of helmet: 9".	Life jacket: Life Boat Yellow; Helmet: gold or white.

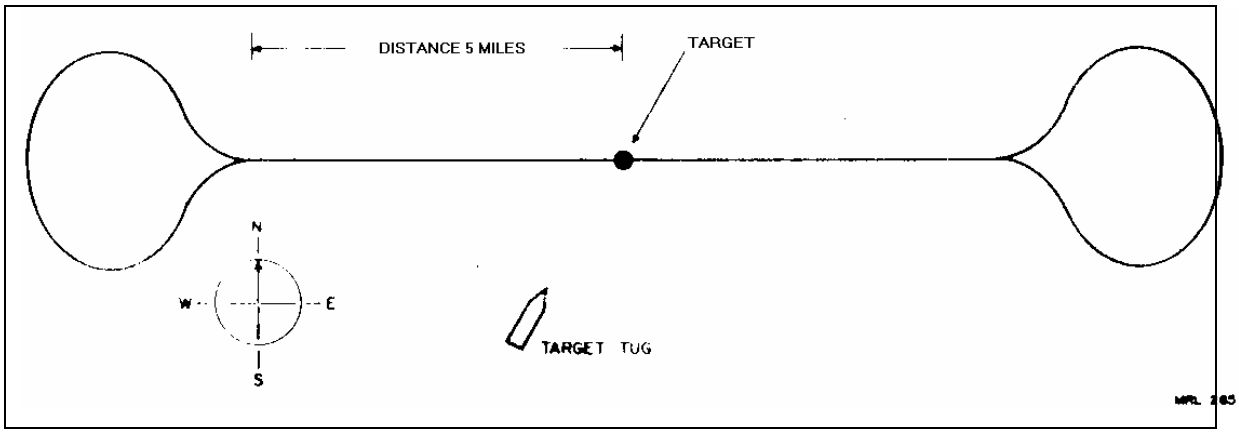

Figure 2.-Flight pattern employed for performing observations of targets.

The combined limitations of the plane and the tug prevented flights during conditions of either low visibility or rough seas. There- fore, flights were made only on days of nearly ideal weather.

The observers were members of the enlisted staff of the labor-atory. Four men were required to make observations of targets from the aircraft. One man operated with the tug crew to direct target re-leases and maintain records.

In Figure 3, a sagittal section of the aircraft is indicated. The positions of the observers may be noted by reference to the Figure. The observers were under the direction of a commissioned officer, from the laboratory, who co-ordinated the activity of the observers with flight and tug operations by intercommunication system on plane and by radio contact with the tug. At approximately thirty minute in-tervals, the observer's rotated positions of observation, which permitted one observer a period of relaxation.

The observers were alerted when the plane approached the line of flight directed over the target. When the target

was first sighted, the observers initiated timing with stop watches and continued timing

until the plane passed over the target. (At the instant of passing over the target, the observers in the lower positions signalled "Mark" over the intercommunication system.) Each observer maintained a record of the number of the run (provided by the co-ordinator), time elapsed from first sighting until passing over the target, apparent color of target when first sighted and color of target when passed over by the plane. A four-point scale was used for reporting various shades of red.

On days when climatic conditions were favorable for flights, operations over the targets were started about 0930 and continued to about 1400. The targets selected for a day were scheduled randomly and the number of runs per target varied with the number of targets included in the day's operation. The number of runs per target was uniform.

The co-ordinator recorded flight number, speed and altitude of plane, speed and direction of wind, visibility (as determined by the pilot), and the condition of the sea.

Treatment of the data

A total of 2753 observations was obtained. Each datum was the time, in seconds, between the first sighting of a target and the moment the plane passed over the target. All the results have been converted into nautical miles (at the constant speed, one mile is equal to 22.5 seconds).

The total set of data consists of several subdivisions repre-senting changes in experimental conditions. Different groups of data allow assessments of the following variables: target color (with ordi-

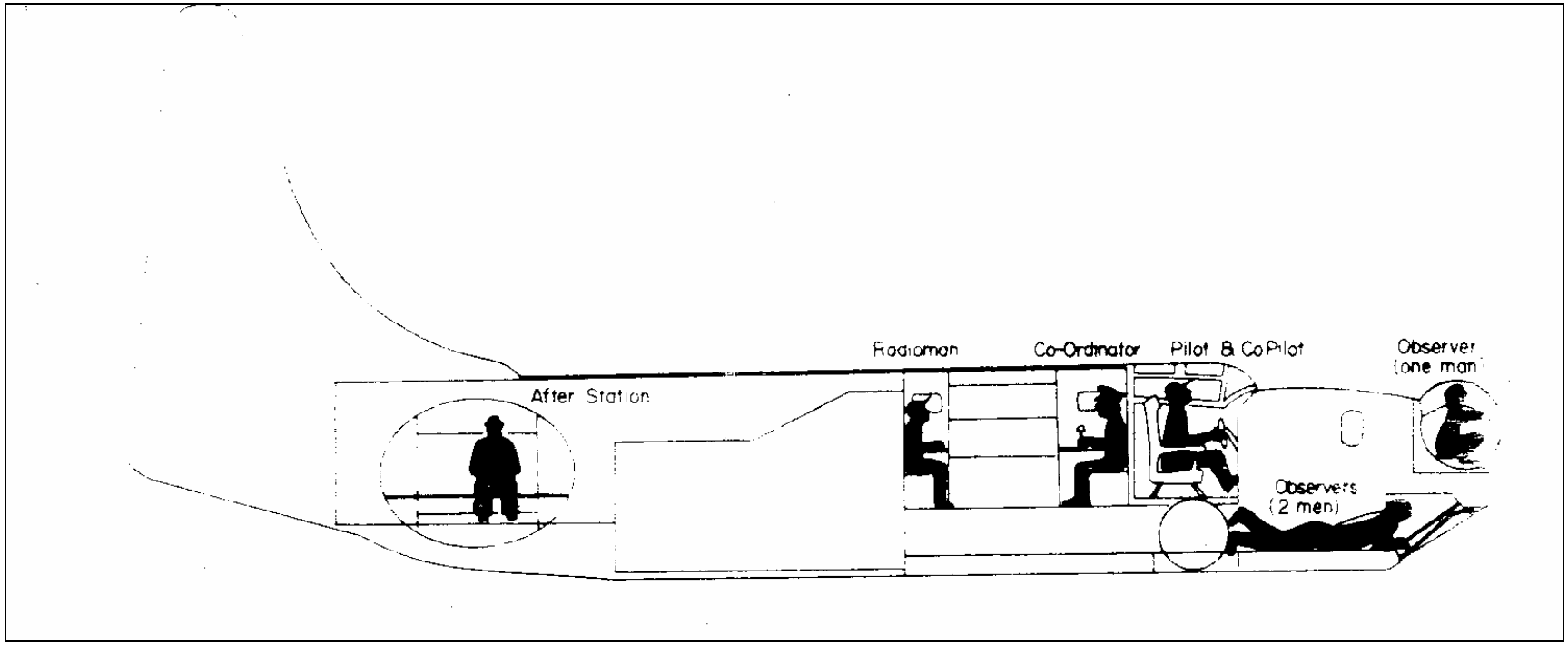

Figure 3. - Sagittal section of a P4Y-2 aircraft, indicating position of personnel in performing observations of targets in air-sea rescue investigations.

nary paint) within a large series of finely graded colors and within an abridged series of special colors; color vs black and white; fluorescent paints; target size, and atmospheric visibility,

For each experimental condition, the data were first grouped into intervals; that is, distributions were obtained showing the fre-quency with which detection distances of 0 to 0.44 miles (0 to 10 sec-onds), 0.44 to 0.89 miles (10 to 20 seconds), and so forth were reported. From these distributions, the following statistics were computed: mean, median, mode, standard deviation (σ), standard error of the mean (σM), and standard error of σ. Comparisons of the means, medians, and modes showed that the distributions were in general normally shaped. Means were therefore used as the most reliable measures. The fre-quency distributions were also plotted to show the probability of detec-tion as a function of search distance for a given condition.

RESULTS

Comparison of colors (ordinary paints)

In the first series of extensive runs, 16 colors were used. Table III shows results, with the colors listed in order of detection dis-tance. Since the standard error of the group mean is 0.09 miles, only those targets whose means are more the 0.18 miles (±2σ) higher or lower than the group mean can be considered significantly different from the overall average. According to this criterion of significance, only du Pont 24534 and du Pont 6478 were detected at significantly greater distances, and the last three colors listed were significantly below average. If a

more stringent criterion of significance (±3 σ) is applied, only du Pont 24534 appears superior.

Figure 4 shows probability-of-detection curves for some of the targets in this experiment. The extreme cases are represented here; all other colors fall within this range in both slope and intercept.

Table III. Air to water day sighting distances at 700 feet altitude, over 15 miles visibility, and cross sun, of spheres 34 inches in diameter colored as indicated.

Color of sphere	N Obs.	Detection distance in miles Mean	σ	σM	Percent missed
du Pont 24534	71	1.9	0.7	0.08	3
du Pont 6478	60	1.9	0.7	0.09	3
10 R 7/8	66	1.8	0.7	0.08	3
7.5 R 5/10	35	1.8	0.7	0.12	0
Life Boat Yellow	72	1.7	0.7	0.08	6
du Pont 5546	72	1.7	0.6	0.07	3
7.5 R 4/8	60	1.7	0.6	0.08	2
10 R 6/10	74	1.7	0.7	0.08	4
7.5 R 6/10	23	1.6	0.5	0.11	0
10 R 6/8	47	1.6	0.7	0.10	11
7.5 R 6/8	80	1.6	0.8	0.08	12
10 R 4/10	80	1.5	0.6	0.07	2
10 R 5/8	72	1.5	0.7	0.08	6
7.5 R 7/7	71	1.4	0.8	0.09	17
5 R 5/10	36	1.2	0.7	0.12	14
5 R 4/10	32	1.2	0.5	0.10	3
Average	(951)	1.62	0.70	0.09	

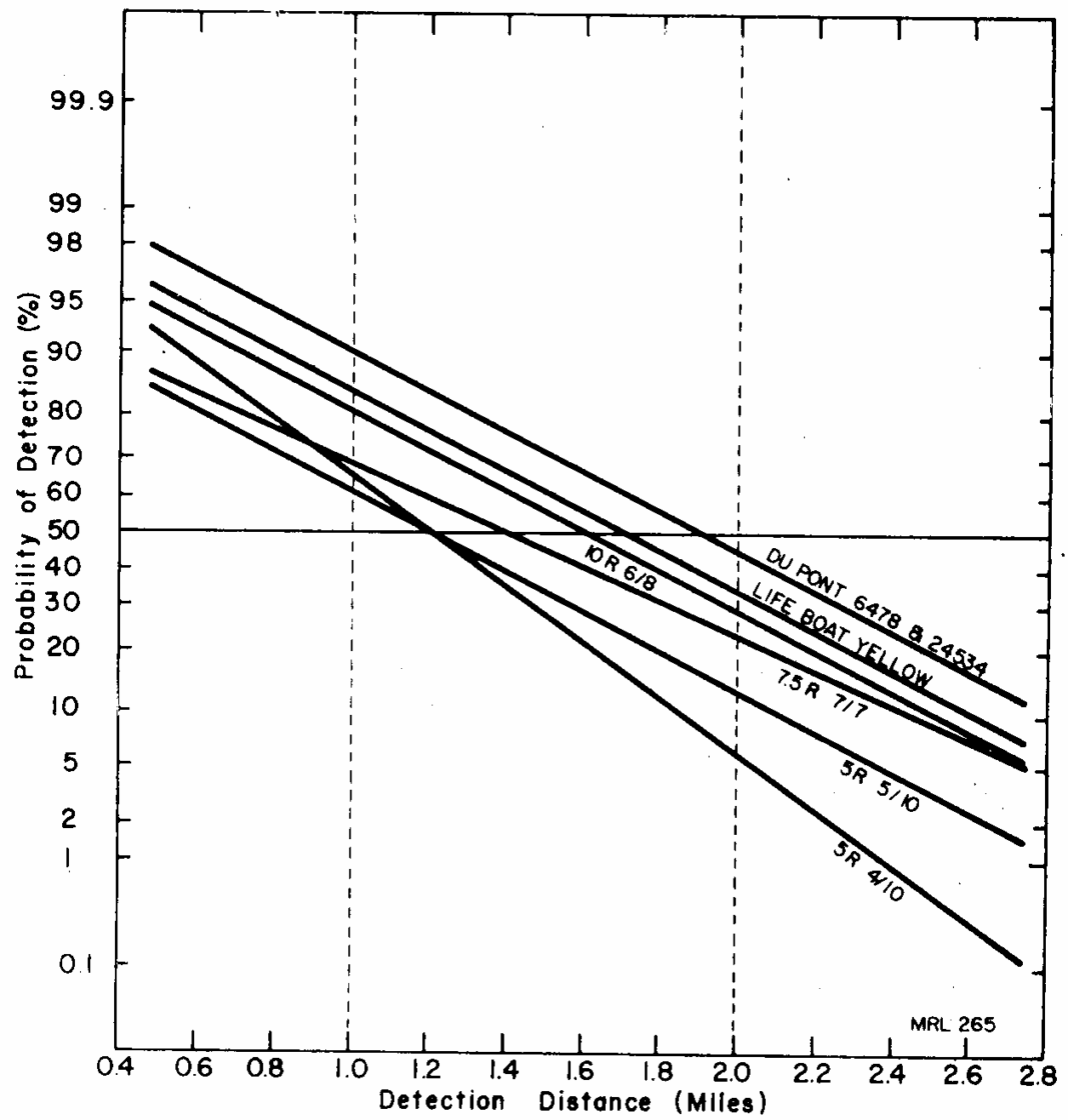

Figure 4.- Air-Water sighting distances from cumulative observations-- at 700 feet altitude, over 15 miles visibility, and cross-sun, of spheres 34 inches in diameter, colored as indicated.

Comparison of colors, black, and white

Three experiments were conducted with abridged series of colors including black and white targets. The results are summarized in Table IV. Those targets which stand out as detectable at greater distances, or as poorly detectable, are starred. A probability-of-de-tection graph for some of the colors in the second experiment is shown in Figure 5.

These data show roughly the same relative order for the colors as in Table III, and reveal the superior detectability of White.

Table IV. Air to water day sighting distances at 700 feet altitude, over 15 miles visibility, and cross sun, of spheres 34 inches in diameter colored as indicated.

Color of sphere	N Obs.	Detection distance in miles			Percent missed
		Mean	σ	σM	
du Pont 24534	32		0.6	0.0	0
		1.7**			
du Pont 6478	54	1.5	0.8	0.11	7
du Pont 5546	54	1.4	0.7	0.10	2
10 R 7/8	53	1.2*	0.5	0.07	0
Average	(193)	1.45	0.68	0.10	
White	48		1.1	0.16	10
		1.9**			
du Pont 24534	17	1.2	0.8	0.20	29
du Pont 6478	51	1.1	0.5	0.07	4
7.5 R 6/8	18	1.0	0.8	0.17	22
10 R 5/8	46	1.0	0.5	0.08	9
Black	47	0.9*	0.4	0.07	2
du Pont 5546	36	0.8*	0.5	0.08	22
Average	(263)	1.16	0.78	0.12	
White	72		1.0	0.12	4
		1.9**			
Life Boat Yellow	72		0.8	0.09	10
		1.8**			
du Pont 6478	70	1.5	0.8	0.09	4
10 R 7/8	72	1.4	0.7	0.08	11

du Pont 5546	71	1.2*	0.5	0.06	3
Average	(357)	1.56	0.74	0.09	

**Significantly higher than the group mean

*Significantly lower than the group mean

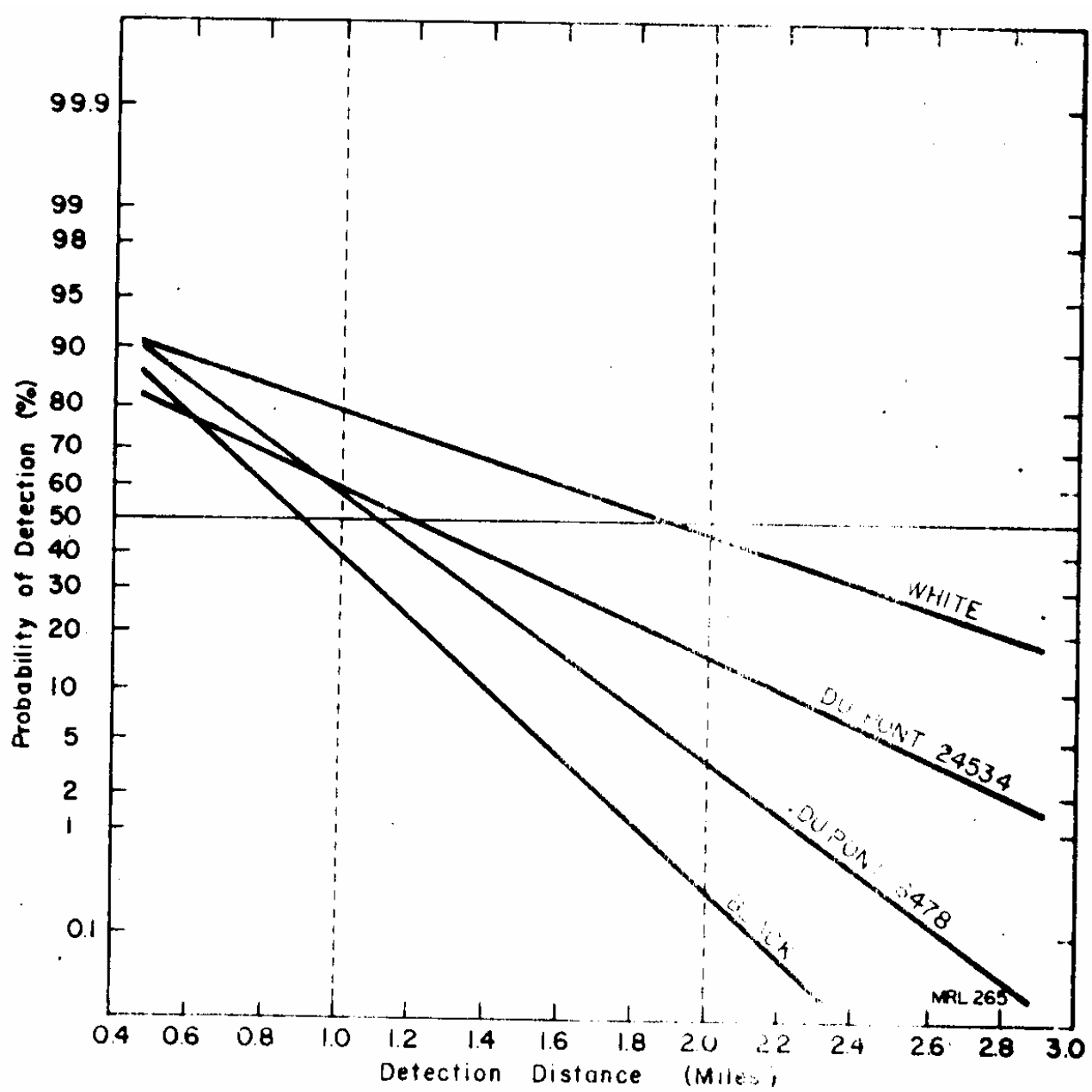

Figure 5.- Air-to-water sighting distances from cumulative observations -- at 700 feet altitude, over 15 miles visibility and cross-sun, of spheres 34 inches in diameter, colored as indicated.

Fluorescent paints

Four fluorescent paints were tested in one series of runs. One ordinary paint, du Pont 6478, was included in the series for compari-son. The statistics for these runs are given in Table V. Figure 6 pre-sents the probability-of-detection curves. The data show the fluores-cents to be highly superior in detectabiity to the ordinary du Pont red.

Table V. Air to water day sighting distances at 700 feet altitude, over 15 miles visibility, and cross sun, of spheres 34 inches in diameter colored with fluorescent paints as indicated.

Color of sphere	N Obs.	Detection distance in miles		Percent missed
		Mean	σ	
Arc Yellow	24	2.6	1.3	0
Fire Orange	24	2.4	0.8	0
Saturn Yellow	24	2.0	0.5	0
Neon Red	24	1.4	0.6	4
Average, all fluorescents	(96)	2.11	0.79	
du Pont 6478 (non-fluorescent)	24	1.0	0.6	21

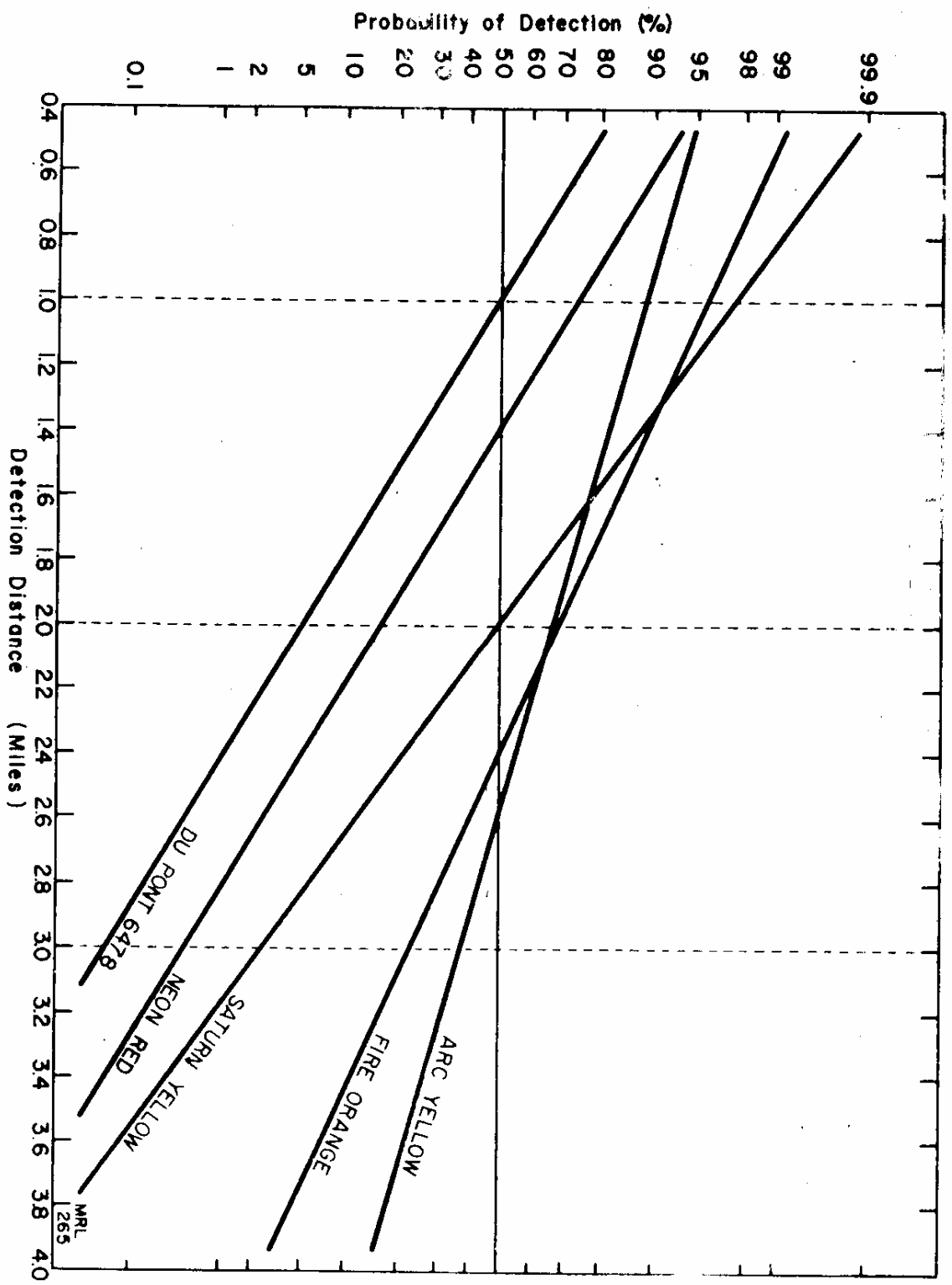

Figure 6.- Air-to-water sighting distances from cumulative observations--at 700 feet altitude, over 15 miles visibility, and cross-sun, of spheres 34 inches

in diameter, colored with fluor-escent paints as indicated.

Effect of atmospheric visibility

Most of the experimental data were obtained under conditions where the atmospheric visibility was excellent -- better than 15 miles. However, several days trials were run under other visibility conditions. Figure 7 shows the mean detection distance, for four targets combined, as a function of visibility. These data are identified in Table VI, which also presents all other measures relating to visibility.

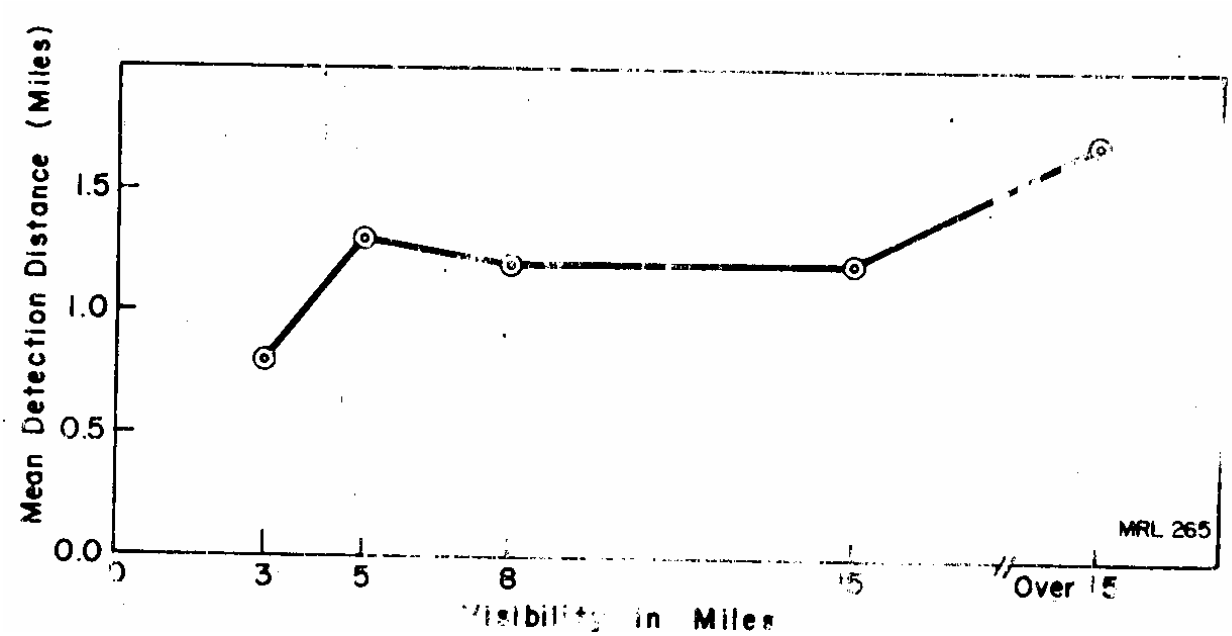

Figure 7.- Air-to-water sighting distances at 700 feet altitude, at various visibility levels and cross-sun, of spheres 34 inches in diameter. Means for four controlled targets.

Table VI. Air to water day sighting distances at 700 feet altitude, various visibility levels, and cross sun, of spheres 34 inches in diameter colored as indicated. Detection distances (M and σ) in miles.

	Visibility in Miles														
	3			5			8			15			over 15 (from Table I)		
Color of sphere	N	M	σ	N	M	σ	N	M	σ	N	M	σ	N	M	σ
du Pont 6478 *#	12	0.9	0.2	11	1.5	0.6	16	1.6	0.4	18	1.4	0.4	63	1.9	0.7
7.5 R 7/7	24	1.3	0.5				27	0.8	0.4				71	1.4	0.8
7.5 R 4/8#				20	1.2	0.4	23	0.8	0.4	17	1.2	0.6	60	1.7	0.6
du Pont 5546 *#	12	0.5	0.3	12	1.4	0.5	37	1.0	0.4	12	1.2	1.1	72	1.7	0.6
7.5 R 5/10*	12	0.9	0.2	12	1.1	0.5	11	0.9	0.5				35	1.8	0.7
7.5 R 6/10*	18	1.2	0.4	10	1.2	0.4	16	1.0	0.4				23	1.6	0.5
10 R 6/8 *#	10	0.8	0.2	11	1.3	0.4	15	1.2	0.4	9	0.9	0.5	47	1.6	0.7
10 R 4/10*	12	1.4	0.6	7	0.9	0.4	7	0.7	0.4				80	1.5	0.6
10 R 6/10*	22	1.1	0.5	16	0.6	0.4	19	1.0	0.6				74	1.7	0.7
Mean 7 colors (*}		1.0			1.2			1.1						1.7	
Mean, 4 colors (#)					1.3			1.2			1.2			1.7	
Mean, 3 colors (*#)		0.8			1.4			1.3			1.2			1.7	

Effect of size: dummies, life rafts

Several runs were made with realistic targets: standard life rafts and man-size dummies. Three spheres were tested at the same time for comparison. The results are shown in Table VII and Figure 8. In general, it can be seen that the larger the target, the greater the detection distance.

Table VII. Air to water day sighting distances at 700 feet altitude, over 15 miles visibility, and cross sun, of various targets.

Target	Predominant color	Largest dimension	N Obs.	Detection distance in miles		Percent missed
				M	σ	
Large raft	Life Boat Yellow	144"	36	2.3	0.7	0
Medium raft	Life Boat Yellow	110"	36	2.3	0.7	0
Small raft	Life Boat Yellow	64"	36	1.!	0.5	8
Sphere	White	34"	18	1.8	0.8	6
Sphere	du Pont 6478	34"	18	1.7	0.5	0
Sphere	Life Boat Yellow	34"	18	1.7	0.4	0
Dummy	Gold Helmet	16"	18	0.7	0.4	17
Dummy	White Helmet	16"	18		0.1	44

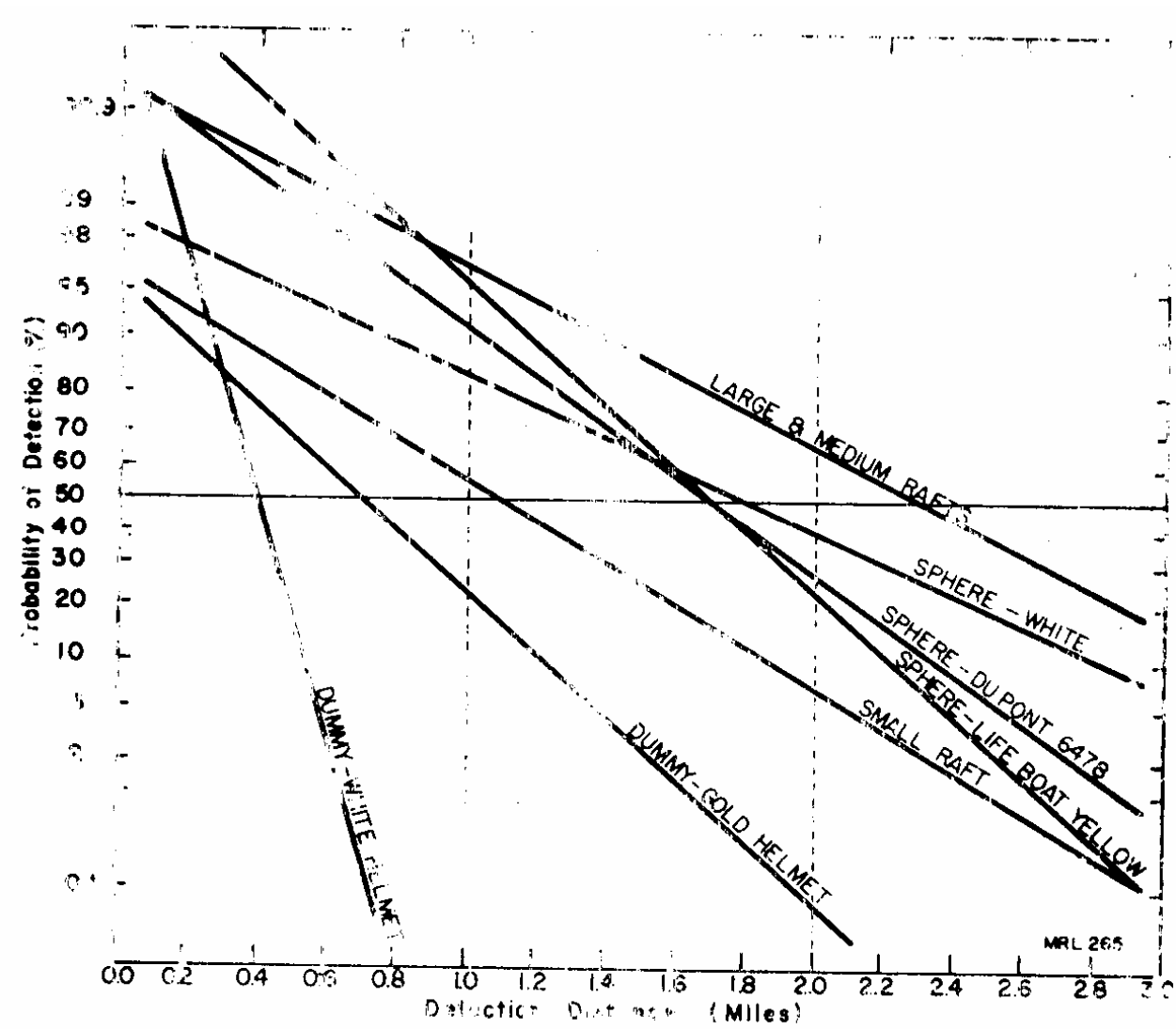

Figure 8.-- Air-to-water sighting distances from cumulative observations -- at 700 feet altitude, over 15 miles visibility, and cross-sun, of varying targets.

Analysis of color reports

Complete color reports were available for relatively few runs. The most complete data obtained are summarized in Table VIII, where the percent of times that each target was called each specific color name is tabulated. "Initial" refers to the subjective appearance of the target when it was first sighted, and "Final;" refers to the color re-ported last for the target - the color noted as the plane flew directly over the target.

Table VIII shows that some colors appeared as their true color (i.e.,final color reported) fairly consistently at the original detection distance, while other colors shifted in appearance with distance. Some targets were very frequently seen as achromatic (black, white, or gray) when first sighted.

Table IX contains the mean detection times for the color re-ports listed in Table VIII. The distance at which the initial report was made is the mean detection distance for the specific trials tabulated. The second column gives mean distances at which definite chromatic reports were made, i.e. the target was named as colored rather than achromatic. In the third column are the mean distances at which the final, or true, colors were reported.

The differences between the means in the first two columns rep-resent the loss in detection distance due to the fact that the targets often appeared achromatic at first sighting. Similarly, the difference between the first and last columns represents that distance travelled before a

target is seen in its true color.

Table VIII. Percent of times each target was reported as a certain color. Air to water sightings at 700 feet altitude, over 15 miles visibility, and cross sun, of spheres 34 inches in diameter colored as indicated. For each target, the per-cents for the most commonly reported colors are circled.

			Color reported									
Color of sphere	N Obs.	Report	Brilliant red	Orange-red	Orange	Pink	Yellow	Yellow-green	Black or Gray	White	Other	No report
du Pont 6478	105	Initial	72	0	3	0	0	0	18	0	1	6
		Final	88	1	6	0	0	0	0	0	3	3
7.5 R 7/7	28	Initial	4	4	25	21	7	0	0	32	0	7
		Final	0	0	36	64	0	0	0	0	0	0
7.5 R 4/8	36	Initial	17	42	17	0	0	0	22	0	3	0
		Final	22	53	22	0	0	0	0	0	3	0
du Pont 5546	107	Initial	10	58	9	0	0	0	18	0	5	0
		Final	13	67	14	0	0	0	0	0	6	0
10 R 6/10	52	Initial	0	0	52	15	0	0	17	2	2	12
		Final	0	0	63	25	0	0	0	0	4	8
10 R 7/8	98	Initial	[illegible]	0	8	62	15	0	3	5	0	0
		Final	0	0	11	76	13	0	0	0	0	0
du Pont 24534	39	Initial	0	3	8	0	5	28	15	38	3	0
		Final	10	8	10	0	33	38	0	0	0	0
Life Boat Yellow	87	Initial	3	2	0	0	70	0	9	14	1	0
		Final	0	0	0	0	100	0	0	0	0	0
White	72	Initial	0	0	0	0	0	0	1	99	0	0
		Final	0	0	0	0	0	0	0	100	0	0
Fire Orange	24	Initial	0	67	0	8	0	0	0	0	17	8
		Final	0	67	0	0	0	0	0	0	21	12
Arc Yellow	24	Initial	0	0	96	0	0	0	0	4	0	0
		Final	0	0	100	0	0	0	0	0	0	0
Neon Red	24	Initial	88	8	0	0	0	0	0	0	0	4
		Final	88	8	0	0	0	[illegible]	[illegible]	0	0	4
Saturn Yellow	24	Initial	0	0	0	0	33	[illegible]	0	67	0	0
		Final	0	0	0	0	100	[illegible]	0	0	0	0

Table IX. Mean distances at which colors of targets were reported. Air to water day sightings at 700 feet altitude, over 15 miles visibility, and cross sun, of spheres 34 inches in diameter, colored as indicated.

Color of sphere	Mean detection distance in miles		
	Initial report made	First "color" reported	Final "color" reported
du Pont 6478	1.7	1.6	1.6
7.5 R 7/7	1.8	*	1.4
7.5 R 4/8	1.6	*	1.4
du Pont 5546	1.4	1.3	1.3
10 R 6/10	1.7	*	1.5
10 R 7/ 8	1.6	*	1.5
du Pont 24534	2.2	1.6	1.6
Life Boat Yellow	2.0	1.8	1.7
Fire Orange	2.3	2.3	2.2
Are Yellow	2.6	2.5	2.5
Neon Red	1.4	1.4	1.4
Saturn Yellow	2.0	1.4	1.4

* Insufficient data

DISCUSSION

Notes on interpretation

Mean detection distances appearing on different tables are not always comparable, because they were obtained under somewhat dif-ferent conditions. The significance of means should not be expected to correspond from table to table because of different selections of tar-gets.

The large standard deviations indicate the great amount of vari-ability in the measures. This variability serves to obscure differences among colors which might have been detected under laboratory condi-tions.

Fluorescents

The superiority of the fluorescent paints is shown in Table V and Figure 6. Two of the paints, Fire Orange and Arc Yellow, present exceedingly high means. Saturn Yellow is also superior. Neon Red although more detectable than du Pont 6478, is well below the other fluorescents, and probably would not have been detected at greater dis-tances than the outstanding ordinary paints, du Pont 24534 and White, if it had been tested with them.

Targets completely missed

In spite of the fact that the plane passed directly over the tar-get on each run, some targets remained undetected. If the observing conditions were standard and the observer alert, a target completely missed was recorded as having a detection time of 0 seconds (0 miles). The occurence of such misses is reflected in the means, and the actual percentage of complete misses is tabulated in the last columns of Tables III, IV, V and VII. Although in general these percentages are not large, they show that a perfect detection record is seldom obtained. Because of the variability in the percentages from experiment to ex-

periment, it is difficult to draw conclusions regarding the relative per-cent of misses for specific colors. Two outstanding results, however, can be cited: (1) the small percent of misses for the fluorescent paints; and (2) the very high percent of misses for the dummies, particularly for the dummy with the white helmet, which was actually completely un-detected 44 percent of the time.

The question arises whether differences in the percent of misses could account for the differences in the means for specific targets. It was found that means calculated on the basis of only positive detection distances (that is, with cases where distance = 0 excluded) showed the same relative standings of the individual targets.

Characteristics of detectable targets

In addition to the fluorescents, colors which proved maximally detectable in one or more of the experiments were: du Pont 6478, du Pont 24534, Life Boat Yellow, and White. These colors, as is shown by the specifications in Table I and Figure 1, have little in common. The superior colors include the extremes in all dimensions of color differ-ence: in hue they range from red to yellow to white; in saturation, from zero to maximum; in brightness, from the lowest value level (with the exception of Black) to the highest.

It is immediately evident that hue alone is not the determining factor. Brightness and saturation, however, offer some clues. Figure 9 is a plot of all the colors giving their brightness (Y) and excitation pur-ity (which appears to be more meaningful in this situation than Munsell Chroma). A vertical line divides the graph into high and low saturation sections; and a horizontal line separates high from low brightness.

All 10 colors appearing in the high saturation section

are above average in detectability, while 9 of the 12 colors of low saturation are below average. All 5 high brightness colors are above average, but so are 8 of the 17 low brightness colors. By using a two-dimensional cut-

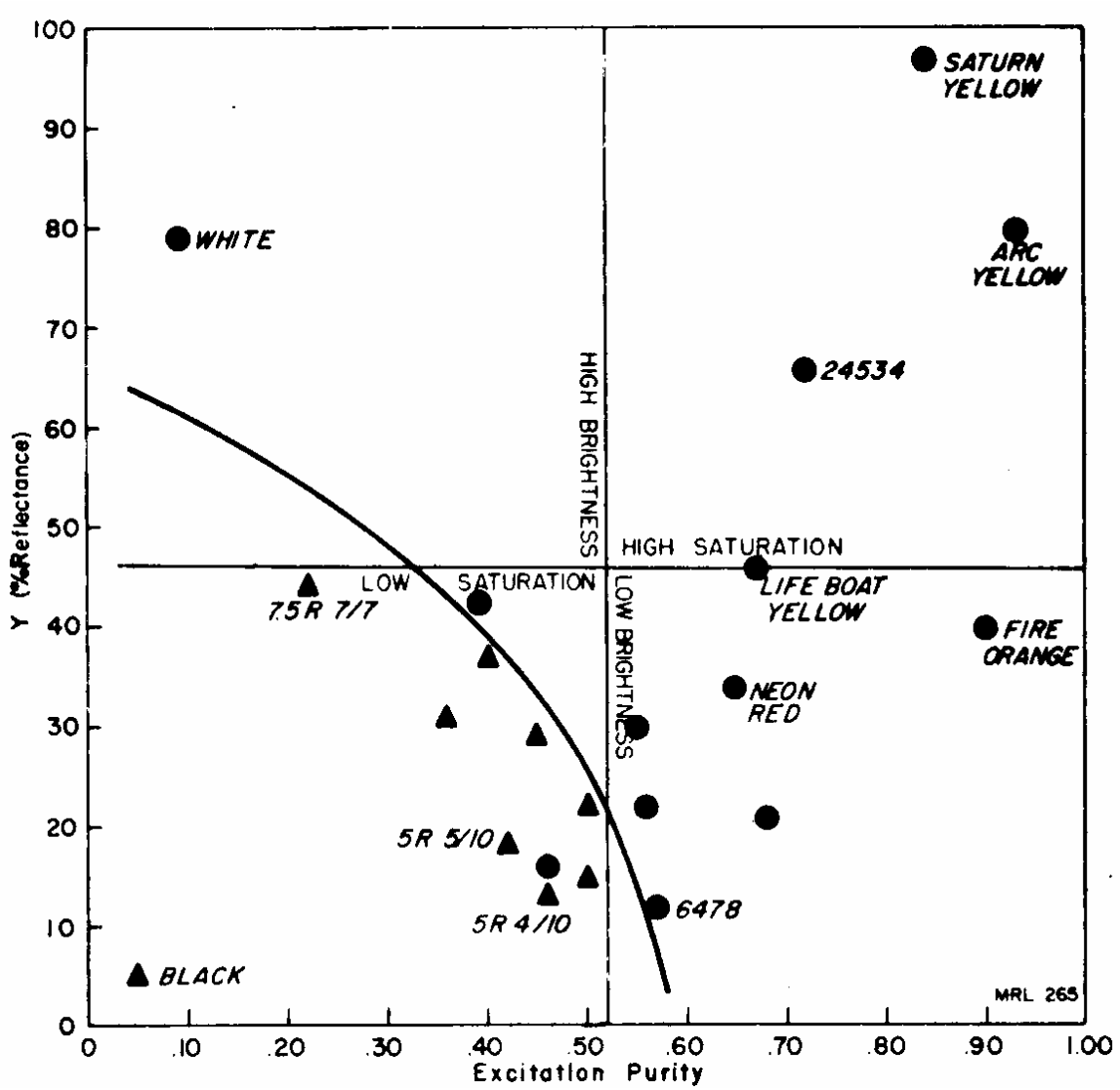

Figure 9. -Brightness (Y) and excitation purity of all colors tested.

Colors above the group mean in detection distance are shown as circles; colors below the mean as triangles. Colors of particular interest are labelled by name or number: those whose means are significantly above or below average (from table III); colors superior in other tests (fluorescents, Life Boat Yellow, White); and inferior colors (Black).

off, all 11 colors of high brightness or high saturation are above average 9 of 11 low brightness and low saturation are below average. The curved line indicates limits which would classify all but one case (which was not significant in Table III).

Thus it appears that both high brightness and high saturation contribute to high detectability, with high saturation alone predicting superior detectability for all outstanding colors except the very high brightness White. If background conditions could have been specified and kept constant, it might be possible to correlate detectability with the amount of total contrast--contributed by both chromatic and achro-matic contrast. (MacAdam (7) has demonstrated the meaningfulness of such calculations under certain conditions.)

Color reports

Three colors, 7.5 R 7/7, du Pont 24534, and Saturn Yellow (fluorescent) appeared white a large percentage of the time at maximum detection distances. In addition, du Pont 24534 was often reported as yellow-green rather than true yellow, even at short distances. As a matter of fact, almost every target was originally reported as black, white, or gray on a considerable number of trials. None of the chro-matic targets were reported as achromatic at minimum distances. Table IX shows the effect that color changes could have on detection distances. If an observer were looking for only colored targets, for example, he would report du Pont 24534 only 1.6 miles from the target, while actually he could have spotted the same target, as white, at 2.2 miles.

White as a target color

It has been shown that White is detectable at greater search distances than some other colors, and its superiority

has been attri-buted to its very high reflectance. However, while White yielded a significantly larger percentage of sightings at far distances, it also

yielded many short-distance reports; for example, at search distances of less than 0.4 mile it is no more detectable than colored targets.

In considering the use of white as a target color, other factors must be considered. It is highly probable that under operational condi-tions, white targets would not be closely tracked, as they would be mis-taken for white-caps, sea-gulls, and flotsam. Such interpretations would be most common if the target were small. Note, for example, the very large number of complete misses (44%) for the dummy with a white helmet. At a distance of one hah mile, this target was; spotted only about 20 percent of the time.

Yellow as a target color

Although du Pont 24534, Saturn Yellow (fluorescent) and (oc-casionally) Life Boat Yellow were highly detectable targets, Tables VIII and IX show that they were often reported as achromatic on first sight-ing. Therefore, at long search distances, they must be treated as white targets, and the considerations outlined above must apply.

Observer attitude -- instructions

Three alternative "mental sets" regarding the color of the tar-get are possible in air-sea rescue operations. From the available data, it is possible to predict somewhat the effects of different instructions on detection distances.

1. The observer may be set to search for only targets of a specific color, then all air-sea rescue gear which is not uniformly o£ this color may be overlooked by the observer. Also, a target which changes its appearance with distance is not likely to be detected. See Table VIII.

2. The observer may be set to search for colored targets he will be on the alert for red, yellow, even green targets, but will not track black or white objects. In this

case, he will also overlook colored targets which appear achromatic at original search distances. Tables

VIII and IX show the targets which would yield the greatest losses under these conditions.

3. The observer may be set to track any object, whether colored or achromatic: White targets assume their position of superiority under these conditions, but the gain may be cancelled by the time and attention wasted in tracking inappropriate targets such as flotsam, buoys, and birds, as discussed above.

Effect of atmospheric visibility

The data in Table VI show little consistency, either for indivi-dual targets or for group means. Detection distance does not seem to be a function of atmospheric visibility, although the means for 3 miles are generally lower, and those for over 15 miles are generally higher, than the average. It is possible that the variability in these data may be due to the small N's involved, inaccuracies in estimating the visibili-ties, or other conditions not properly controlled.

Effect of size

In order to facilitate more precise comparisons of the data in Table VII, Table X has been prepared. This gives the approximate visual angles of the various targets at specific distances, and at the mean detection distance for each target. These calculations are based on the length and width dimensions for the rafts, as given in Table II; for the dummies, calculations were based on the length across the jacket and the diameter of the helmet; for the spheres, only the diameter was used. The altitude of the plane was not used in estimating these visual angles. Assuming a perfectly horizontal position of the target, only a cross-sectional view (length or width x height of tube) would be ob-tained at most detection distances. In practice, the visual angles

were usually smaller than those listed here, due to the target's being splashed by water or partially hidden in a trough. In some cases, larger angles

could have been obtained: if the target were viewed along its diagonal, or from a more nearly perpendicular position (for example, at close range or as it is tossed on the surface).

Table X. Approximate visual angles of targets at specified distances. The first figure of a pair is based on the smaller dimension; the second figure is based on the maximum dimension (see text).

	Visual angle in minutes of arc			
Target	at 1 mile	at 2 miles	at 3 miles	at mean detection distance
Large raft	3.2 - 6.8	1.6 - 3.4	1.1 - 2.3	1.4 - 3.0
Medium raft	2.8 - 5.2	1.4 - 2.6	0.9 - 1.7	1.2 - 2.3
Small raft	1.7 - 3.0	0.8 - 1.5	0 6 - 1.0	1.5 - 2.7
Sphere	1.6	0.8	0.5	0.9
Dummy	0.4 - 0.7	0.2 - 0.4	0,1 - 0.3	0.6 - 1.1

Table VII shows that detection distance does not increase con-tinuously with target size as would be expected. Furthermore a smooth function is not obtained by plotting the percent of targets detected at 1, 2 or 3 miles (Figure 8) against the visual angle at these distances (Table X). It is necessary to examine the target specifications closely to discover possible reasons for certain reversals. The fact that the large and medium rafts have identical mean detection distances can perhaps, be explained by the addition, on some runs (unfortunately un-recorded), of a reddish fluorescent tarpaulin. As the raft tossed on the water the bright color would become visible, thus increasing the de- tectability of

the target over that of the standard Life Boat Yellow. The superiority of the spheres can probably be attributed to their relative

constancy of angle; while the poor record of the small raft is probably due to its small height, which may have allowed portions of the target to be obscured by water much of the time.

The visual angles listed in Table X are surprisingly small. Al-though by no means approaching the limit of visual acuity, these values compare favorably with data obtained under much better experimental conditions. It is noteworthy that the smallest visual angle ever per-ceived in the course of these experiments was 26 seconds (0.43 min- utes), -- for a fluorescent sphere at a distance of over four miles (cal-culations based on the diameter). Many other targets of only slightly larger visual angles were detected.

If visual acuity were the limiting factor in determining detec-tion distances, one would expect a constant level of detection for con-stant visual angle -- that is, at their mean detection distances, all tar-gets should have the same visual angle. Table X shows that this con-stancy is not attained. Some possible explanations for the irregulari-ties have been outlined above. In addition, there seems to be a tendency for small targets to be detected at smaller visual angles than large targets.

It should also be noted that the dummies were detected only at very close range --an average of about a half mile, and an absolute maximum of one and a half miles. These figures demonstrate the im-probability of discovering a man lost at sea with no equipment larger than a life jacket and helmet.

Test vs operational conditions

The conditions of the field test were much more favorable to target detection that would ever be found in an actual rescue operation.

First, the observers were familiar with the shape and size of the tar-gets; second, they were notified at the beginning of each run and there-fore needed to maintain a high level of alertness for only a few seconds; and third, they knew that the target would appear dead ahead on the course. Other favorable factors included practice, constant plane speed, and uniform weather conditions. The data reported apply only to calm seas and fair weather.

Application to air-sea rescue procedures

The data obtained in this study are applicable to the preparation of air-sea rescue instructions and in the indoctrination of search and rescue teams. Since the conditions under which these data were ob- tained were most favorable they can be used as a ceiling for the cal-culations of probability of detection. The considerations discussed in the paragraphs under "Observers attitude" above, should be incorpora- ted.

CONCLUSIONS

1. Fluorescent paints, particularly the yellow-orange and red orange, are superior in detectability to ordinary paints.

2. Of the ordinary paints tested, the most conspicuous colors were those of high saturation and/or brightness.

BIBLIOGRAPHY

1. F.L. Malone, M.S. Sexton and D. Farnsworth, The detectability of yellows, yellow-reds, and reds, in air-sea rescue, MRL No. 182 (1951).
2. M.S. Sexton, F.L. Malone and D. Farnsworth, The relative detecta-bility of red-purples, reda, and yellow-reds, in air-sea rescue, MRL No. 195 (1952).
3. F.L. Malone, A preliminary field evaluation of the relative detecta-bility of colors for air-sea rescue, MRL No. 237 (1953).
4. D.G.V. Whittingham and W.H.B. Ellis, Conspicuity of coloured fluo-rescent fabrics for air/sea rescue, Flying Personnel Research Com-mittee, F.P.R.C. 844, R.A.F. Institute of Aviation Medicine (1953).
5. H. Hartridge, Colours and How We See Them (G. Bell and Sons Ltd, London, 1949) p. 83.
6. W. E. Creedon, Comparative visibility of colored life jackets, Report No. 1 of Project No. CGTD-3-22-29, Testing and Development Div-ision, Coast Guard Headquarters, (September, 1948).
7. Eastman Kodak Company, Influence of color contrast on visual acui- ty, NDRC Contract No. OEMsr-1070, Section 16.3-3, November 1, 1944.