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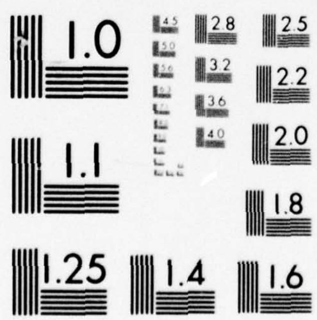

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Ship Acquisition on Television: Three Laboratory Experiments

by
Hubert O. Whitehurst
Systems Development Department

AUGUST 1977

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

F. H. M. Kinley, Capt., USN . . . . Commander

R. M. Hillyer . . . . Technical Director (Acting)

FOREWORD

Three laboratory experiments on the ranges at which ships could be identified, recognized, and their orientation (direction of movement) determined were conducted at the Naval Weapons Center (NWC), China Lake, Calif., between August 1975 and April 1977. This work was performed for the Naval Air Systems Command to determine the range at which ship images on television can be classified as conditions vary. The first and second experiments were supported by AirTask No. A3400000/008B/5F55-525-402. The third experiment was supported by AirTask No. A03A3400/008B/7F55-525-000. All were under the direction of CDR Paul Chatelier, AIR-340F.

This report has been reviewed for technical accuracy by Ronald A. Erickson.

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(U) *Ship Acquisition on Television: Three Laboratory Experiments*, by Hubert O. Whitehurst. China Lake, Calif., Naval Weapons Center, August 1977. 86 pp. (NWC TP 5978, publication UNCLASSIFIED.)

(U) This report consists of a summary of three laboratory experiments on ship acquisition on television, plus information on how to apply the prediction equations that are included. Examples are given, along with limitations on the conditions under which the equations can be used. Some comparisons of the results of these experiments with the results of similar studies are also included.

(U) Experiment I was conducted to determine the relative importance of seven factors to ship identification on television. Targets had the strongest effect, followed by subjects, light position, ship wake, ship aspect angle, slant range, and camera depression angle. Ranges at which a ship could be recognized as a merchant ship or combatant under varying light azimuth, light elevation, ship aspect angle, and ship wake size conditions were determined in Experiment II. Multiple regression analysis yielded an equation to estimate recognition ranges. Experiment III was conducted to determine the ranges at which ships can be recognized and their orientation (direction of movement) determined. The factors of primary interest were target-to-background contrast, contrast sign, and ship aspect angle. Multiple regression analyses were performed and four prediction equations are included.

INTRODUCTION

Weapons that employ electro-optical imaging systems are an important and effective element of the armed forces arsenal. The Navy's requirement for such air-to-surface weapons, usable against enemy ships and other targets, is obvious. These weapons can be employed most effectively if all the factors that affect ship target acquisition on television can be isolated. The important factors can then be related to each other quantitatively to provide some index for target acquisition prediction under various conditions.

Three laboratory experiments were conducted to isolate the important factors and obtain prediction equations. These experiments are included as Appendix A of this report. Experiment I was conducted to separate factors that have relatively strong effects on ship identification performance on television from those having weaker effects. Seven factors plus their interactions were rank-ordered according to the variability in the data accounted for by each. Factors found to have a strong effect were included in Experiment II, which was conducted to arrive at an equation that would provide an estimate of ship recognition range as a function of four environmental factors. A full factorial design was used in Experiment III to estimate the quantitative relationship that exists between three environmental factors and the range at which observers can (1) differentiate between merchant and combatant ships, and (2) determine the ship's direction of movement.

The main body of the report consists of a summary of the three methodologies plus the more important findings, along with details on how the results can be applied and comparisons with related research findings.

SUMMARY OF METHODOLOGIES

SUBJECTS

Eight employees of the Naval Weapons Center (NWC), China Lake, Calif., participated in the first experiment, while six served in both the second and third experiments. All subjects had corrected or uncorrected near and far binocular visual acuity of 20/20 or better.

DESIGNS

Completely crossed factorial designs were employed in the first and third experiments. The design for Experiment II was one of the within-subjects, response surface methodology central-composite varieties described by Clark and Williges.[1] The independent and dependent variables for each experiment are given in Table 1.

TABLE 1. Independent and Dependent Variables for Each Experiment.

Variables					
Independent[a]			Dependent		
Experiment No.			Experiment No.		
I	II	III	I	II	III
Ship targets	Ship targets	Ship targets	Percent correct identifications	Slant range at recognition	Slant range at recognition
Aspect angle off bow	Aspect angle off bow	Aspect angle off bow	The subject had to indicate which one of four ships was shown on the TV monitor (see p. 31)	Percent correct recognitions	Percent correct recognitions "recognition" was combatant or merchant (same as Experiment II)
Slant range	Light azimuth	Target/ background contrast		The subject had to indicate only whether the ship being shown was combatant or merchant from four ships, two of each type (see p. 39)	
Light position	Light elevation	Contrast sign			Slant range for direction of movement (orientation)
Camera depression angle	Ship wake				
Ship wake					Percent correct orientations

[a] Subjects were treated as independent variables in the analyses of Experiments I and III.

APPARATUS

The electronic equipment used in all three experiments included a television camera with a 525-line rate and 2:1 interlace, a 2-inch videotape recorder, a television monitor, an oscilloscope, oscillator, amplifier, and a speaker. A zoom lens was used to simulate a system with a 5.7-degree horizontal field of view (HFOV).

---

[1] C. Clark and R. C. Williges, "Response Surface Methodology Central-Composite Design Modifications for Human Performance Research," *Hum Factors*, Vol. 15 (1973), pp. 295–310.

The targets used in each of the experiments were 1:1250 scale-model waterline ships. The background for the first and second experiments consisted of several shades of gray paint applied to a square surface to simulate a large body of water. Two backgrounds were used in Experiment III; one was darker than the ships and simulated water, and the other was lighter, to simulate the horizon. The target and background were lighted with a lamp containing a single 3200 K, 1,000-watt bulb in the first two experiments. Two such lamps, plus additional lighting for shadow fill, were used in Experiment III.

Other apparatus common to each experiment included reference cards with photographs of the ships, a vision tester, and a subject room partially surfaced with acoustic tile.

PROCEDURES

The ships were videotaped under each set of conditions with the zoom lens calibrated for fast changes in the simulated slant ranges. For Experiments II and III, videotaping was done at four discrete ranges per condition. The first trial was recorded at a simulated distant range, e.g., 36 kilometers. The next three trials for a condition were recorded at progressively closer ranges, usually at 8-kilometer intervals. A tone was also recorded near the end of each trial to signal the subject to respond immediately.

For all three experiments, each subject was screened to ensure 20/20 or better visual acuity. Following this, the subject was seated at a monitor and recorded instructions were played. The subject then placed his forehead against a pad, which fixed the head height and distance from the monitor, and videotaped practice trials were presented. This was followed by a short break; then the data trials were presented. Some of the methodological differences among the three experiments are given in Table 2.

TABLE 2. Some Methodological Differences Among the Three Experiments.

Methodological item	Experiment No.		
	I	II	III
Distance between subject's head and monitor, cm	38	38	71
How subject responded	Marked scoresheet	Marked scoresheet	Pushed buttons
Number of practice trials	64	100	72
Number of data trials	128	480	288
Trials per block	32	160	48
Time per trial, sec	15	12	16
Time from start of trial until tone sounds, sec	10	9	14

RESULTS

SUMMARY

Experiment I

The objective of this experiment was to rank-order the independent variables, including subjects, based on the contribution of each to the total variability of the data. The important factors were to be included in the next experiment. The sum of squares for a factor, plus its second- and third-order interactions divided by the total sum of squares and then converted to percent, gave the index used to estimate a factor's strength of effect. This index was then used to rank-order the factors (Table 3). The factor plus interactions that ranked number one (targets) had the strongest effect, while the factor plus interactions that ranked seventh (depression angle) had the weakest effect.

TABLE 3. Rank Order of Factors Based on Percent of Total Sum of Squares Accounted for By Each Factor and Its Second- and Third-Order Interactions.

Factor	Sum of squares	Percent of total sum of squares	Rank order
Targets			
Main effect	10.58	19.02	1
Interactions	148.71		
Subjects			
Main effect	3.75	18.73	2
Interactions	153.16		
Light position			
Main effect	0.02	13.79	3
Interactions	115.46		
Wake			
Main effect	10.77	13.31	4
Interactions	100.70		
Aspect angle			
Main effect	14.77	12.95	5
Interactions	93.74		
Range			
Main effect	5.79	11.40	6
Interactions	89.72		
Depression angle			
Main effect	0.05	10.80	7
Interactions	90.46		
Total[a]	837.68	100.00	

[a] The actual total sum of squares is 274.55. The total used in this table is much larger since each interaction was counted more than once.

Neither depression angle nor slant range were included in Experiment II as independent variables. Depression angle was dropped and slant range became one of the dependent measures.

Experiment II

Observations were totalled over subjects and targets to compute the percent of the ships *recognized as a combatant or merchant ship* at each condition and simulated range. Figures 1, 2, 3, and 4 give the percent of the ship targets recognized as a function of slant range and one other factor. TV lines across the target are also given.

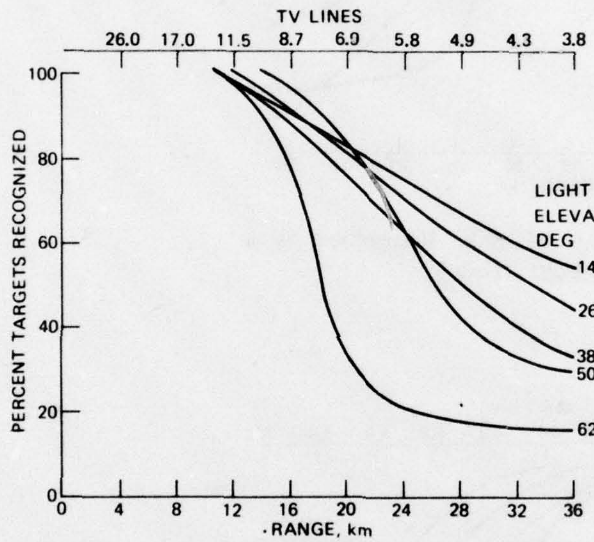

FIGURE 1. Probability of Ship Recognition as a Function of Range and Light Elevation.

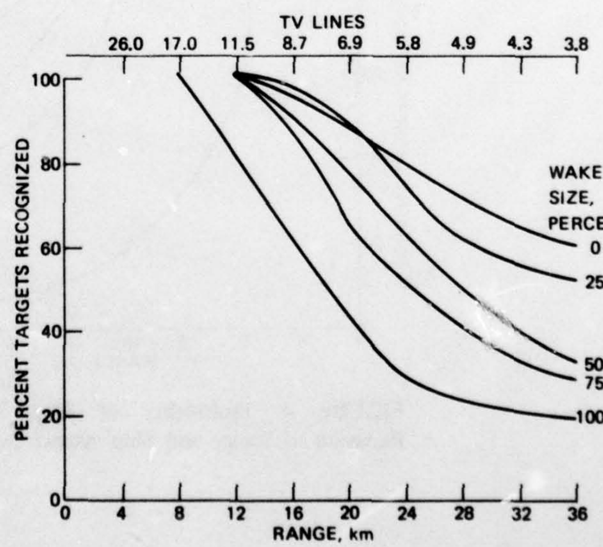

FIGURE 2. Probability of Ship Recognition as a Function of Range and Wake Size.

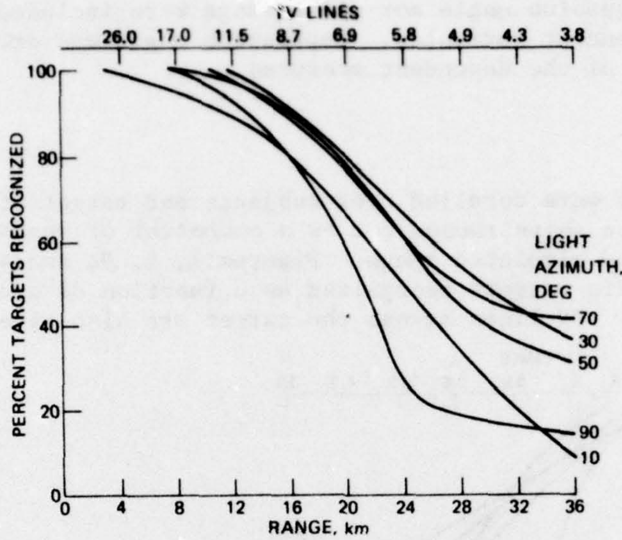

FIGURE 3. Probability of Ship Recognition as a Function of Range and Light Azimuth.

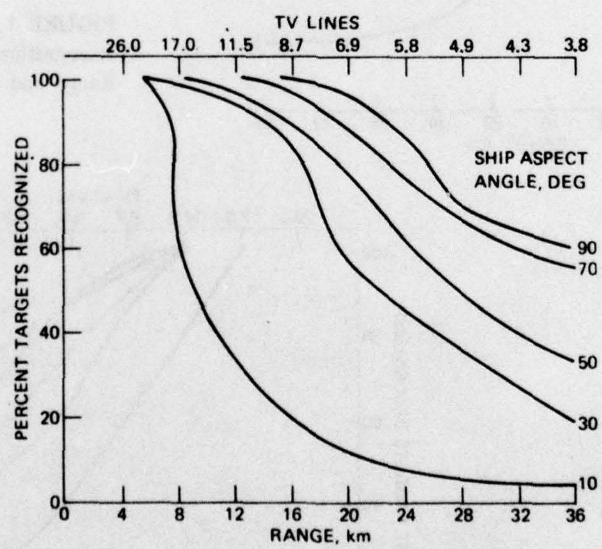

FIGURE 4. Probability of Ship Recognition as a Function of Range and Ship Aspect Angle.

The range at which five of the six subjects recognized the target under each condition was computed for use in multiple regression analyses. The data were further reduced by averaging across ships. The first analysis showed that light azimuth contributed almost nothing to the accuracy of the prediction equation, so the data were averaged across that factor and another analysis was conducted. The second analysis yielded the equation

$$\text{Recognition range} = -0.11(E) + 0.20(A) - 0.10(W) + 22.39 \qquad (1)$$

where

E = light elevation in degrees
A = ship aspect angle in degrees off the bow
W = ship wake size as a percent of the ship's width

as the best least-squares fit to the data. This equation accounted for 85% of the variance.

Experiment III

The data consisted of simulated ranges at which the ship was *recognized as a merchant or combatant ship,* and ranges at which the ship's direction of movement (orientation) was correctly determined. The observations were totalled over subjects and targets to compute the percent correct ship recognitions (Figure 5) and percent correct orientation responses (Figure 6). TV lines across the target are also given.

Figure 7 provides a direct comparison of positive and negative contrast conditions for the range at which five of the six subjects made correct recognition responses at each target-to-background (T/B) contrast and aspect angle condition. Orientation range was graphed over the same conditions (Figure 8).

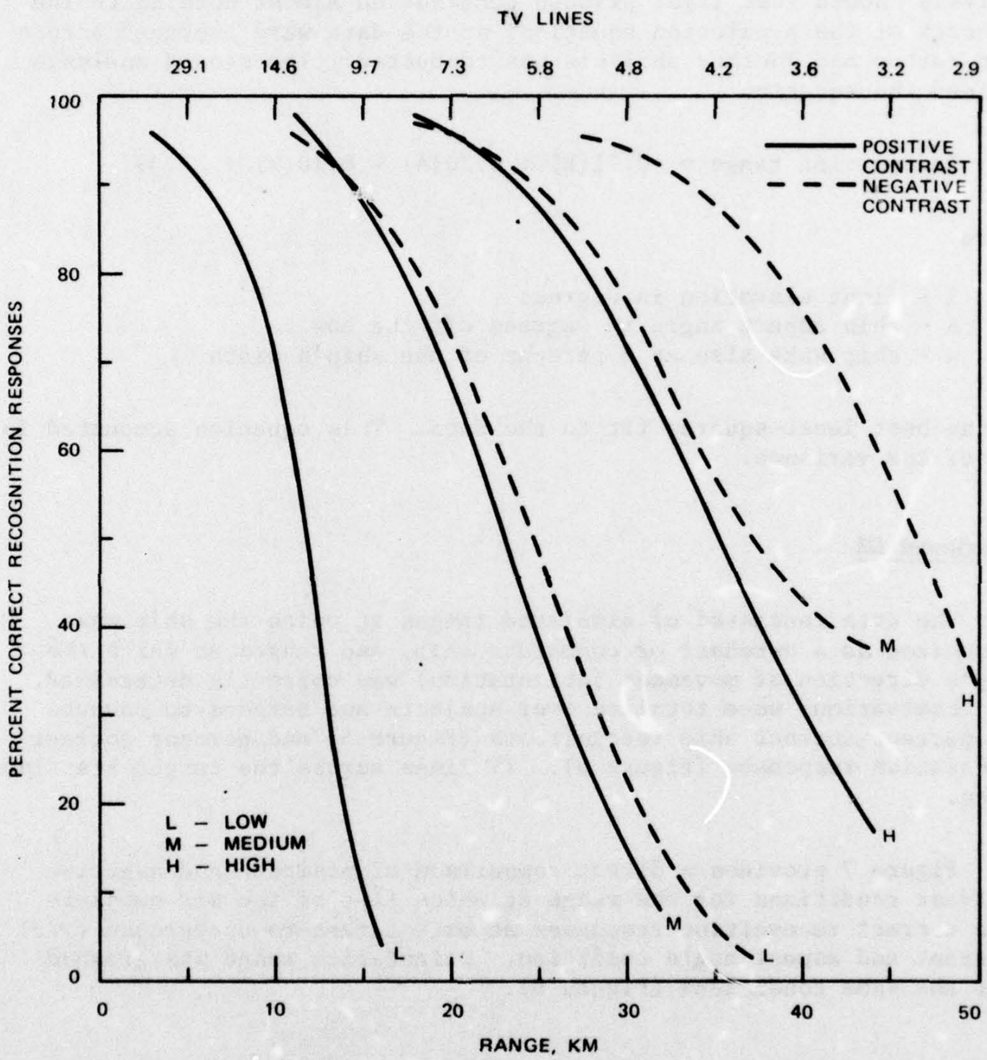

FIGURE 5. Probability of Ship Recognition as a Function of Range, T/B Contrast, and Contrast Sign With Aspect Angle 45 Degrees Off Ship's Bow.

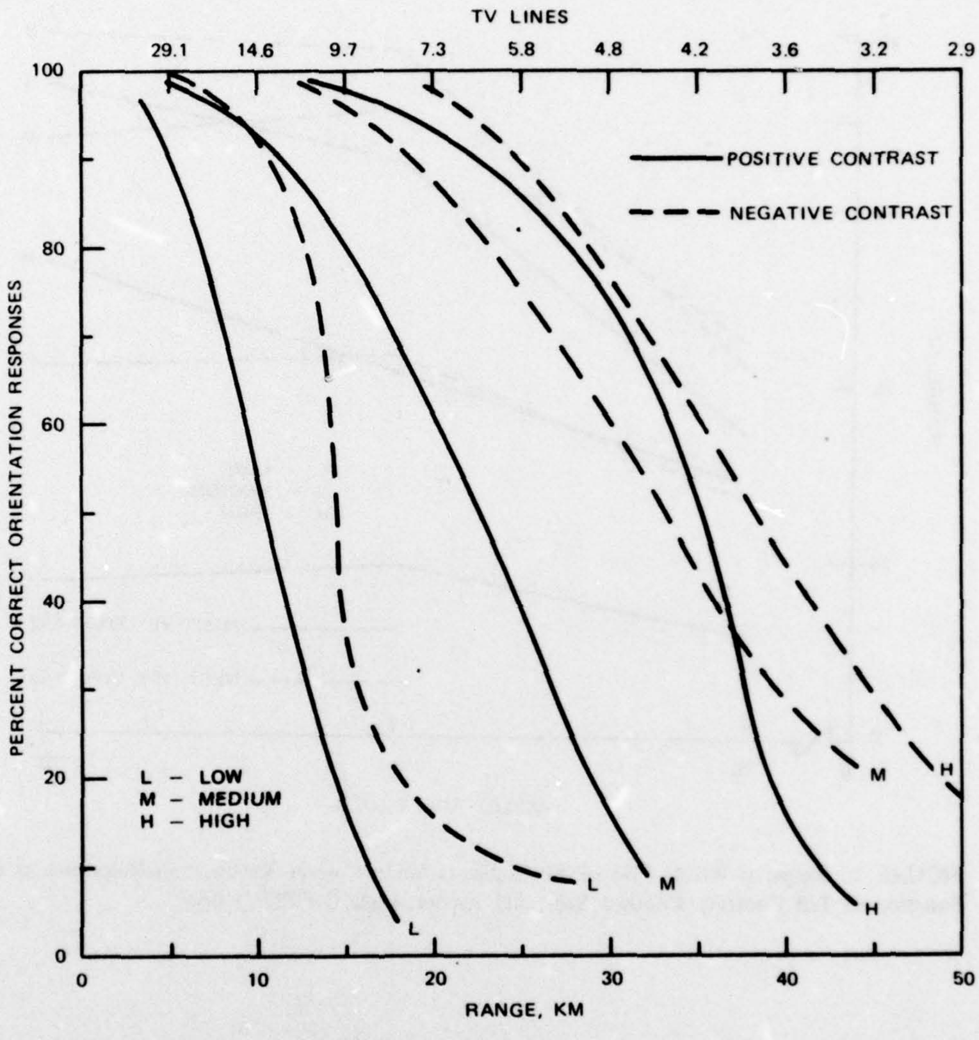

FIGURE 6. Probability of Determining Ship Direction of Movement as a Function of Range, T/B Contrast, and Contrast Sign With Aspect Angle 45 Degrees Off Ship's Bow.

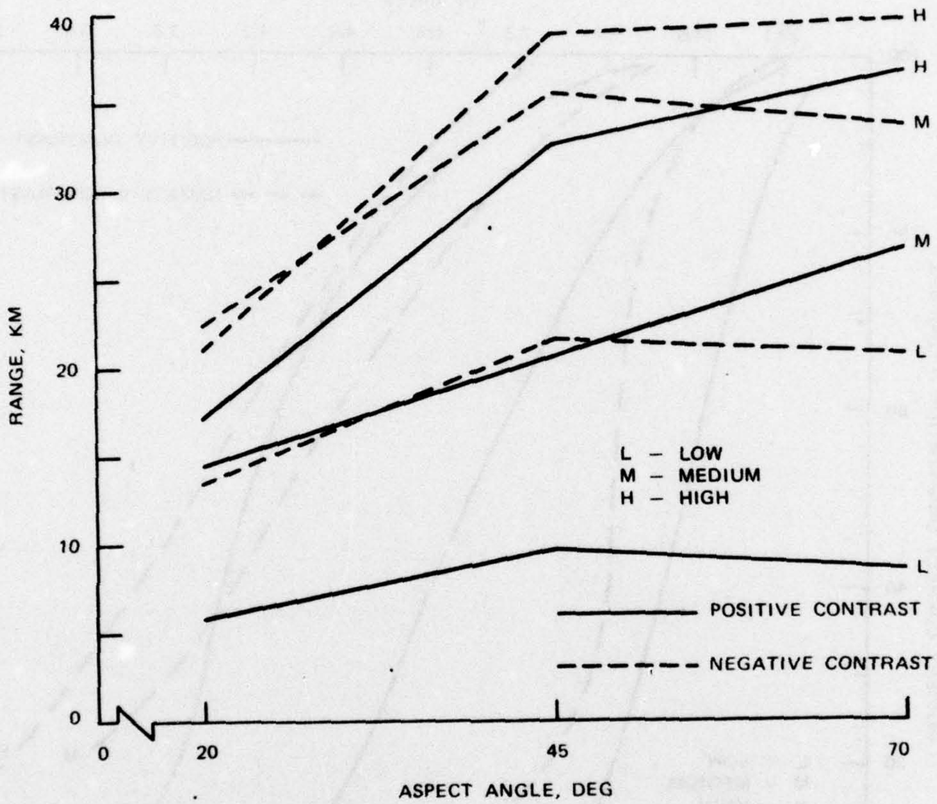

FIGURE 7. Range at Which Five of Six Subjects Made Correct Recognition Responses as a Function of T/B Contrast, Contrast Sign, and Aspect Angle Off Ship's Bow.

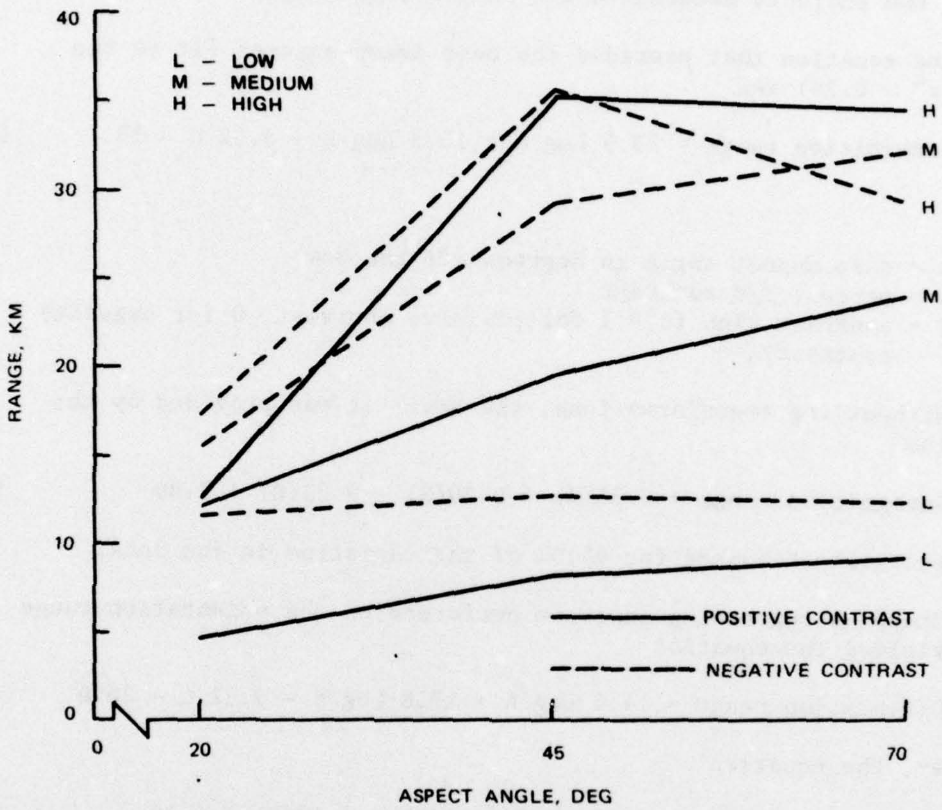

FIGURE 8. Range at Which Five of Six Subjects Made Correct Orientation Responses as a Function of T/B Contrast, Contrast Sign, and Aspect Angle Off Ship's Bow.

Stepwise regression analyses were conducted on the ranges at which five of the six subjects recognized the targets and the ranges at which 5/6 of the subjects determined the ship's orientation.

The equation that provided the best least-squares fit to the data ($r^2 = 0.74$) was

$$\text{Recognition range} = 23.5 \text{ Log A} + 15.5 \text{ Log B} - 8.32 \text{ C} - 33.1 \qquad (2)$$

where

A = ship aspect angle in degrees off the bow
B = percent T/B contrast
C = contrast sign (C = 1 for positive contrast, 0 for negative contrast).

Without log transformations, the best fit was provided by the equation

$$\text{Recognition range} = 0.25(A) + 0.20(B) - 9.22(C) + 7.80 \qquad (3)$$

This equation accounted for 66.5% of the variation in the data.

Stepwise regression analyses performed on the orientation range data yielded the equation

$$\text{Orientation range} = 14.4 \text{ Log A} + 17.8 \text{ Log B} - 3.32 \text{ C} - 26.0 \qquad (4)$$

However, the equation

$$\text{Orientation range} = 0.15(A) + 0.24(B) - 4.40(C) + 6.32 \qquad (5)$$

accounted for almost as much of the variation in the data ($r^2 = 43.5$ and 42.2%, respectively).

APPLICATIONS

Computing T/B Contrast

With the exception of Equation 1 (from Experiment II), it is necessary to have an estimate of the T/B contrast before the prediction equations can be used. Equation 1 can be used only if the visibility is unlimited and the T/B contrast is relatively high. The other equations can be used under various T/B contrast conditions.

Since atmospheric attenuation affects T/B contrast, some method is required for an observer to convert inherent T/B contrast to apparent T/B contrast, i.e., to estimate the extent to which the T/B contrast is reduced by particles in the atmosphere. Actual observer-to-target (or sensor) slant range and meteorological range (visibility), plus the inherent T/B contrast, are factors that must be known before apparent T/B contrast can be estimated. If these factors are known, Figure 9 can be used to compute apparent T/B contrast.

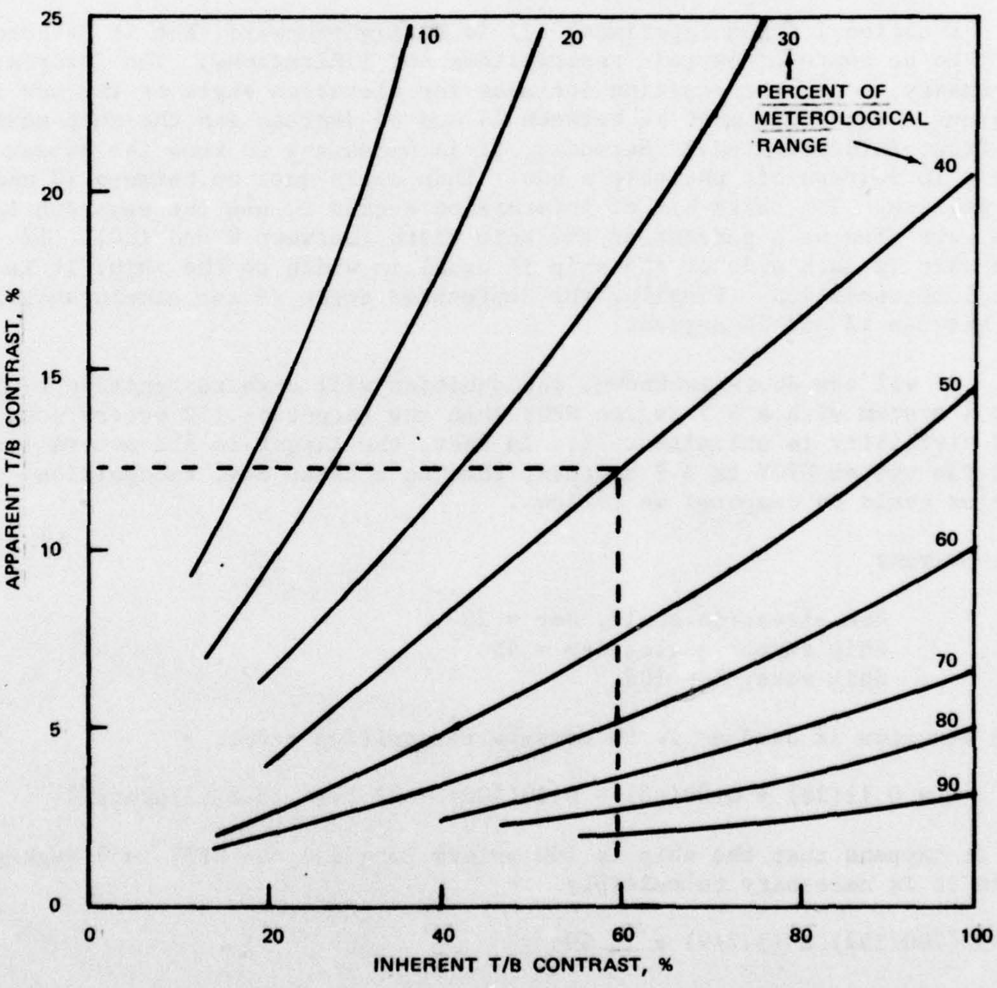

FIGURE 9. Relationship Between Inherent T/B Contrast and Apparent T/B Contrast for Several Observer-to-Target Ranges Given as a Percent of Meteorological Range.

It can be seen that if the inherent T/B contrast is 60% and the observer-to-target range is 40% of the meteorological range, then the apparent T/B contrast is about 12%. When the observer-to-target range is reduced to 30% of the meteorological range, the apparent T/B contrast becomes 18%. Decreases in observer-to-target range cause apparent T/B contrast to increase at an accelerated rate. More complete derivations are given in Appendix B.

Equation 1: Aspect, Wake, and Sun Angle

Equation 1 (from Experiment II) is straightforward, but it is necessary to be aware of certain restrictions and limitations. The information necessary to use the equation includes the elevation angle of the sun in degrees. The angle must be between 14 and 62 degrees and the ship must be front-/side-lighted.* Secondly, it is necessary to know the aspect angle in degrees off the ship's bow. This angle must be between 10 and 90 degrees. The third bit of information needed to use the equation is the wake size as a percent of the ship width (between 0 and 100). If the wake on each side of the ship is equal in width to the ship, it is the 100% condition. Finally, the depression angle of the camera should be between 12 and 24 degrees.

If all the above is known, the equation will give recognition ranges for a system with a 5.7-degree HFOV when the target is 152 meters long and visibility is unlimited. If, in fact, the target is 152 meters long and the system HFOV is 5.7 degrees, then on a clear day, recognition ranges could be computed as follows.

Given:

Sun elevation angle, deg = 20
Ship aspect angle, deg = 45
Ship wake, % = 100,

the equation is used as is to compute recognition range, R

$$R = 0.11(20) + 0.20(45) - 0.10(100) + 22.39 = 23.6 \text{ kilometers}$$

If it happens that the ship is 100 meters long and the HFOV is 9 degrees, then it is necessary to multiply

$$(100/152) \times (5.7/9) \times 23.59$$

to correct for differences in ship size and HFOV. The predicted range then becomes 9.8 kilometers.

---

* Over-the-shoulder lighting should probably be avoided because it gives three-dimensional forms a flat appearance while light coming in from the side (90 degrees with respect to the camera) may produce confusing shadows. Light azimuths of about 30 to 70 degrees would probably be optimal for positive contrast targets.

However, if the system HFOV is over about 15 degrees, tangents should be used, and the final equation for recognition range, R, is

$$R = [0.11E + 0.20A - 0.10W + 22.39]\left[\frac{SL}{152}\right]\left[\frac{0.05}{\tan\ (HFOV/2)}\right] \qquad (6)$$

where

R = combatant/merchant recognition, in kilometers
SL = the actual ship length, in meters
HFOV = the system's horizontal field of view, in degrees

Equation 2: Aspect and Contrast

Equation 2 (Experiment III) is for low-altitude approaches (less than 1-degree camera depression angle). It is necessary to compute logarithms to the base 10 and target-to-background contrast using the formula:

$$T/B\ \text{contrast} = B = [(L_t - L_b)/L_b] \times 100,$$

where

L_t = luminance of the target
L_b = luminance of the background.

To use this equation it is necessary to know: (1) the ship aspect angle in degrees off the bow, which must be between 20 and 70 degrees; (2) percent T/B contrast (between -75 and +100%); and (3) the contrast sign, positive (1) or negative (0). Contrast values that are less than -75% can be used by inserting 75 into the equation, and contrast values that are greater than 100% can be used by inserting 100 into the equation. The same thing that applied to Equation 6 with regard to ship length and HFOV is also true in this case. Therefore, the complete equation for recognition range, r, is

$$R = [23.5\ \text{Log}\ A + 15.5\ \text{Log}\ B - 8.32\ C - 33.1]\left(\frac{SL}{152}\right)\left(\frac{\tan\frac{5.7^\circ}{2}}{\tan\frac{HFOV}{2}}\right) \qquad (7)$$

Predicting Visibility Effects

The target-background contrast, B, is the contrast at the imaging system. The effects of atmospheric attenuation can be included by introducing the meteorological range, or visibility, V, and the contrast at the target (inherent contrast), C_o. The derivation of the equations and the modification to Equation 7 are given in Appendix B. With these additional terms, Equation 7 becomes

$$R = \frac{23.5 \text{ Log } A + 15.5 \text{ Log } C_o - 8.32\, C - 33.1}{\dfrac{3058 \tan \frac{HFOV}{2}}{SL} + \dfrac{26.33}{V}} \qquad (8)$$

where

A = ship aspect angle in degrees off the bow

C_o = inherent contrast of the ship, in percent

C = 1 if the contrast is positive and 0 if it is negative

SL = ship length in meters

HFOV = the horizontal field of view of the sensor system

V = visibility, in kilometers

R = range at which combatant can be differentiated from merchant ship, in kilometers.

Given the following situation:

Aspect angle (A) = 45 degrees
T/B contrast at the sensor (B) = 7.5%
Contrast sign (C) = positive
Ship length = 160 meters
System HFOV = 18 degrees,

the equation would be solved by first computing Log 45 and Log 7.5. Inserting the numbers into Equation 7 gives

$$R = (23.5(1.65) + 15.5(0.88) - 41.4)\ (160/152 \times \tan (5.7/2)/\tan (18/2)$$

which yields a recognition range of 3.6 kilometers. The effect of visibility on the above situation is shown in Figure 10, where an inherent contrast, C_o, of 7.5% was assumed.

Orientation

Equation 4, also from Experiment III, is the better of the two equations for predicting orientation ranges. The conditions under which the equation can be used are the same as those for Equation 7, i.e., low camera depression angle, ship aspect angle between 20 and 70 degrees, and so forth. Also, the same modifications must be made for various ship lengths and camera HFOVs; therefore, the final equation for predicting the range at which a ship's orientation can be determined is

$$O = [14.4 \text{ Log } A + 17.8 \text{ Log } B - 3.32\, C - 26.0]\left(\frac{SL}{152}\right)\left(\frac{\tan \frac{5.7°}{2}}{\tan \frac{HFOV}{2}}\right) \qquad (9)$$

where 0 is the range at which the direction of travel of the ship can be recognized.

As before, the effects of the atmosphere can be included to yield

$$0 = \frac{14.4 \text{ Log } A + 17.8 \text{ Log } C_o - 3.32\ C - 26.0}{\frac{3058 \tan \frac{HFOV}{2}}{SL} + \frac{30.2}{V}} \qquad (10)$$

The other two equations from Experiment III (Equation 3, which predicts recognition range, and Equation 5, which predicts orientation range) do not make use of log transformations and predict with less accuracy, although the difference in prediction accuracy between Equations 4 and 5 is small. These equations are used in the same manner as Equations 7 and 8; i.e., different ship lengths and camera HFOVs are accounted for the same way. The limits on the conditions under which they can be used are also the same.

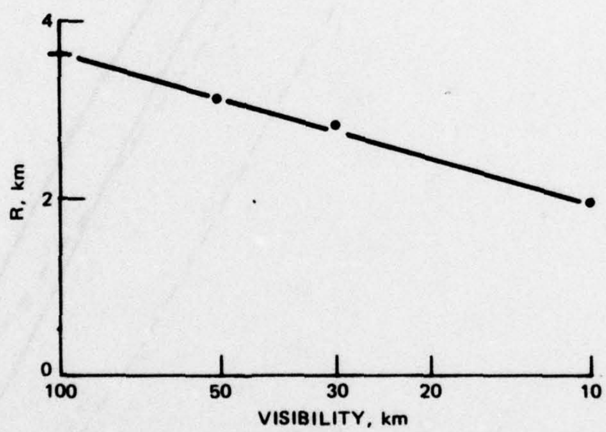

FIGURE 10. Effect of Visibility on Recognition Range.

COMPARISON OF RESULTS

Experiments II and III

It is worth while to compare some of the results of Experiment II and III since the targets were the same for both experiments and the television systems were very similar. Comparison of the curves for percent targets recognized at each range when the ship aspect angles are the same (Figure 11) should show the effects due to changes in the camera depression angle and/or ship wake differences between the two experiments.

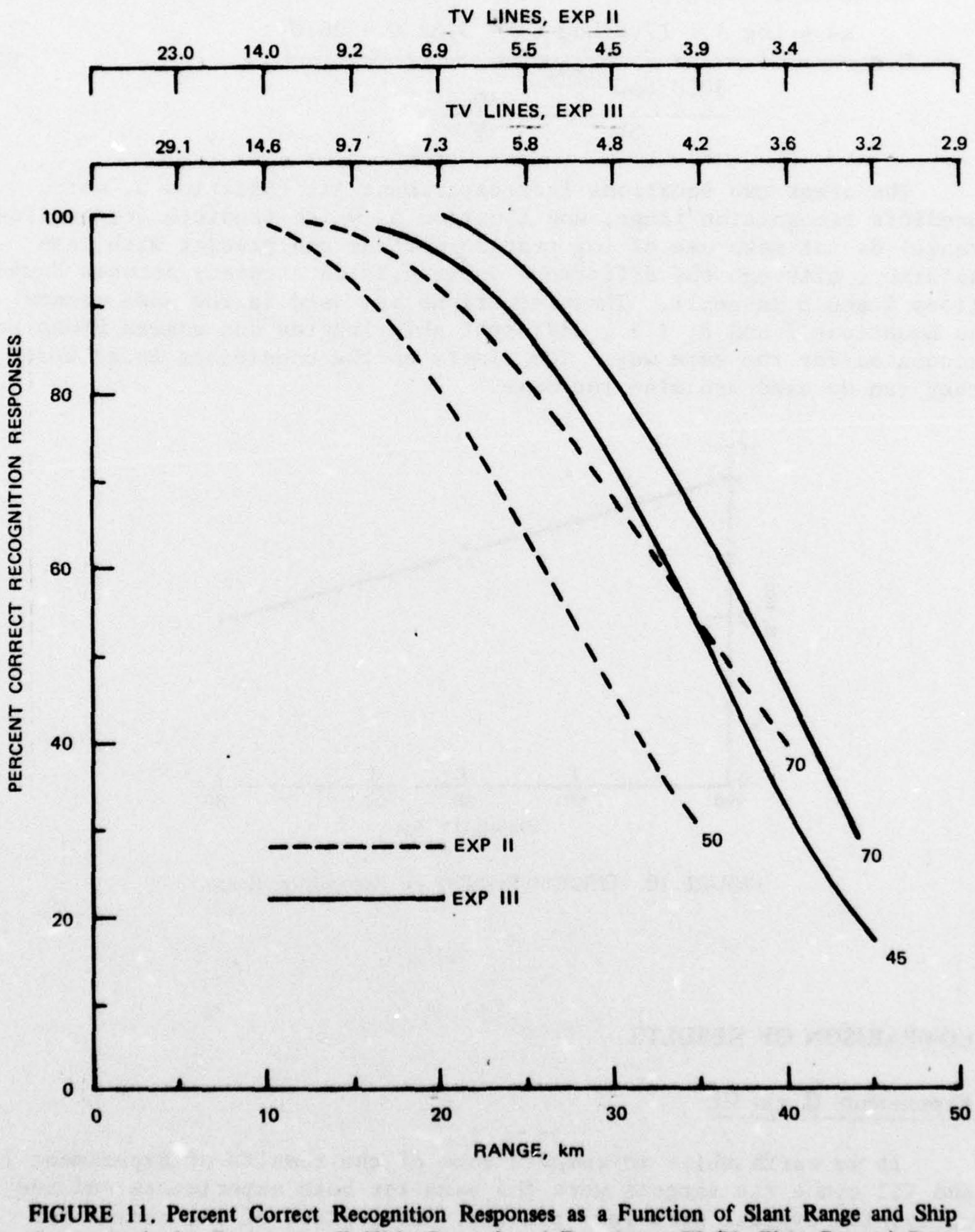

FIGURE 11. Percent Correct Recognition Responses as a Function of Slant Range and Ship Aspect Angle for Experiment II (Wake Present) and Experiment III (No Wake Present) Data.

It can be seen that, for a given ship aspect angle and number of TV lines across the target, targets were recognized at more distant ranges in Experiment III than Experiment II. This can be attributed to differences in camera depression angle (16.9 minutes versus 18 degrees) or to the effect from ship wake differences. The data seem to point to the latter.

A wake of some size was present under most conditions in Experiment II. These wakes were clearly visible on the television monitor, greatly affecting the T/B contrast and causing some glare just around the target. Although flat wakes were used in each condition of Experiment III, they were never visible on the television monitor. Therefore, they did little to change the T/B contrast and caused no glare.

Additional evidence that wakes and not camera depression angle differences caused the differences in recognition ranges can be seen in Figure 2, where the recognition ranges were longer for the zero wake condition than for any of the other conditions. Camera depression angle was held constant at 18 degrees and the data were averaged over the other factors (aspect angle, light elevation, etc.).

Finally, in Experiment I it was found that ship wake and its interactions accounted for more of the variation in the data than camera depression angle and its interactions. Also, the main effect of ship wake was statistically significant while camera depression angle was not.

Other Studies

For a number of reasons, it is difficult to make meaningful comparisons among the data collected in various experiments dealing with the same subject. One problem concerns the reporting of the experiment. Pertinent information (e.g., camera HFOV, target dimensions, image length or width, visual angle, etc.) are often not reported. For this reason it is impossible to graph the results on a common scale. Other things (e.g., camera resolution and T/B contrast), if not reported, make it virtually impossible to interpret what caused differences among sets of data. Therefore, although several experiments were reviewed, few comparisons could be made.

One that could be compared with Experiment III of this report was reported by Decker.[2] He conducted a laboratory experiment in which the subjects' task was to identify positive T/B contrast ship images on television. Six 1:1250 scale-model ships, which were approximately the same size as the ones used in Experiment III, provided the broadside target images. The data Decker collected in the no-noise, high modulation transfer function (MTF) condition was graphed on a common scale

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[2] Naval Weapons Center. *Warship Identification With Electro-Optical Imaging Systems*, by P. R. Decker. China Lake, Calif., NWC, September 1976. (NWC TP 5895, publication UNCLASSIFIED.)

with data from Experiment III in which the T/B contrast was high-positive and the ship aspect angle was 70 degrees (Figure 12). Target image lengths at recognition (Experiment III) were about half as long as the identification lengths obtained by Decker. Apparently most of the difference can be attributed to the more difficult task of identifying one of six targets as compared to recognition with only two possibilities.

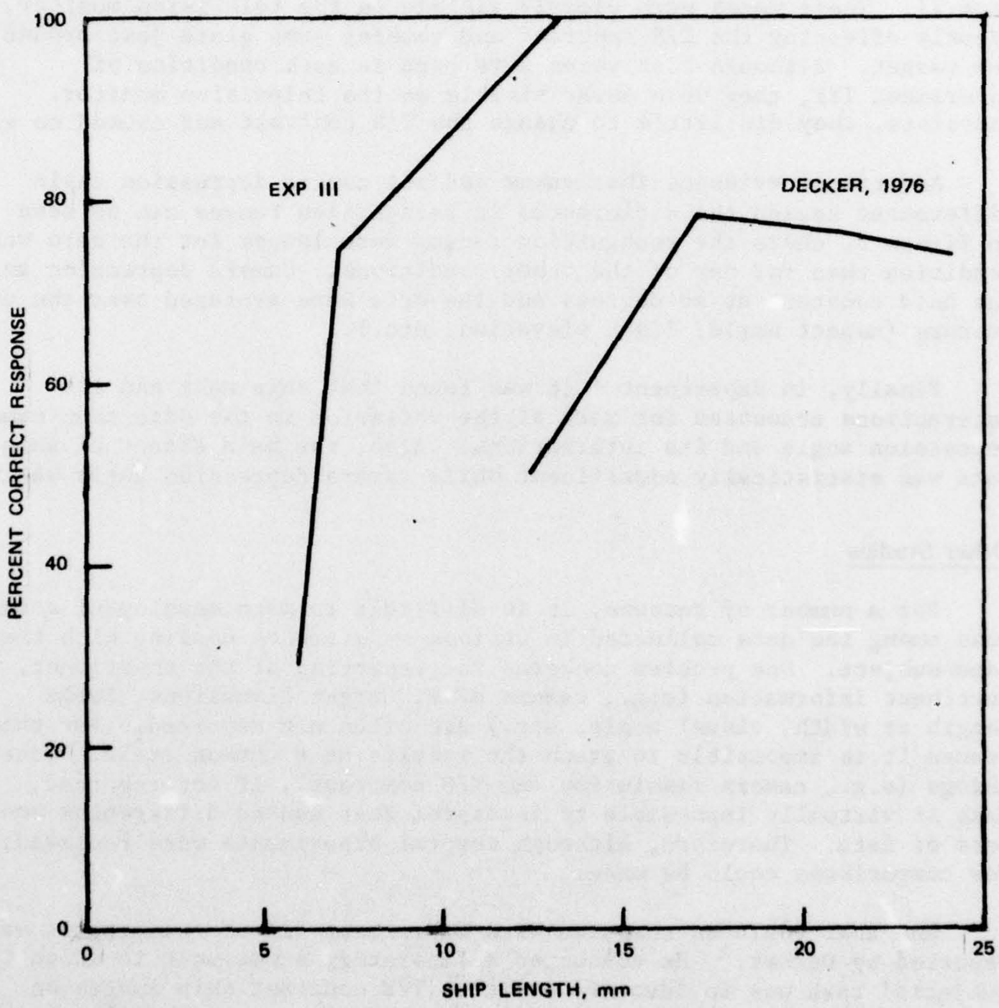

FIGURE 12. Comparison of the Results of Experiment III With Those Obtained by Decker, 1976.

Tables that give the number of scan lines and the visual angle required for 80 to 100% probability of target detection, recognition, or identification were published in a previous NWC report.[3] It was reported that 9 to 12 scan lines are required for ship, vehicle, building, bridge, and aircraft recognition, while target image visual angles required for recognition varied from about 10 to 30 minutes of arc.

At least one full degree of arc was required for 80% recognition of the high-positive contrast ship images in Experiment II of this report. The same level of performance was achieved in Experiment III at visual angles of about 30 minutes of arc (high-positive contrast) and 24 minutes of arc (high-negative contrast). The large difference in visual angle was due to differences in subject viewing distance (38 centimeters in the second experiment and 71 centimeters in the third). Apparently the subjects in Experiment II could have been moved back from the monitor until the visual angle was reduced to 30 minutes of arc or less without affecting performance.

A study was conducted by Richardson in 1962 in which he analyzed 3,465 detailed reports of surface vessel sightings from aircraft.[4] Seventeen factors were evaluated to determine the effect of each on threshold ship detection ranges. The rank order of some of the factors, from stronger to weaker effect on performance, is given in Table 4. Rank order of the factors from Experiments II and III, based on each factor's effect on ship recognition range, is given in the first column.

It can be seen that there is agreement on the relative rank order of several factors even though the dependent measures were not the same in the two reports. Meteorological visibility (simulated in the laboratory by varying T/B contrast) was ranked number one in each case. There is disagreement on the rank-ordering of target-relative bearing, wake size, and aircraft altitude. Target-relative bearing and wake size apparently have a stronger effect on recognition range than detection range, while the reverse is true for aircraft altitude.

Our data are in agreement on how sun altitude affects target acquisition. Richardson's analysis revealed increasing detection ranges with decreases in sun altitude from 90 to 0 degrees. The same relationship held for recognition ranges as light elevation was varied in Experiment II of this report.

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[3] Naval Weapons Center. *Line Criteria in Target Acquisition With Electro-Optical Devices*, by R. A. Erickson. China Lake, Calif., NWC, March 1976. (NWC TP 5854, publication UNCLASSIFIED.)

[4] Bureau of Ships. *A Study of the Factors Affecting the Sighting of Surface Vessels From Aircraft*, by W. H. Richardson. Scripps Institution of Oceanography, San Diego, Calif., SIO, June 1962. (SIO Ref. 62-13, publication UNCLASSIFIED.)

The two sets of data partially agree on the way ship acquisition is affected by the relative bearing of the sun. Richardson found detection ranges to be longest with the sun directly behind the observer. Shorter ranges were obtained at a 90-degree angle. In Experiment II, the optimum light azimuth was found to be 30 to 70 degrees, with poorer performance when the light was at 90 degrees or over-the-shoulder.

TABLE 4. Comparison of Factor Rank Orders.

Factors		Rank
Experiments II and III	Richardson's study[4]	
Meterological visibility (T/B contrast)	Meterological visibility	1
Target-relative bearing (aspect angle)	Aircraft altitude	2
Contrast sign	Ship size	3
Wake size	Height of major swells	4
Sun altitude (light elevation)	Cloud cover	5
Target differences	Wind velocity	6
Relative bearing of sun (light azimuth)	Target-relative bearing	7
Aircraft altitude (camera depression angle)	Sun altitude	8
	Relative bearing of sun	9
	Wake size	10

CONCLUSIONS

1. T/B contrast, contrast sign (the target is darker or lighter than the background), ship aspect angle, ship wake size, and light (sun) elevation each have statistically significant effects on ship recognition/identification range on television. These variables also affect the range at which ship orientation can be determined.

2. Ship images can be recognized at longer ranges if the camera depression is less than 1 degree than if it is over 12 degrees, probably because the wake is not visible at lower altitudes.

3. Recognition and orientation ranges are longer when the ship is darker than the background than when it is lighter.

4. Ship images are more difficult to recognize if they are at a 20-degree aspect angle to the observer than if they are at a 45- or 70-degree angle; however there is little difference between 45- and 70-degree angles.

5. Recognition range decreases as wake size increases, at least until it reaches 100% of the ship width on both the port and starboard sides.

6. Recognition range decreases as the sun elevation increases (between 14 and 62 degrees).

7. Recognition ranges are longer for positive-contrast ship images if the target is front-/side-lighted (about 30 to 70 degrees azimuth).

Appendix A
DETAILS OF THREE LABORATORY EXPERIMENTS

EXPERIMENT I

METHOD

Subjects

The subjects participating in Experiment I were eight employees of the Naval Weapons Center (four men and four women), each with near and far binocular visual acuity (corrected or uncorrected) of 20/20 or better.

Design

A completely crossed-factorial design was employed to test the effects of seven factors on the variation in observers' ability to identify ship targets on television. The factors were: (1) targets, (2) target aspect angle with respect to the camera,* (3) slant range, (4) light position, (5) depression angle, and (6) wake (Table A-1). Subjects were also considered a factor in the analysis.

TABLE A-1. The Experimental Design.

			Slant range, km															
			8								16							
			Aspect angle, deg															
			30				90				30				90			
Wake	Depression angle, deg	Light position	Ship				Ship				Ship				Ship			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
No	12	Front																
		Back																
	24	Front																
		Back								Eight subjects								
Yes	12	Front																
		Back																
	24	Front																
		Back																

* Also known as relative bearing.

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The 128 conditions tested per subject were divided into four blocks of 32 trials each. The 32 trials are randomized within each of the four blocks. A Latin-square technique was used to partially counterbalance the order of presentation of the four blocks of trials between subjects (Table A-2). Each of the four pairs of subjects received a different order. Each pair of subjects tested together saw the conditions in the same order.

TABLE A-2. Order of Presentation of the Four Blocks of Trials (A, B, C, D) for Each Pair of Subjects.

Subjects	Order			
	1	2	3	4
1,2	A	B	D	C
3,4	B	C	A	D
5,6	C	D	B	A
7,8	D	A	C	B

A forced-choice technique was used to obtain the dependent variable, which was either correct or incorrect identification of the ship target for each condition.

Apparatus

Electronic Equipment. The electronic equipment used in recording and display of the imagery consisted of the following items:

1. Ampex camera, Model CC450, 525-nominal line rate with 2:1 interlace.

2. Video tape recorder, Model 660B, with 40-dB peak-to-peak, signal-to-noise ratio.

3. Conrac monitors, Model RND9, with 228.6-millimeter diagonal display, reduced to 13 centimeter by black tape placed around perimeter of the rasters.

4. Oscilloscope, Tektronix Model 7613.

An oscillator, amplifier, and speaker were also used to record and play back verbal instructions and tones. The complete equipment configuration is shown in Figures A-1 and A-2.

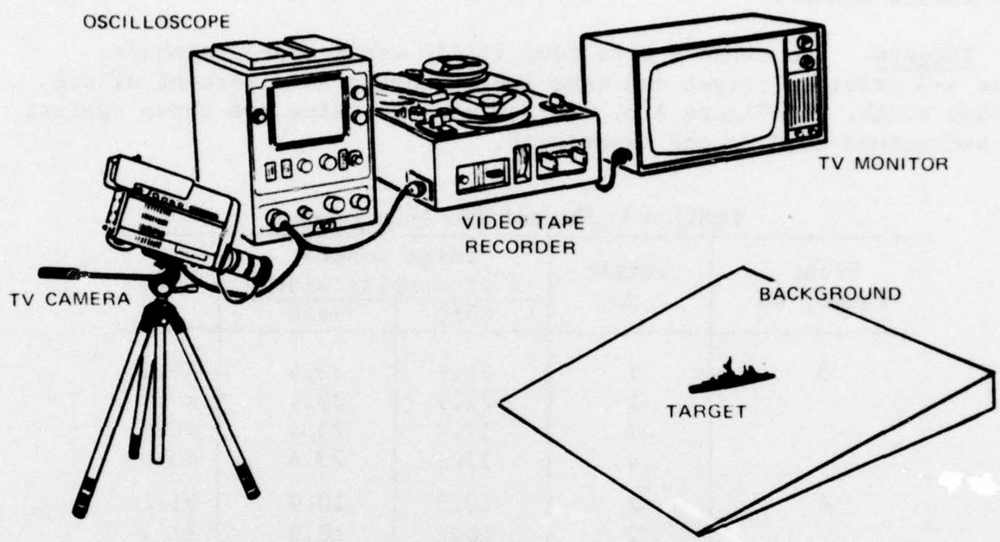


FIGURE A-1. Recording Configuration.

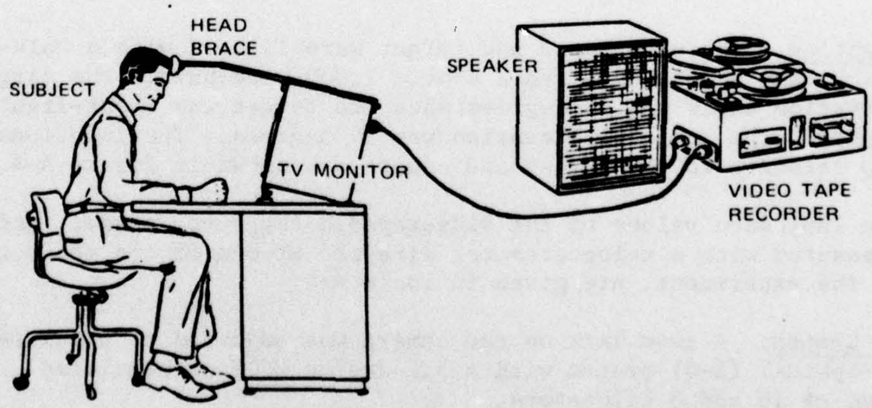


FIGURE A-2. Playback Configuration.

Background. A calm sea state was simulated by applying several shades of gray acrylic paint to a styrofoam/cardboard surface which was 2.44 meters square.

Targets. The targets were four 1:1250 scale-model warships. Table A-3 provides target and wake image lengths as a percent of the display width. In Figure A-3, the scale-model ships are shown against the background used in the experiment.

TABLE A-3. Ship and Wake Image Lengths.

Slant range, km	Target No.	Image length, % of display width[a]		Total
		Ship	Wake	
8	1	21.9	23.4	45.3
	2	21.9	23.4	45.3
	3	17.2	23.4	40.6
	4	17.2	23.4	40.6
16	1	10.2	10.9	21.1
	2	10.2	10.9	21.1
	3	7.8	10.9	18.7
	4	7.8	10.9	18.7

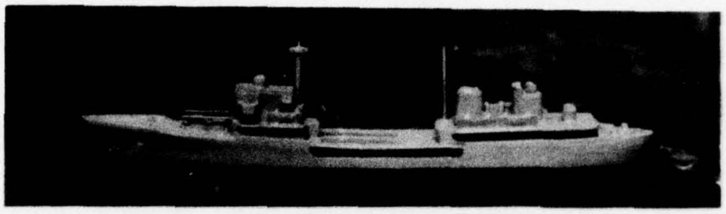
[a] The display widths of the rasters used for playback were 101.6 mm each, after partially masking with black tape.

Lighting. The background and target were lighted with a Mole-Richardson lamp which contained a single 1,000-watt bulb. The target-to-lamp elevation angle was 38 degrees when the target was front-lighted. Back-lighted, the angle of elevation was 19 degrees. The locations of the lamp relative to the target and camera are shown in Figure A-4.

The luminance values of the videotaped background, target, and wake, measured with a telephotometer directed at one of the monitors used in the experiment, are given in Table A-4.

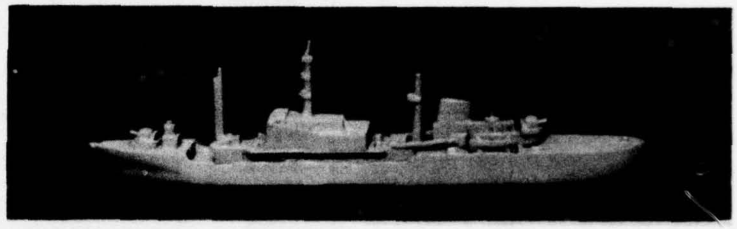
TV Camera. A zoom lens on the camera was adjusted to simulate an electro-optical (E-O) system with a 5.7-degree HFOV at simulated distances of 16 and 8 kilometers.

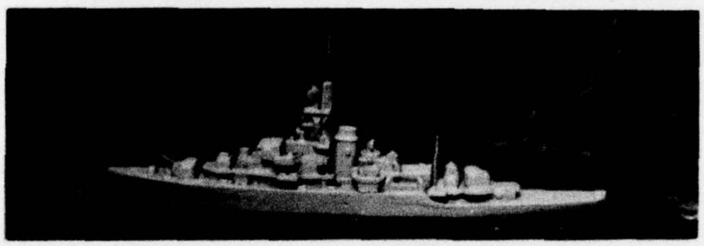
Elevations simulated when the depression angle of the camera was 12 degrees were 3,320 meters when the simulated slant range was 16 kilometers, and 1,660 meters at the 8-kilometers slant range. With the depression angle of the camera at 24 degrees, the elevations simulated were 6,500 and 3,250 meters (for 16- and 8-kilometers slant ranges, respectively).



(1)

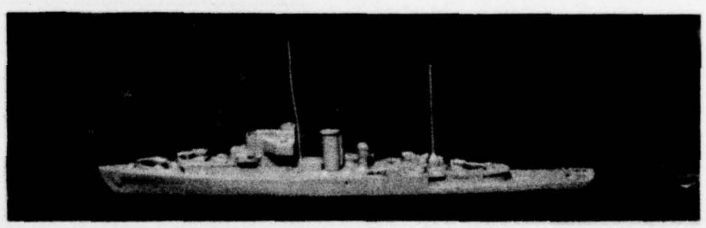
(2)





(3)

(4)



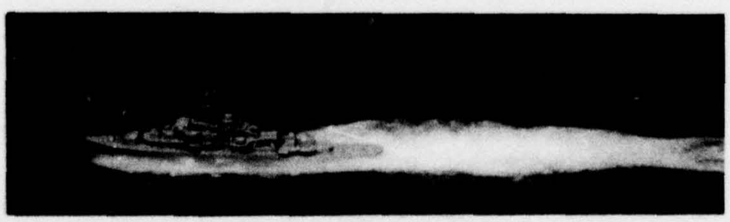


FIGURE A-3. Photograph of Four Scale-Model Warships Against Simulated Ocean Background. (One ship is shown with wake attached.)

TABLE A-4. Luminance of Videotape-Recorded Background, Target, and Wake Under Experimental Conditions.

Wake	Slant range, km	Light position	Luminance, footlamberts[a]		
			Background	Target	Wake
Yes	8	Front	18.0	36.5	56.5
		Back	15.0	13.5	39.5
	16	Front	11.0	16.0	20.5
		Back	7.0	6.0	20.5
No	8	Front	17.5	31.5	...
		Back	14.5	11.5	...
	16	Front	10.0	13.0	...
		Back	7.0	5.5	...

[a] 0.292 Footlambert = 1 Nit.

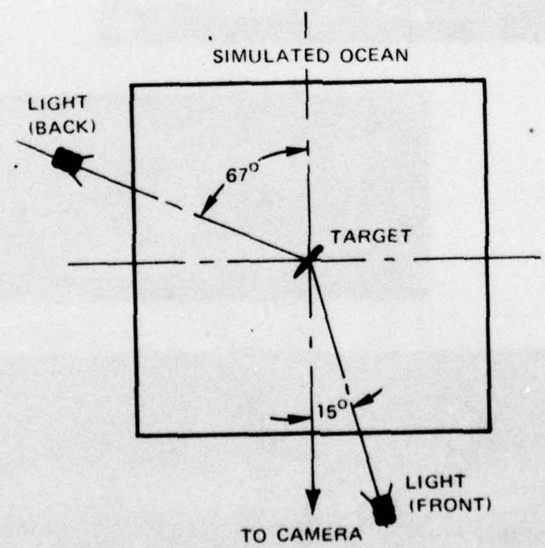


FIGURE A-4. Sketch of Light Location Relative to Target and Camera.

Subject Room. During the experiment, each subject was seated in a room surfaced with acoustic tile. The room was divided into three separate spaces with large sheets of styrofoam/cardboard which extended from the ceiling to the floor. A vision tester was in one space and each of the other two spaces contained one monitor on a table. A speaker was also located in the room so the experimenter could provide instructions for the subjects. Other subject room equipment included briefing cards, scoresheets, and tensor lights. The lights enabled subjects to see the briefing card and scoresheet clearly.

Reference Card. A reference card with two photographs of each ship was available to each subject throughout the experiment. One photograph showed the ships at a 90-degree angle to the subject (broadside) and the other at 30 degrees.

Vision Testing. A Bausch and Lomb Armed Forces Vision Tester was used to test each subject's binocular visual acuity.

Procedure

Videotape Recording. The background and equipment used to videotape the trials for later presentation to subjects were set up in one long room with the camera at a distance of 5.2 meters from the target.

The equation

$$W = 2R(SF) \tan (F/2),$$

where

R = simulated range
SF = scale factor
F = FOV of the simulated system,

was used to calculate the width of the background section that was visible on the monitor at the desired ranges and FOV. The equipment was calibrated, using these distances, to provide for a quick simulated range change between conditions whenever necessary.

The ship targets were videotape-recorded against the background. Necessary changes between conditions were made for each run and each trial was timed with a stopwatch.

Subject Testing. Two subjects at a time participated in the experiment. Each was seated at one of the two tables where the monitors were located and recorded instructions were played (Appendix A-1). Following the instructions, each subject placed his forehead against a pad which was fixed at a distance of 38 centimeters from the monitor. In this position the subject could easily see the briefing card, which was just below the raster, and the scoresheet. The subjects were then tested on 64 practice trials which were randomly selected from the 128 conditions tested in the actual experiment. The subjects were told the correct target number at the end of each of the first 32 practice trials. The second set of 32 practice trials were run in a manner identifical to the data trials, without identification of the ships following the subject's response.

Each trial lasted 15 seconds. A buzzer sounded at the end of 10 seconds, signaling the subjects to respond immediately. Each subject independently made a response for each trial, writing what he believed to be the correct ship number in the appropriate space on the scoresheet. There was no rest period between the trials.

RESULTS AND DISCUSSION

The objective of the experiment was to rank-order the seven factors tested according to the contribution of each to the total variability in the data. Therefore, an analysis of variance was conducted on the data. This gave, in addition to significance levels, the sum of squares for each factor and interaction. The sums of squares were then used to compute the percent of data variance for which each factor and its respective second- and third-order interactions accounted. The outcome of these computations is presented in Table A-5. The factor and its interactions ranked number one (targets) had the strongest effect, while the factor plus interactions ranked seventh (depression angle) had the weakest effect.

A summary of the analysis of variance is in Appendix A-2. Results of the analysis are given for all the main effects but only the significant interactions are given. Eta^2, the sum of squares for a factor or interaction divided by the total sum of squares, is also given in the analysis of variance table. Strictly speaking, the calculations of percent variability in Table A-5 cannot be called Eta^2 since the total sum of squares was greatly inflated. This had to be the case since the sums of squares for the interactions were counted more than once; i.e., second-order interactions were totaled twice and third-order interactions were totaled three times. It was felt, however, that interactions plus main effects would more accurately indicate the strength of a factor than the main effect alone. A factor may have almost no main effect while the interactions account for a great deal of the variance in the data. This was, in fact, the case with light position, ranked number three.

TABLE A-5. Rank Order of Factors Based on Percent of Total Sum of Squares Accounted for By Each Factor and Its Second- and Third-Order Interactions.

Factor	Sum of squares	Percent of total sum of squares	Rank order
Targets			
Main effect	10.58	19.02	1
Interactions	148.71		
Subjects			
Main effect	3.75	18.73	2
Interactions	153.16		
Light position			
Main effect	0.02	13.79	3
Interactions	115.46		
Wake			
Main effect	10.77	13.31	4
Interactions	100.70		
Aspect angle			
Main effect	14.77	12.95	5
Interactions	93.74		
Range			
Main effect	5.79	11.40	6
Interactions	89.72		
Depression angle			
Main effect	0.05	10.80	7
Interactions	90.46		
Total[a]	837.68	100.00	

[a] The actual total sum of squares is 274.55. The total used in this table is much larger since each interaction was counted more than once.

Unfortunately, targets (ranked one) and subjects (ranked two) accounted for over a third of the total sum of squares. These factors, together with their respective interactions, had relatively stronger effects on ship identification probability than the other factors. This was partly due to the levels chosen for each of the other five factors. For example, if the aspect angles off the ship's bow had been 10 and 90 degrees instead of 30 and 90 degrees, the effect due to this factor would probably have been much greater. Also, the effect due to targets resulted from differences in size as well as shape. Holding size constant across targets would have decreased the strength of this factor's effect.

Only one factor, depression angle, was dropped from the selection of independent variables for the next experiment, while slant range became one of the dependent measures.

EXPERIMENT II

OVERVIEW

Scale-model combatant and merchant ships were placed singly on a simulated ocean background and videotape-recorded at various levels of light azimuth and elevation, ship aspect angle, and wake size. The recorded imagery was then played back for observers who tried to recognize the ships (combatant or merchant) at each of four simulated ranges. The data were used to construct curves of range versus probability of recognition under various conditions and to generate an equation to predict recognition range as a function of the independent variables tested.

METHOD

Subjects

The subjects were six employees of the Naval Weapons Center with corrected or uncorrected near and far binocular visual acuity of 20/20 or better.

Design

A within-subject response surface methodology (RSM) central composite design was employed to determine the range at which ship targets could be recognized on television (see publication cited in Footnote 1, p. 4). The design consisted of: (1) a 2^4 factorial portion, and (2) an axial or star portion. The independent variables were light azimuth (Z), light elevation (E), ship aspect angle (A), and wake size (W). Table A-6 gives the levels of each independent variable for both the factorial and axial parts of the design.

TABLE A-6. Factors and Levels for Each Part of the Design.

Factor	Level	
	Factorial portion	Axial portion
Light azimuth, deg	30,70	10,50,90
Light elevation, deg	26,50	14,38,62
Ship aspect angle, deg	30,70	10,50,90
Wake size, %[a]	25,75	0,50,100

[a] Percent of the scale-model ship's width and length.

Each of 25 conditions were tested at four simulated ranges using four scale-model ship targets. One of the conditions (center point) was replicated six times. Therefore, each subject received a total of 480 trials (30 x 4 x 4 = 480). Table A-7 shows the location of the 25 conditions tested in this experiment with respect to a full factorial design of four factors each at five levels.

TABLE A-7. The Conditions Tested.

The 0s mark the conditions comprising the 2^4 factorial part of the design while the Xs mark the axial portion.

		A, DEG																								
		10					30					50					70					90				
		W, %																								
A, DEG	E, DEG	0	25	50	75	100	0	25	50	75	100	0	25	50	75	100	0	25	50	75	100	0	25	50	75	100
10	14																									
	26																									
	38													X												
	50																									
	62																									
30	14																									
	26							0		0								0		0						
	38																									
	50							0		0								0		0						
	62																									
50	14													X												
	26																									
	38			X								X		X		X								X		
	50																									
	62													X												
70	14																									
	26							0		0								0		0						
	38																									
	50							0		0								0		0						
	62																									
90	14																									
	26																									
	38													X												
	50																									
	62																									

Apparatus

Electronic Equipment. With the exception of the camera, the electronic equipment used in recording and display of the imagery was the same as that used in Experiment I. A Cohu camera, 3100 series, 525-nominal line rate with 2:1 interlace was used in this experiment.

Background. A calm sea state was simulated by applying several shades of gray acrylic paint to a 2.44-meter square surface.

Targets. The targets were four 1:1250 scale-model ships. The ship's orientation was measured in degrees off the bow which was always in the left front quadrant of the background with respect to the camera. Table A-8 provides scale-model target image lengths as a percent of the horizontal field of view based on ship length of 12.2 centimeters at 90-degrees aspect angle. The visual angle is based on a viewing distance of 38 centimeters. The scale-model ships are shown in Figure A-5 against the simulated ocean background. Photographs of the actual videotaped imagery are in Appendix A-3. The resolution is slightly poorer in the photographs than it was on the monitor.

TABLE A-8. Image Length, and Visual Angle HFOV, at Each Range Tested.

Simulated range, km	HFOV at ship, cm	Ship length, % of HFOV	Image length on monitor, mm	Visual angle, deg
36	288.0	4.24	17.5	1.13
32	256.0	4.76	8.5	1.28
28	224.0	5.45	9.7	1.46
24	192.0	6.35	11.3	1.70
20	160.0	7.62	13.6	2.05
16	128.0	9.53	17.0	2.56
12	96.0	12.71	22.6	3.41
8	64.0	19.06	33.9	5.11

Lighting. Lighting for the target and background was provided by a Mole-Richardson lamp with a single 1,000-watt bulb. The target was front-lighted with the lamp always in the right front quadrant of the background as shown in Figure A-6. In this figure the lamp and target are each shown in only one orientation with respect to the camera. Of course, the light was varied both in azimuth and elevation, but it was always in the right front quadrant.

The luminance values of the videotaped background, target, and wake, measured with a telephotometer directed at the monitor used in the experiment, are given in Table A-9. The measurements were taken under one condition (center point) with the images at a simulated range of 8 kilometers.

TABLE A-9. Luminance of Videotape-Recorded Background, Target, and Wake.

Measurements were taken on the TV monitor.

Wake size, %	Luminance, ftL[a]		
	Background	Target	Wake
0	15.0	52.0	...
25	15.5	55.0	100.0
50	16.0	57.0	130.0
75	16.0	58.0	135.0
100	16.0	58.0	145.0

[a] 0.292 ftL = 1 nit.

(1)

(2)

(3)

(4)

FIGURE A-5. Photographs of the Four Scale-Model Ships Against Simulated Ocean Background.

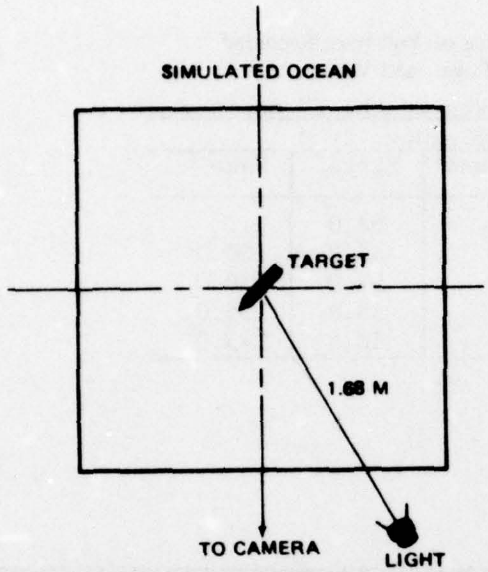


FIGURE A-6. Sketch of Light and Target With Respect to the Camera.

TV Camera. A zoom lens was used to simulate an E-O system with a 5.7-degree HFOV at simulated distances varying from 36 to 8 kilometers at 4-kilometer intervals. The horizontal and vertical resolution of the recorded imagery were 300 and 250 TV lines per raster height, respectively.

The camera-to-target depression angle was 18 degrees. Table A-10 gives the simulated altitudes for each simulated range tested in the experiment.

TABLE A-10. Simulated Altitudes.

Simulated range, km	Simulated altitude, m
36	11,124
32	9,888
28	8,652
24	7,416
20	6,180
16	4,944
12	3,708
8	2,472

Subject Room. During the experiment the subject was seated in a room surfaced with acoustic tile. The room was divided into two spaces, one for vision-testing equipment and one for the television monitor. A speaker was also in the room to provide instructions and warning tones for the subject. Other subject room equipment included a reference card, score-sheets, and a tensor light.

Reference Card. A reference card with two photographs of each ship was available to the subject throughout the experiment. One photograph showed the ships oriented at 90 degrees and the other was at 30 degrees off the bow.

Vision Testing. A Bausch and Lomb Armed Forces Vision Tester was used to test each subject's binocular visual acuity.

Procedure

Videotape Recording. Instructions to the subjects were videotaped for presentation before the actual test trials began. These instructions consisted of broadside close-ups of each of the four ship targets to be used in the tests accompanied with verbal instructions on the sound track of the tape (see Appendix A-4).

For the actual test imagery, 16 trials (four ships x four ranges) were recorded with target orientation, wake, light azimuth, and light elevation each set at a particular value. This combination of values was called a condition to correspond to the notation in Table A-7. Then another 16 trials were videotaped at another set of values (another condition), and so on, until all 25 conditions were recorded once except the center point shown in Table A-7, which was recorded six times.

The first trial for a condition was recorded at a simulated slant range of either 36 or 32 kilometers. Then the zoom lens was used to decrease the simulated slant range by 8 kilometers and another trial was recorded. This was repeated at four ranges (36, 28, 20 and 12 kilometers or 32, 24, 16, and 8 kilometers). The ship target was changed after each set of four trials until each of the four targets had been videotaped at four ranges, then the condition was changed and the whole process repeated.

Each trial was videotaped for 12 seconds. After 9 seconds had elapsed, a tone was recorded to cue the subject to respond immediately.

Additional ship images were videotape-recorded for use in practice trials. The imagery was very similar to that used in the actual data trials, the major difference being the simulated ranges. For the practice trials the nearest range was about 5 kilometers.

Subject Testing. Following a visual acuity test, the subject was seated at a table in the subject room where the monitor was located and instructions were played. The subject then placed his forehead against a fixed pad located 38 centimeters from the monitor, and videotaped practice trials were presented. There were 100 practice trials in all. For each trial the subject marked a C (combatant) or M (merchant) in the appropriate space on a scoresheet. All 25 conditions were presented, each with one target at four ranges. The target was easily recognizable at the fourth range (nearest) for each set of four practice trials.

After the practice trials, the subject was given a break of about 10 minutes. This was followed by 160 of the 480 data trials and that ended the first data collection session. The subject returned the following day and was administered the remaining 320 data trials. There was another break of about 10 minutes after 160 of the remaining trials had been presented. Data collection ended with the presentation of the remaining 160 trials. This entire procedure was repeated for each of the six subjects tested.

The presentation of the three orthogonal blocks of 160 trials each was completely counterbalanced among subjects. Two of the blocks were each one-half replicates of the 2^4 factorial part of the design plus two center points each. The third block of trials consisted of the axial portion of the design plus two center points.

RESULTS

Data Description

The raw data consisted of simulated slant ranges at which the subjects recognized the target as either a combatant or a merchant ship under each set of conditions tested. Observations were totaled over subjects and ship targets to compute the percent of the ships recognized at each simulated range and each set of conditions tested. These computations were used to construct four graphs. Each graph gives the percent of the ship targets recognized as a function of a range and one other factor (Figures A-7, A-8, A-9, and A-10). The number of scan lines across the target are also given for each simulated range.

The number of scan lines across the target required for recognition agrees with the results of previous studies at NWC.[3] Requirements derived from the data indicated that 9 to 12 lines were sufficient for ship, vehicle, building, and aircraft recognition at 80% or better probability. Except for the most extreme conditions, approximately 9 scan lines were sufficient for 80% recognition probability in the present experiment.

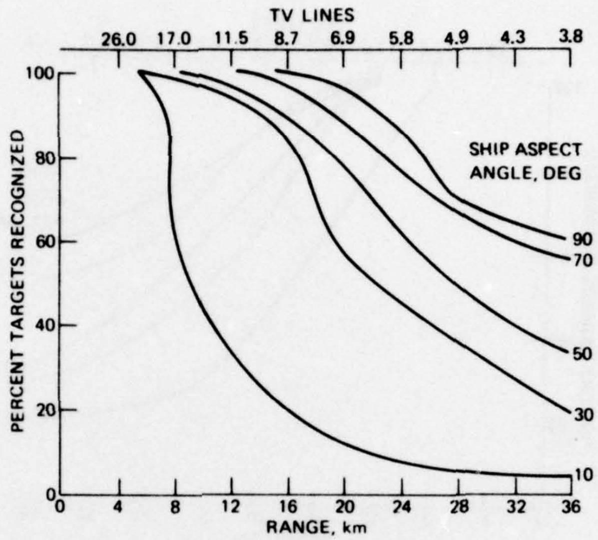


FIGURE A-7. Probability of Ship Recognition as a Function of Range and Ship Aspect Angle.

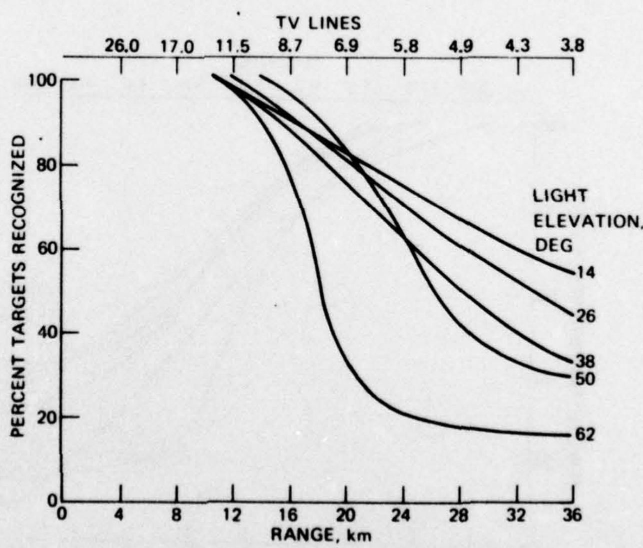


FIGURE A-8. Probability of Ship Recognition as a Function of Range and Light Elevation.

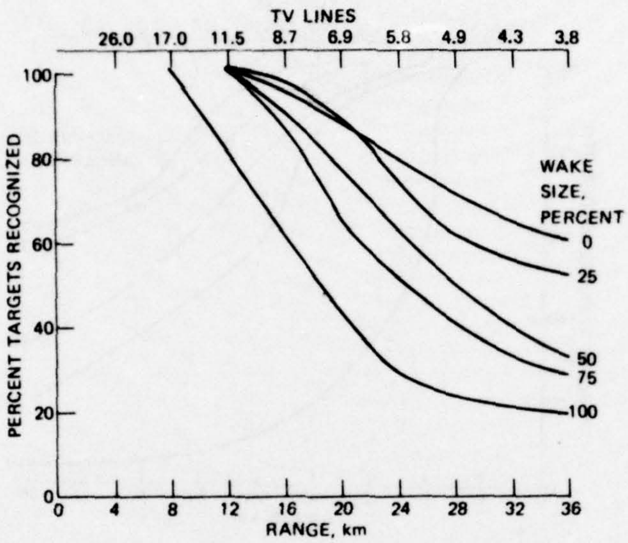


FIGURE A-9. Probability of Ship Recognition as a Function of Range and Wake Size.

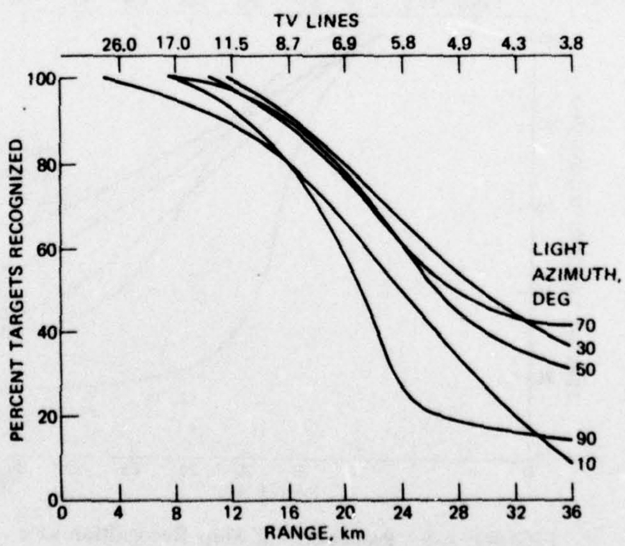


FIGURE A-10. Probability of Ship Recognition as a Function of Range and Light Azimuth.

Multiple Regression Analysis

One range, the range at which five out of the six subjects recognized the target for each set of conditions, was computed for use in subsequent analyses. An explanation of the computational procedures is contained in Appendix A-5.

The data were further reduced by taking the mean range at which the four ships were recognized by five out of the six subjects for each of the 25 combinations of A, E, O, and W. Since the center point was replicated six times, a total of 30 data points was used in this analysis, a multiple regression of the slant range on the four independent variables followed by an analysis of variance on the results of the regression. A computer program developed specifically for RSM designs was employed to perform the analysis.[5]

The analysis yielded the equation

$$\text{Range} = 0.009(Z) - 0.109(E) + 0.188(O) - 0.100(W) + 23.113$$

as the equation which provided the best least-squares fit to the data. The multiple regression coefficient was 0.867. Table A-11 presents the results of an analysis of variance on the results of the regression.

TABLE A-11. Regression Analysis of Variance.

Source of variation	df	MS	F	<P
Regression	4	132.35	30.45	0.005
Light azimuth	1	0.84	0.19	[a]
Light elevation	1	40.82	9.39	0.05
Ship orientation	1	338.25	77.81	0.001
Wake size	1	149.48	34.39	0.005
Residual	25	6.99	...	...
Lack of fit	20	7.65	1.76	[a]
Replications	5	4.35	...	...

[a] Probability greater than 0.25.

[5] Aviation Research Laboratory, Institute of Aviation. *General Computer Program for Response Surface Methodology Analyses*, by C. Clark, R. C. Williges, and S. G. Carmer. University of Illinois, Urbana-Champaign, May 1971. (Technical Report No. ARL-71-8/AFOSR-71-1, Contract No. F44620-70-C-0105, publication UNCLASSIFIED.)

Since the light azimuth factor was not statistically significant and contributed very little to the total sum of squares, it was dropped, the data were averaged across that factor, and another analysis was conducted. A multiple regression of slant range on the three independent variables that remained revealed

$$\text{Range} = -0.113(E) + 0.195(A) - 0.097(W) + 22.389$$

to be the equation that provided the best least-squares fit to the data. The multiple regression coefficient was 0.919. The outcome of an analysis of variance on the results of the regression is given in Table A-12.

TABLE A-12. Regression Analysis of Variance.

Source of variation	df	MS	F	<P
Regression	3	122.19	28.09	0.005
Light elevation	1	29.43	6.77	0.05
Ship orientation	1	242.58	55.77	0.001
Wake size	1	94.56	21.74	0.001
Residual	16	4.19	...	...
Lack of fit	11	4.12	0.95	[a]
Replications	5	4.35	...	...

[a] Probability greater than 0.25.

The actual ranges at which five out of six subjects recognized the targets averaged across ships and light azimuth are given in Table A-13, along with the range calculated by the prediction equation for each set of conditions.

TABLE A-13. Observed Range and Predicted Range for Each Condition.

Light elevation, deg	Ship orientation, deg	Wake size, %	Observed range, km	Calculated range, km
50	30	25	22.4	20.1
50	70	25	28.0	27.9
50	30	75	17.3	15.3
50	70	75	24.4	23.1
26	30	25	25.2	22.9
26	70	25	31.7	30.6
26	30	75	17.9	18.0
26	70	75	26.6	25.8
14	50	50	24.6	25.7
62	50	50	18.4	20.3
38	10	50	11.5	15.2
38	90	50	28.7	30.8
38	50	0	26.0	27.8
38	50	100	17.1	18.1
38	50	50	23.4	23.0
38	50	50	26.3	23.0
38	50	50	21.0	23.0
38	50	50	20.9	23.0
38	50	50	23.3	23.0
38	50	50	24.6	23.0

DISCUSSION OF RESULTS

The results of this experiment are consistent with the results of the preliminary ship identification study conducted by the author.[6] In that experiment, both wake size and ship orientation with respect to the camera were statistically significant. In the present experiment, the range at which the ship targets could be recognized increased steadily as the ship's aspect angle increased. There was also a steady increase in recognition range as wake size decreased. Light position was a factor in the preliminary experiment which did not have a significant effect. The light was varied both in azimuth and elevation, but the two factors were confounded and could not be analyzed separately.

[6] Naval Weapons Center. *Ship Identification of Television: The Relative Effects of Some Environmental Factors*, by H. O. Whitehurst. China Lake, Calif., NWC, March 1976. (NWC TM 2715, publication UNCLASSIFIED.)

In the present experiment, the target was always front-lighted and the light position was varied to allow independent estimates of effects due to light azimuth and elevation. Recognition range was found to increase steadily as the angle of elevation of the light decreased. Light azimuth did not have a statistically significant effect and accounted for very little variance.

However, it was clearly shown in Figure A-10 that fewer targets were recognized when the light azimuth was 10 or 90 degrees than when it was 30, 50, or 70 degrees. Therefore, the relationship between recognition range and light azimuth must be curvelinear for azimuths between 0 and 90 degrees. Flat lighting could make form discrimination more difficult when the light azimuth is 10 degrees (or over the shoulder). Confusion resulting from too many shadows could be the cause of shorter recognition ranges when the light azimuth is 90 degrees.

Both prediction equations provide predicted ranges that fit the data very well as evidenced by the high multiple regression coefficients and insignificance of the lack of fit. They give an accurate estimate of recognition range with no transformations necessary and without higher order terms being included. The recognition range predicted by the second equation (without light azimuth) differed from the observed range by an average of 1.56 kilometers. The difference accounted for only 6.8% of the average observed range.

The prediction equation arrived at in this report will provide an accurate estimate of recognition range under certain conditions, e.g., unlimited visibility, calm sea state, similar T/B contrast, etc. The television equipment must also be similar in terms of image quality, and be equipped with a 5.7-degree FOV lens.

EXPERIMENT III

OVERVIEW

Scale-model ships were placed singly against a simulated ocean or horizon background and videotape-recorded under several conditions of ship aspect angle, T/B contrast, and contrast sign (positive or negative). The recorded imagery was then played back for observers who tried to recognize the ships (combatant or merchant) and determine the ship's orientation (left or right) at each of four ranges. The data were used to construct curves of range at recognition and direction of movement determination as a function of the independent variables. Prediction equations were also generated.

METHOD

Subjects

The subjects were six male employees of the Naval Weapons Center with corrected or uncorrected near and far binocular visual acuity of 20/20 or better.

Design

A completely crossed factorial design was employed to test the effects of three quantitative factors and two qualitative factors on the range at which observers' can determine which direction a ship is moving (orientation), and the range at which ship targets can be recognized on television (Table A-14). The factors were: (1) T/B contrast, (2) contrast sign (i.e., the ship was lighter or darker than the background), (3) ship aspect angle off the bow, (4) targets, and (5) subjects, which were included as a separate factor in two analyses.

The formula C = Lt - Lb/Lb x 100 was used to compute percent contrast. Percent contrast for the low-, medium-, and high-contrast conditions was not the same at each videotaped range, nor was the percent contrast for the high-positive and high-negative conditions the same. Percent contrast for each contrast condition is given in Table A-15 for two ranges.

The orientation of the ship with respect to the camera was not included as a separate factor in the design. Since the silhouette of a ship moving to the left was virtually identical to the same ship moving to the right, any variation due to orientation should have been extremely small or nonexistent. Any effect due to orientation was confounded with the target factor and its interactions only since: (1) each combination of T/B contrast, contrast sign, and aspect angle was repeated four times, once for each ship; and (2) within each of these combinations, which were identical except for the ship and orientation, the orientation of the ship was left twice and right twice. In addition, the merchant ships and the combatants were oriented left and right an equal number of times. The orientations of the ships for eight of the 72 conditions are given in Table A-16.

TABLE A-14. The Experimental Design.

The simulated ranges in km at which each ship was videotaped are given in each cell.

Contrast sign	T/B contrast	Aspect angle, deg: 20				45				70			
		Ship targets: 1	2	3	4	1	2	3	4	1	2	3	4
Positive	Low	16	16	16	16	16	16	16	16	16	16	16	16
		12	12	12	12	12	12	12	12	12	12	12	12
		8	8	8	8	8	8	8	8	8	8	8	8
		4	4	4	4	4	4	4	4	4	4	4	4
	Medium	32	28	28	28	32	28	28	28	36	36	36	36
		24	20	20	20	24	20	20	20	28	28	28	28
		16	12	12	12	16	12	12	12	20	20	20	20
		8	4	4	4	8	4	4	4	12	12	12	12
	High	32	32	28	28	44	36	36	36	44	44	44	44
		24	24	20	20	36	28	28	28	36	36	36	36
		16	16	12	12	28	20	20	20	28	28	28	28
		8	8	4	4	20	12	12	12	20	20	20	20
Negative	Low	32	32	28	28	36	32	32	32	36	36	36	36
		24	24	20	20	28	24	24	24	28	28	28	28
		16	16	12	12	20	16	16	16	20	20	20	20
		8	8	4	4	12	8	8	8	12	12	12	12
	Medium	32	32	32	32	44	44	36	44	44	44	44	44
		24	24	24	24	36	36	28	36	36	36	36	36
		16	16	16	16	28	28	20	28	28	28	28	28
		8	8	8	8	20	20	12	20	20	20	20	20
	High	44	36	36	36	52	52	52	52	52	52	52	52
		36	28	28	28	44	44	44	44	44	44	44	44
		28	20	20	20	36	36	36	36	36	36	36	36
		20	12	12	12	28	28	28	28	28	28	28	28

TABLE A-15. Percent Contrast for Each Contrast Condition at Two Simulated Ranges.

Range, km	Contrast sign	T/B contrast		
		Low	Medium	High
8	+	07.7	34.0	100.0
	-	07.7	34.0	74.0
20	+	06.8	31.0	90.0
	-	06.8	31.0	68.0

TABLE A-16. Eight Conditions Which Illustrate How Target Orientation Was Handled.

Conditions				Target orientation
T/B contrast	Aspect angle, deg	Contrast sign	Ship target	
High	20	+	1	L
High	20	+	2	R
High	20	+	3	L
High	20	+	4	R
High	20	-	1	R
High	20	-	2	L
High	20	-	3	R
High	20	-	4	L

Apparatus

Electronic Equipment. The electronic equipment used in recording and display of the imagery was the same as that used in Experiment II.

Background. Two rectangular plywood backgrounds, one painted with a light shade of gray and the other a darker shade, were used. The former was lighter than the ships and simulated the horizon, and the latter was darker than the ships and simulated a perfectly calm sea state.

Targets. The four targets used in Experiment II were used again in this experiment. Table A-17 provides target image lengths on the monitor for each aspect angle and seven of the simulated ranges. The raster was 17.8 centimeters wide. Photographs of some of the videotaped imagery are in Appendix A-6. The resolution is slightly poorer in the photographs than it was on the monitor.

TABLE A-17. Target Image Length, Percent of Display Width, and Visual Angle.

Range, km	Aspect angle, deg	Target image		
		Length, mm	Display width, %	Visual angle, deg[a]
4	20	23	12.9	1.86
4	45	48	27.0	3.87
4	70	64	36.0	5.16
12	20	8	4.5	0.65
12	45	16	9.0	1.29
12	70	21	11.8	1.69
20	20	5	2.8	0.40
20	45	10	5.6	0.81
20	70	13	7.3	1.05
28	20	3	1.7	0.24
28	45	7	3.9	0.56
28	70	9	5.0	0.73
36	20	3	1.7	0.24
36	45	5	2.8	0.40
36	70	7	3.9	0.56
44	20	2	1.1	0.16
44	45	4	2.2	0.32
44	70	6	3.4	0.48
52	20	2	1.1	0.16
52	45	4	2.2	0.32
52	70	5	2.8	0.40

[a] The viewing distance was 71 cm.

Lighting. The main light source for the target was provided by a Mole-Richardson lamp with a single 1000-watt bulb. The same type of lamp also provided the main light source for the background. The background light was connected to a variac. Changing the variac setting changed the intensity of the light, thus allowing for quick and accurate changes in T/B contrast between conditions. Fluorescent lights were placed above and slightly in front of the target to provide shadow fill. The position of the lights with respect to the target and camera is shown in Figure A-11.

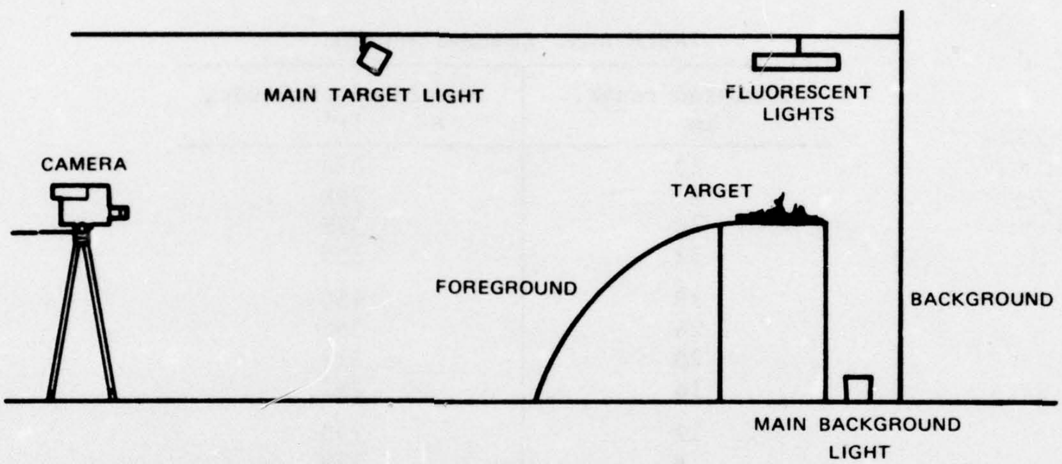


FIGURE A-11. Schematic Drawing of Experimental Arrangement During Videotaping.

Luminance values of the videotaped target and background for all contrast conditions are given in Table A-18. The measurements were taken with a photometer directed at the monitor used in the experiment. The target was broadside at a simulated range of 8 kilometers.

TABLE A-18. Luminance of Videotape-Recorded Target and Background.

Contrast sign	T/B contrast	Luminance, ftL[a]	
		Target	Background
Positive	Low	49.0	45.5
	Medium	51.0	38.0
	High	64.0	32.0
Negative	Low	48.0	52.0
	Medium	43.0	65.0
	High	30.0	116.0

[a] 0.292 ftL = 1 nit.

TV Camera. A zoom lens was used to simulate an E-O system with a 5.7-degree HFOV at simulated distances varying from 52 to four kilometers. The horizontal and vertical resolution of the recorded imagery was about 250 TV lines per raster height.

The camera-to-target depression angle was 16.9 minutes of arc. Table A-19 gives the simulated altitude for each simulated range used in the experiment.

TABLE A-19. Simulated Altitudes.

Simulated range, km	Simulated altitude, ft[a]
52	836
44	708
36	579
32	515
28	450
24	386
20	322
16	257
12	193
8	128
4	64

[a] 1 ft = 0.3048 meter.

Because of the curvature of the earth, a target on the ocean may be masked from view if the observer's altitude is not high enough. The minimum altitude required depends on the ground range--the greater the range, the higher the altitude must be for an unmasked view of the target. Appendix A-7 includes an equation for computing the maximum unmasked range to the target for a given altitude. The altitudes simulated in this experiment were over twice the minimum required for an unmasked view of the target.

Subject Room. During the experiment the subject was seated in a space within a larger room which was partially surfaced with acoustic tile. Equipment included a television monitor and speaker to provide instructions and warning tones for the subject, a table and chair, a reference card, and push button switches connected to a response recorder.

Reference Card. A reference card with four photographs of each ship was available to the subject throughout the experiment. The photographs were silhouettes taken from the monitor. Two of the photographs of each ship were high positive contrast and two were high negative contrast, with each shown at aspect angles of 33 and 58 degrees off the bow.

Vision Testing. A Bausch and Lomb Armed Forces Vision Tester was used to test each subject's binocular visual acuity.

Procedure

Videotape Recording. Instructions to the subject were videotaped for presentation before the actual test trials began. These instructions consisted of broadside close-ups of each of the four ship targets accompanied by verbal instructions very similar to those used in Experiment II.

The 72 experimental conditions were randomized and separated into six blocks of 12 conditions each before videotaping began. Each condition (i.e., a particular combination of target), aspect angle, contrast sign, and T/B contrast was then videotaped at four ranges for a total of 288 test trials per subject.

The first trial for a condition was recorded at a simulated range of 16, 28, 32, 36, 44, or 52 kilometers. A zoom lens was used to decrease the slant range by 8 kilometers, unless the first trial was 16 kilometers in which case the slant range was decreased at 4-kilometer intervals. After the slant range was decreased, another trial was videotaped. Thus, videotaping was done at four ranges per condition with the simulated distance of the far range depending upon the levels of the factors of a particular condition.

Each trial was videotaped for 16 seconds. After 14 seconds had elapsed, a tone was recorded to cue the subject to respond immediately.

Eighteen of the 72 conditions (all combinations of T/B contrast, contrast sign, and aspect angle) were videotape-recorded for use in practice trials. Each of the 18 trials was videotaped with only one of the ship targets. Each target was videotaped at least four times over the 18 conditions. Since each condition was recorded at four ranges, there was a total of 72 practice trials. The practice trials were nearly identical to the actual data trials.

Subject Testing. Following a visual acuity test, the subject was seated at a table in the subject room where the monitor was located and the recorded instructions were played. The subject then placed his forehead against a fixed pad and the 72 videotaped practice trials were presented. For each trial the subject pressed one of two buttons marked "Merchant" or "Combatant" and/or one of two other buttons for left or right ship orientation. If the subject could not determine the ship's orientation or recognize the ship, he did not have to respond (i.e., this was not a forced choice test).

After the practice trials, the subject was given a break of about 5 minutes. This was followed by 96 of the 288 data trials and that ended the first data collection session. The subject returned later in the day and was administered the remaining 192 data trials. The subject was given a 5-minute break after each presentation of 48 data trials. This entire procedure was repeated for each of the six subjects tested.

The presentation of the six blocks of data trials was partially counterbalanced among subjects. The entire experiment lasted about 2.5 hours per subject.

RESULTS

Data Description

The data collected from each subject consisted of simulated slant ranges at which the target was recognized as a merchant or a combatant ship and ranges at which the ship's direction of movement (orientation) was correctly determined. The raw data from each subject were then used to compute the probability of target recognition at each range tested (Figures A-12, A-13, and A-14) and the probability of correctly determining the ship's orientation (Figures A-15, A-16, and A-17). The graphs show the probabilities at several ranges for each aspect angle and contrast condition computed over subjects and targets. The number of TV scan lines across the target are also given for each simulated range, based on a scale-model target height of 18 millimeters (22.5 meters simulated height).

A total of 864 data points was collected from the six subjects combined--432 recognition responses and 432 orientation responses. These were reduced to 144 data points by computing the range at which five of the six subjects made correct responses. The formula used to compute the range for each set of 72 recognition and 72 orientation conditions was the same one used in Experiment II.

Figure A-18a gives the range at which five of the six subjects recognized the target and the range at which 5/6 of the subjects determined the ship's orientation for each T/B contrast and aspect angle condition. This graph presents data for the positive contrast condition based on median target ranges; i.e., one range (median) was determined for the four ships at each condition and these ranges were then used to compute the ranges at which five of the six subjects responded correctly. Figure A-18b is a graph which presents similar information for the negative contrast condition.

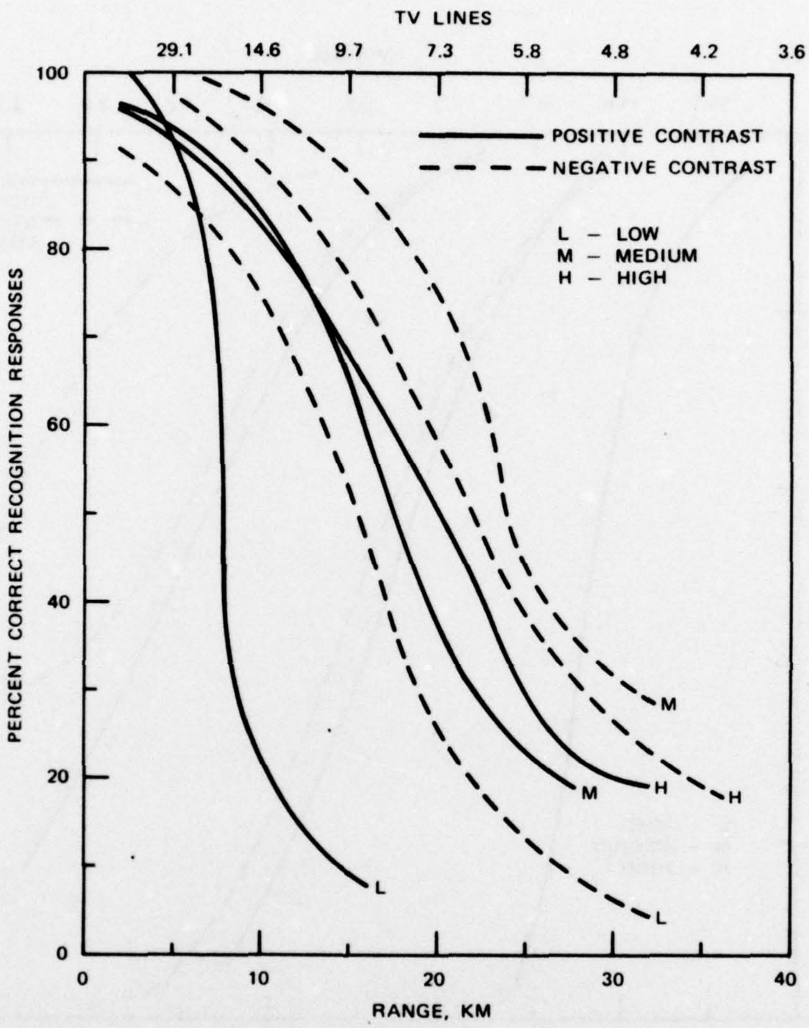


FIGURE A-12. Probability of Ship Recognition as a Function of Range, T/B Contrast, and Contrast Sign With Aspect Angle 20 Degrees Off Ship's Bow.

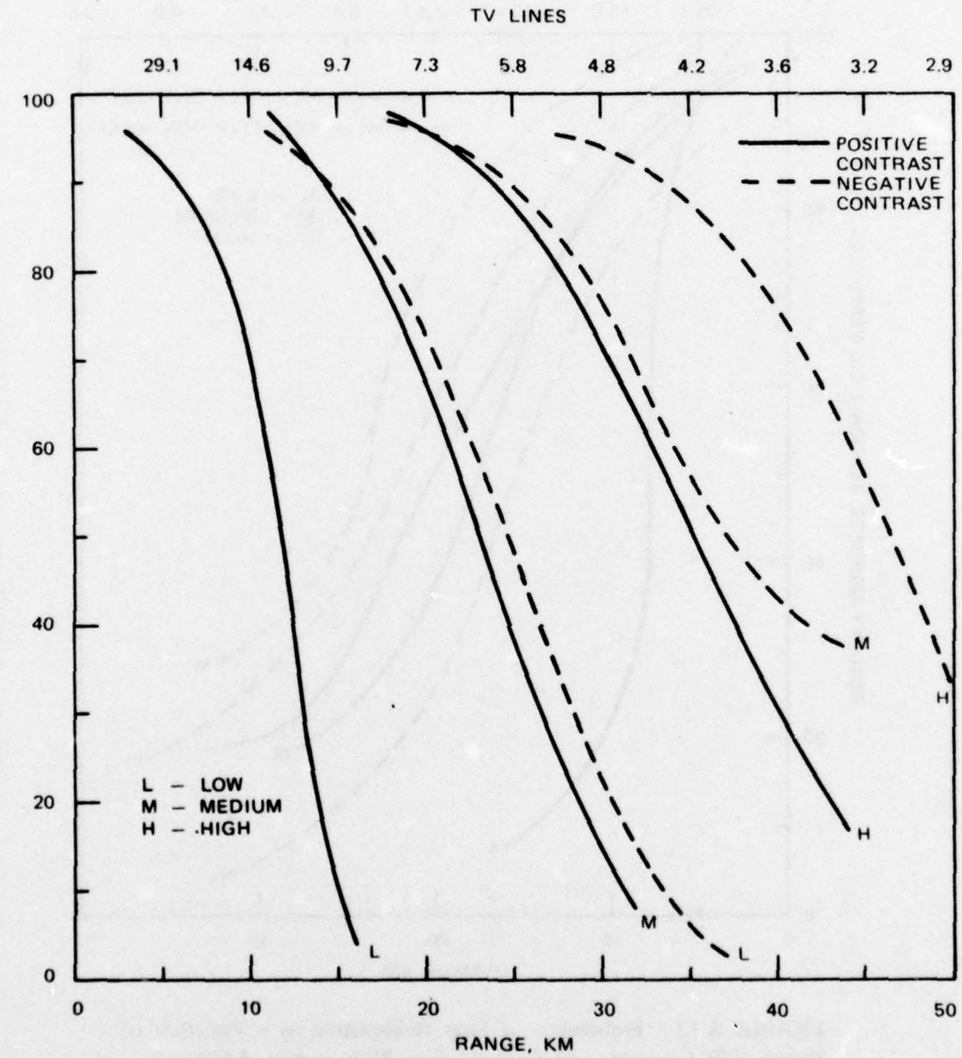


FIGURE A-13. Probability of Ship Recognition as a Function of Range, T/B Contrast, and Contrast Sign With Aspect Angle 45 Degrees Off Ship's Bow.

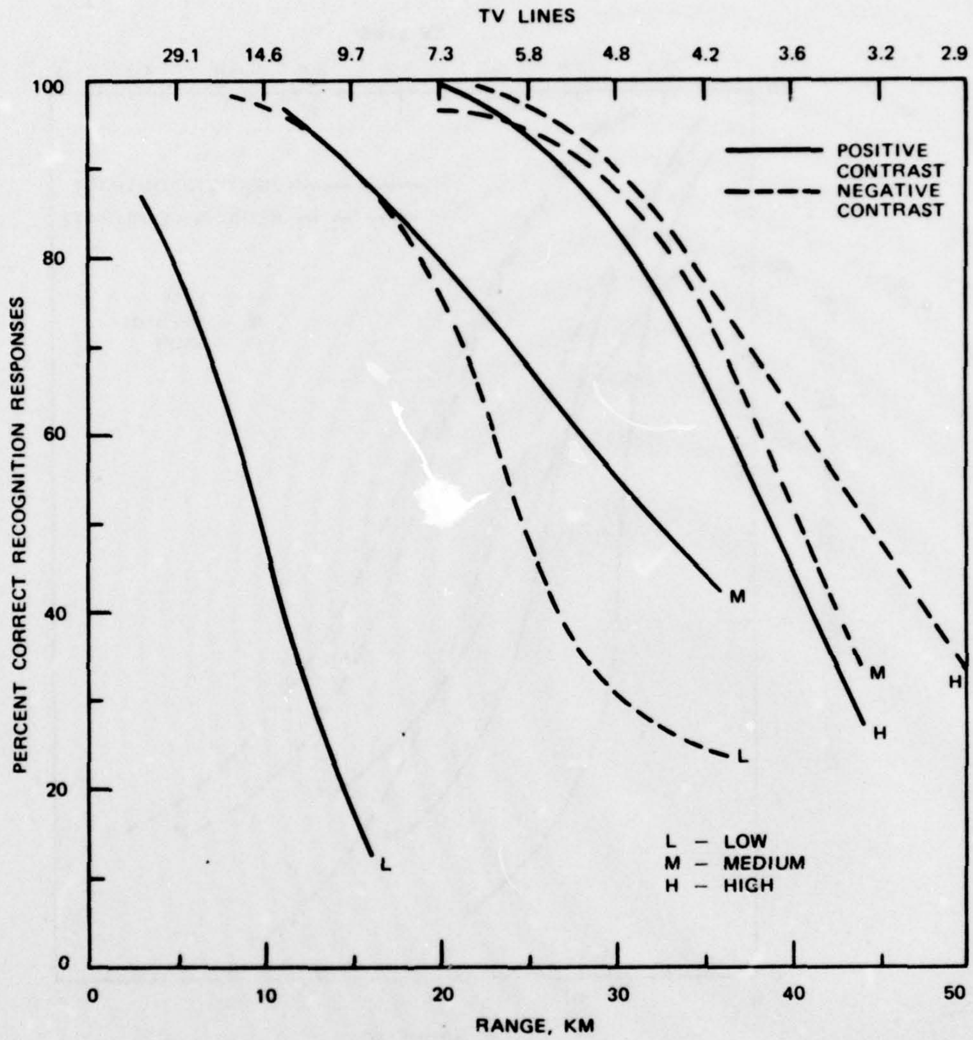


FIGURE A-14. Probability of Ship Recognition as a Function of Range, T/B Contrast, and Contrast Sign With Aspect Angle 70 Degrees Off Ship's Bow.

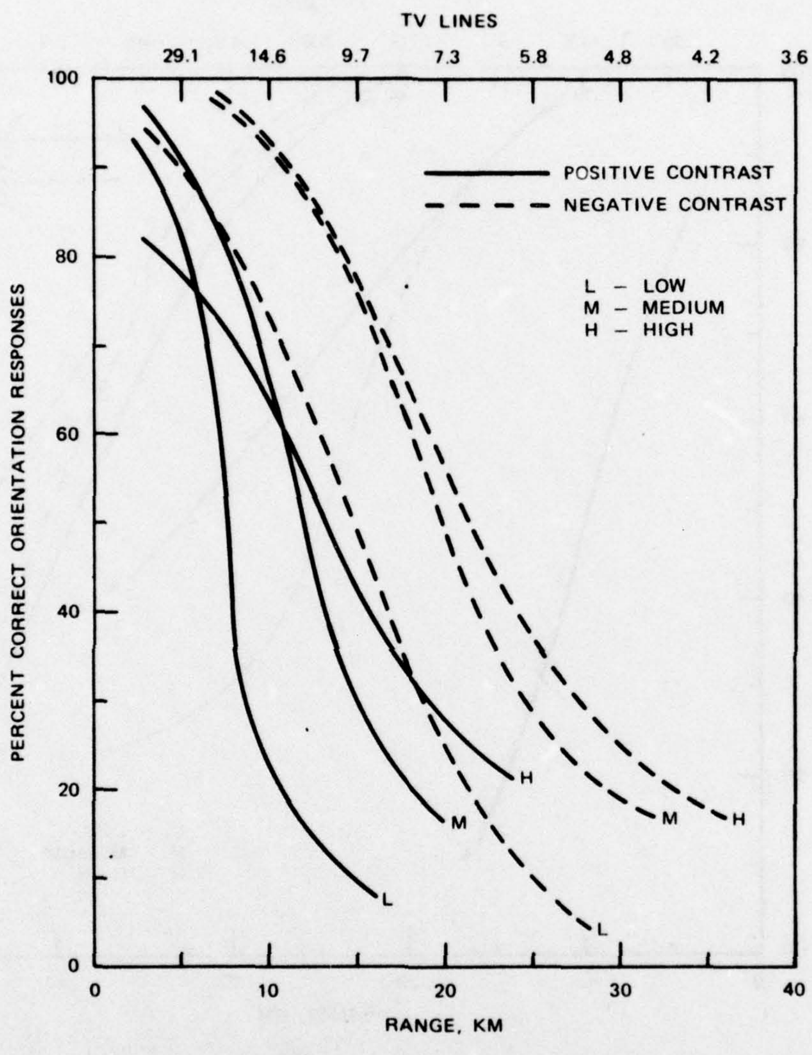


FIGURE A-15. Probability of Determining Ship Direction of Movement as a Function of Range, T/B Contrast, and Contrast Sign With Aspect Angle 20 Degrees Off Ship's Bow.

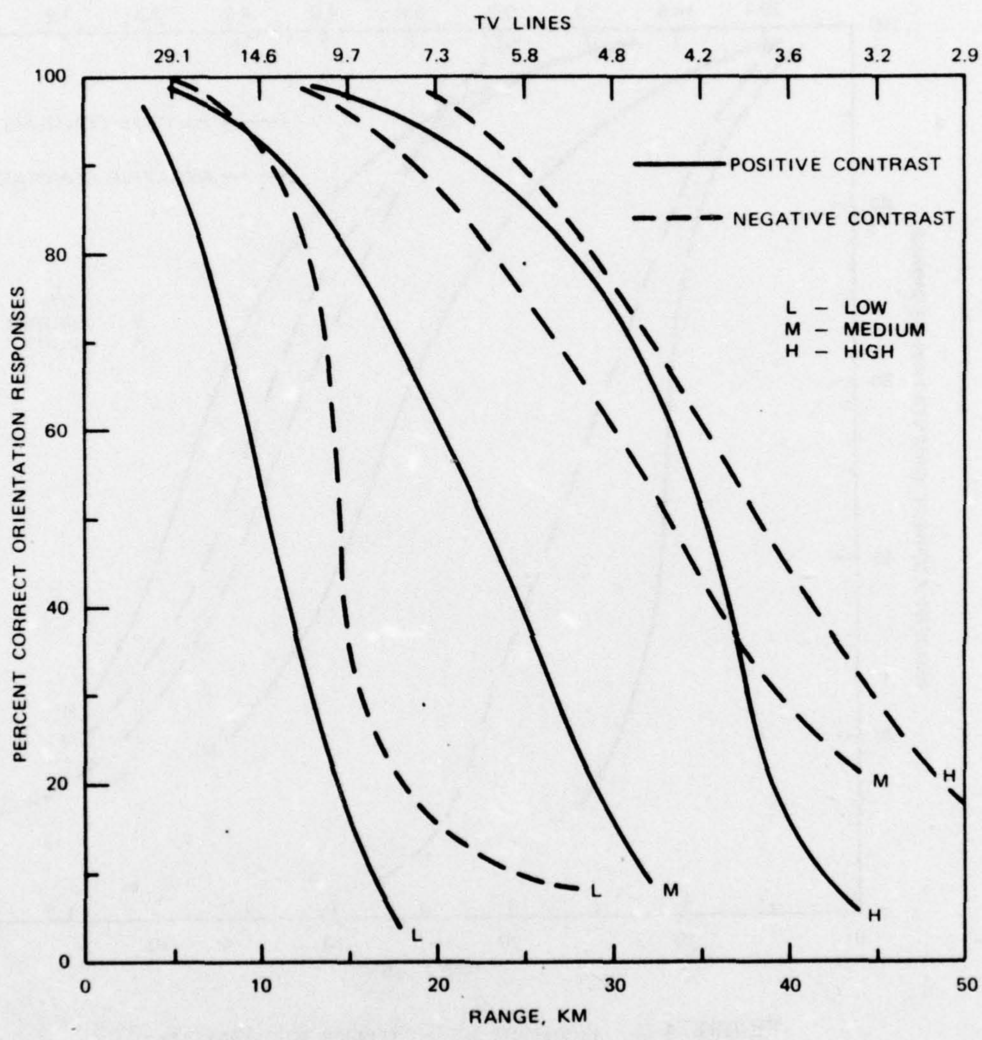


FIGURE A-16. Probability of Determining Ship Direction of Movement as a Function of Range, T/B Contrast, and Contrast Sign With Aspect Angle 45 Degrees Off Ship's Bow.

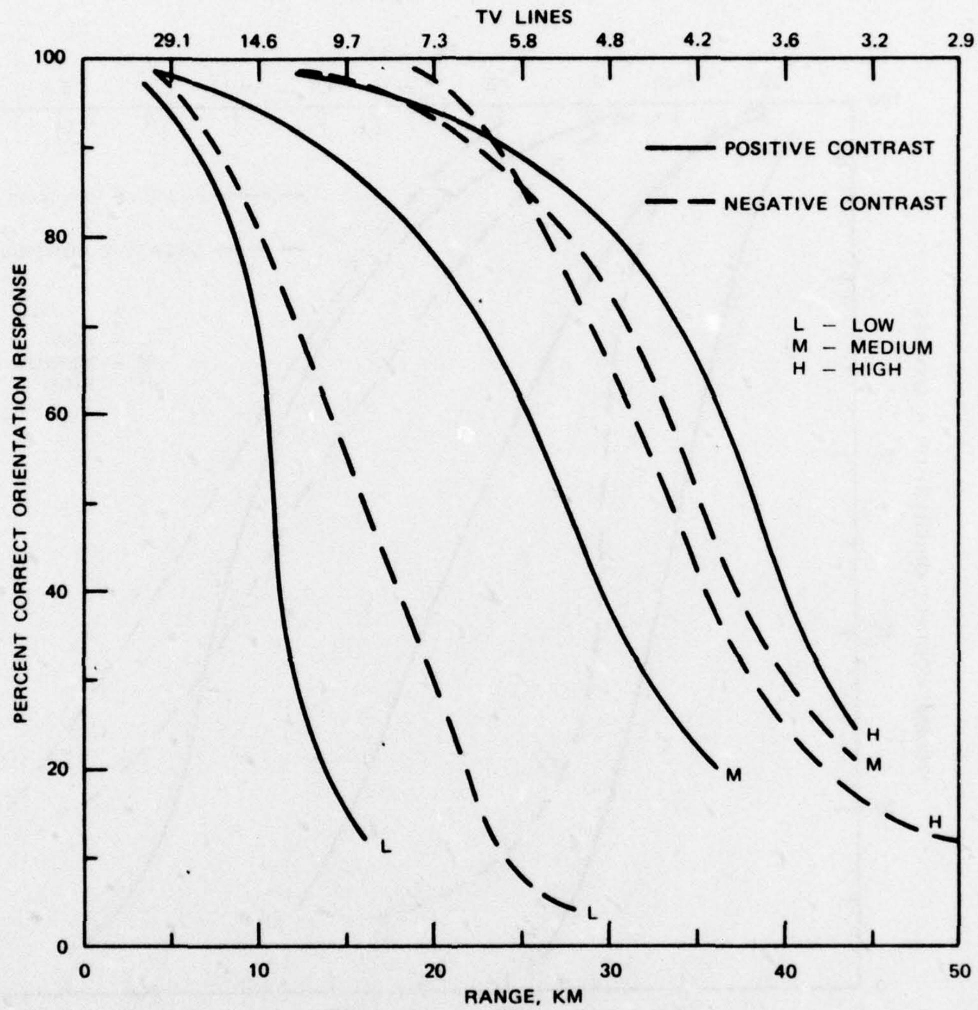
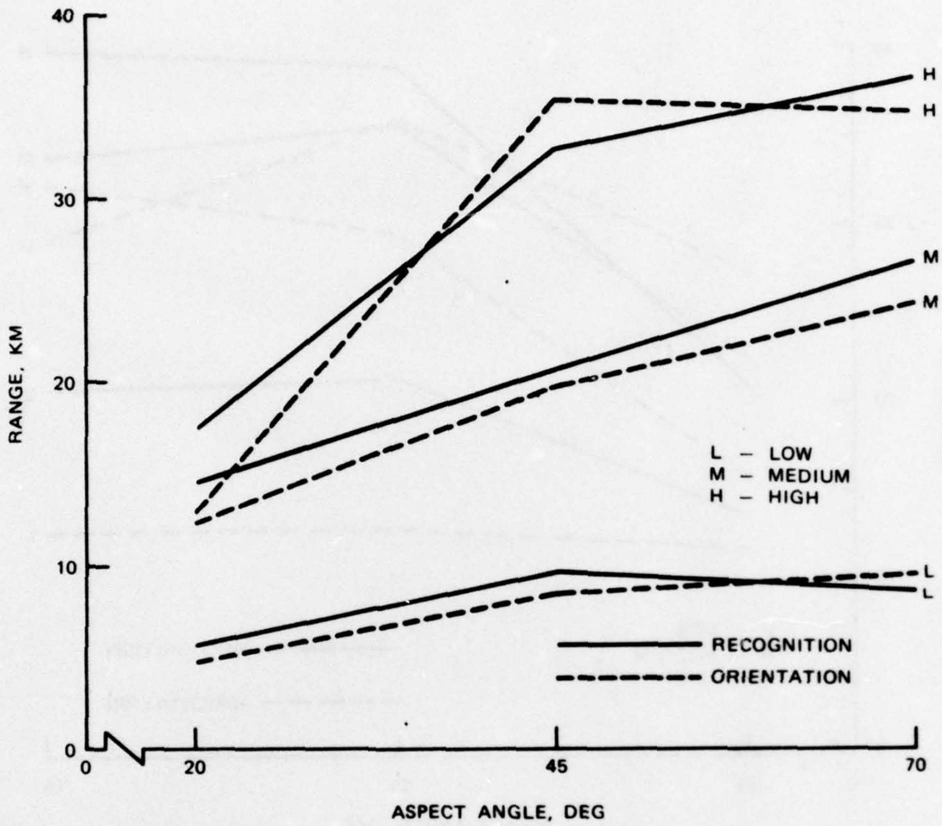
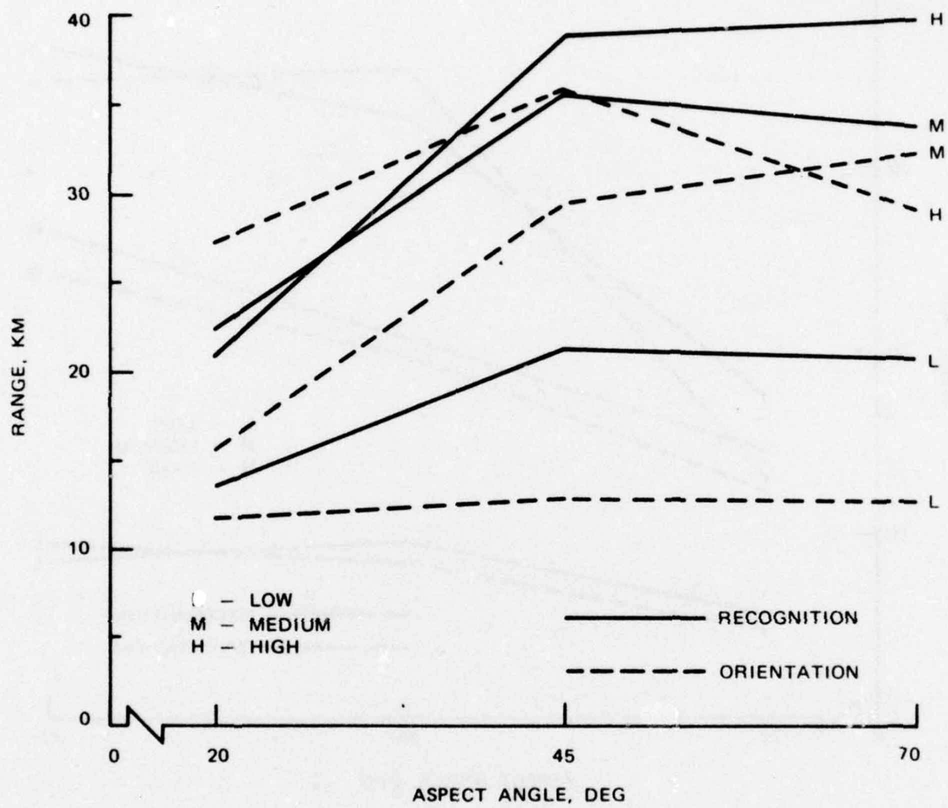


FIGURE A-17. Probability of Determining Ship Direction of Movement as a Function of Range, T/B Contrast, and Contrast Sign With Aspect Angle 70 Degrees Off Ship's Bow.



(a) Positive Contrast.

FIGURE A-18. Range at Which Five of Six Subjects Made Correct Responses as a Function of T/B Contrast and Aspect Angle Off Ship's Bow.



(b) Negative Contrast.

FIGURE A-18. (Contd.)

Figure A-19 provides a direct comparison of the positive and negative contrast conditions for recognition responses at each *T/B* contrast and aspect angle condition. The points represent the range at which five of the six subjects recognized the target. Median target ranges were again used to compute the 5/6 range. Correct orientation responses were also graphed over the same conditions (Figure A-20).

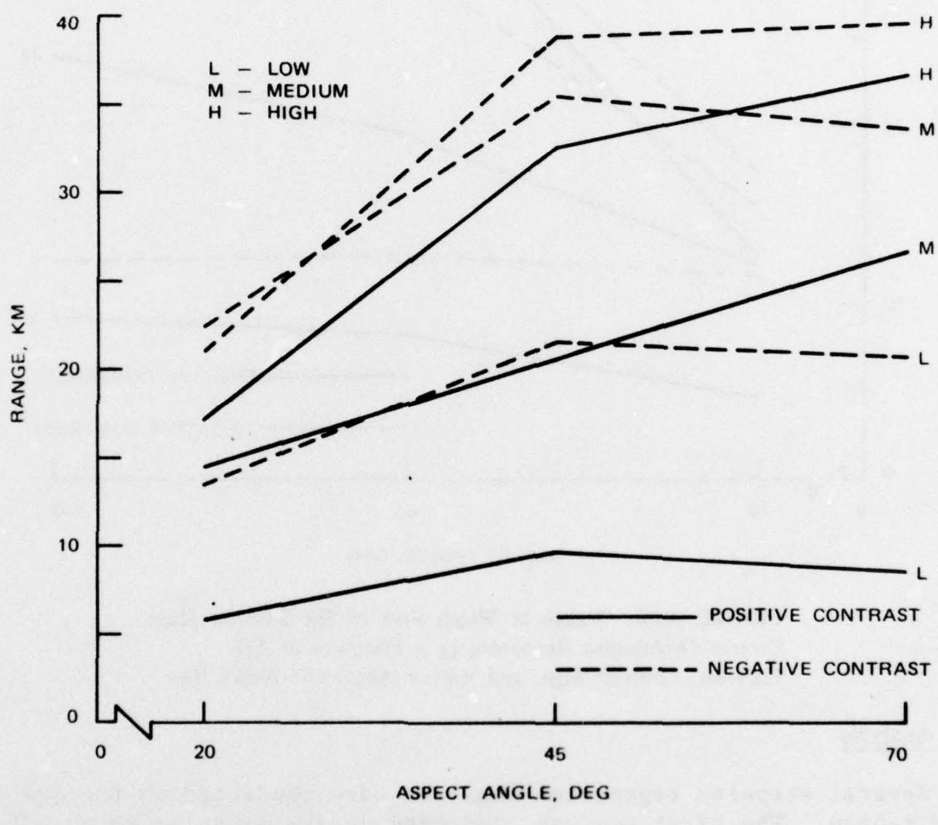


FIGURE A-19. Range at Which Five of Six Subjects Made Correct Recognition Responses as a Function of T/B Contrast, Contrast Sign, and Aspect Angle Off Ship's Bow.

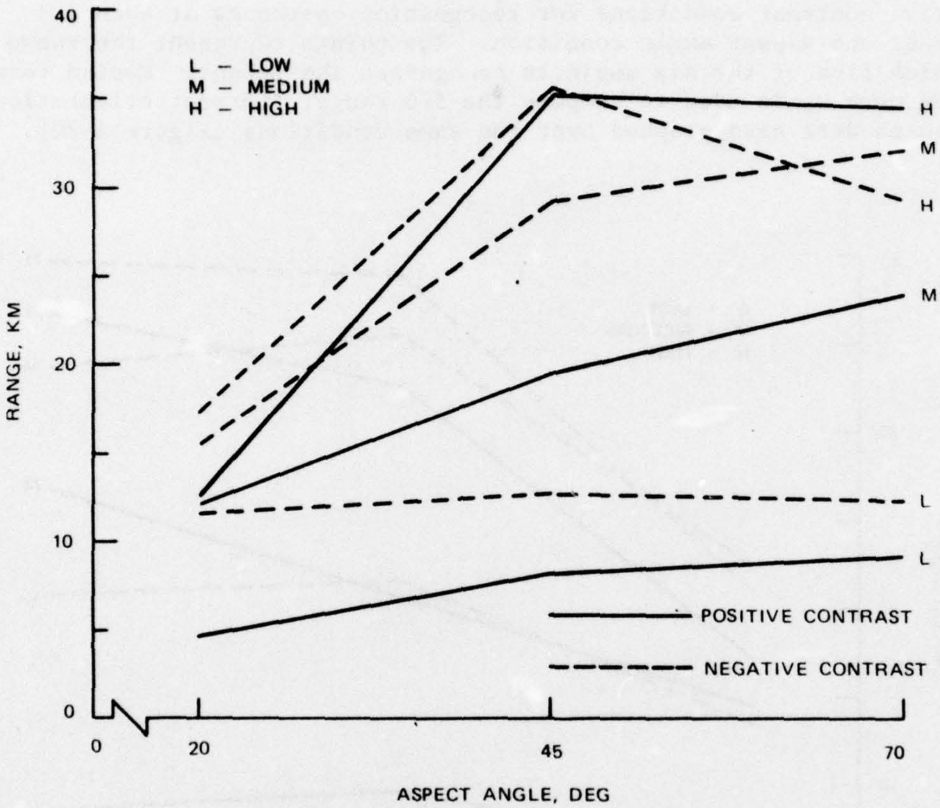


FIGURE A-20. Range at Which Five of Six Subjects Made Correct Orientation Responses as a Function of T/B Contrast, Contrast Sign, and Aspect Angle Off Ship's Bow.

Data Analysis

Several stepwise regression analyses were conducted on the 144 computed ranges. The first one was conducted on the range at which 5/6 of the subjects recognized the target at each of the 72 conditions tested. The equation which provided the best least squares fit to the data was

$$\text{Range} = 23.5(\text{Log}A) + 15.5(\text{Log}B) - 8.32(C) - 33.1 \qquad \text{(A-1)}$$

where

A = Ship aspect angle in degrees off the bow

B = Percent T/B contrast,

C = Contrast sign (negative = 0, positive = 1)

The three factors accounted for a combined total of 73.7% of the total variance in the data (multiple correlation (R) = 0.858, R^2 = 0.737). Most of the remaining variation in the data can be attributed to target differences. Of course, subject variation was eliminated before the analysis and there were no replications.

A stepwise multiple regression analysis was also performed on the recognition data without log transformations of the two factor values. This analysis yielded the equation

$$\text{Range} = 0.25(A) + 0.20(B) - 9.22(C) + 7.80 \qquad \text{(A-2)}$$

The R^2 was high, 66.5% but the fit was not quite as good as it was when log transformations were made.

The observed recognition range averaged over targets at each condition and the range predicted by Equations A-1 and A-2 are given in Table A-20.

TABLE A-20. Actual Range at Which Five of Six Subjects Recognized Target and Predicted Ranges and Average Errors of Equations A-1 and A-2.

T/B Contrast	Contrast sign	Aspect angle, deg	Observed range, km	Predicted range, km		Average error, %	
				Eq. A-1	Eq. A-2	Eq. A-1	Eq. A-2
Low	+	20	5.8	2.5	5.0		
	+	45	9.8	10.7	11.3	49.0	45.8
	+	70	8.4	15.2	17.5		
	-	20	13.5	10.4	14.2		
	-	45	21.2	18.6	20.4	15.8	12.8
	-	70	20.6	23.1	26.7		
Medium	+	20	14.5	12.6	10.1		
	+	45	20.8	20.8	16.3	5.8	22.2
	+	70	26.5	25.4	22.6		
	-	20	22.3	20.9	19.3		
	-	45	35.3	29.2	25.6	7.8	15.5
	-	70	33.7	33.7	31.8		
High	+	20	17.1	19.8	22.6		
	+	45	32.7	28.1	28.8	13.5	16.0
	+	70	36.5	32.6	35.1		
	-	20	21.0	26.2	27.0		
	-	45	38.8	34.4	33.2	12.7	14.5
	-	70	39.7	38.9	39.5		

Stepwise multiple regression analyses were also performed on the orientation recognition range data. The best linear fit to the data was provided by the equation

$$\text{Range} = 14.4(\text{LogA}) + 17.8(\text{LogB}) - 3.32(C) - 26.0 \quad \text{(A-3)}$$

but the equation

$$\text{Range} = 0.15(A) + 0.24(B) - 4.40(C) + 6.32 \quad \text{(A-4)}$$

accounted for almost as much of the variation in the data (R^2 = 43.5 and 42.2%, respectively). Neither of these equations will produce ranges at which observers can determine a ship's direction of movement with the accuracy of the recognition ranges produced by Equations A-1 and A-2.

Table A-21 provides observed orientation recognition ranges and ranges predicted by Equations A-3 and A-4.

TABLE A-21. Actual Range at Which Five of Six Subjects Determined Target's Orientation, and Predicted Ranges and Average Errors of Equations A-3 and A-4.

T/B Contrast	Contrast sign	Aspect angle, deg	Observed range, km	Predicted range, km		Average error, %	
				Eq. A-3	Eq. A-4	Eq. A-3	Eq. A-4
Low	+	20	4.8	4.8	6.6		
	+	45	8.2	9.9	10.4	18.6	33.1
	+	70	9.4	12.7	14.1		
	-	20	11.9	7.7	10.6		
	-	45	12.9	12.8	14.7	20.0	24.3
	-	70	12.5	15.5	18.5		
Medium	+	20	12.2	16.5	12.7		
	+	45	19.7	21.6	16.5	15.2	12.2
	+	70	24.1	24.3	20.2		
	-	20	15.5	19.8	17.1		
	-	45	29.4	24.9	20.9	18.9	20.9
	-	70	32.1	27.7	24.6		
High	+	20	12.7	24.8	27.7		
	+	45	35.2	29.9	31.5	38.6	43.6
	+	70	34.5	32.6	35.2		
	-	20	17.1	25.9	26.4		
	-	45	35.4	30.9	30.1	26.7	28.6
	-	70	29.1	33.7	33.9		

Analyses of variance were performed on the 432 recognition range data points and on the orientation range data. Table A-22 presents a summary of the results of an analysis of variance on these data. Eta^2, the percent of the variation in the data accounted for by each factor and interaction (SS factor ÷ SS total x 100 = Eta^2), was also computed.

TABLE A-22. Summary of Analysis of Variance on Recognition Range Data.

Source of variance	SS	df	MS	F	<P	Eta^2
A. Recognition Range Data						
Subjects (S)	3,210.11	5	642.02	10.98	0.001	3.98
Error	3,507.85	60	58.46			4.35
Aspect angle (A)	12,088.22	2	6,044.11	58.08	0.001	15.00
A x S	1,040.67	10	104.07			1.29
T/B contrast (B)	22,728.67	2	11,364.33	196.75	0.001	28.20
B x S	577.56	10	57.76			0.72
Contrast sign (C)	8,286.26	1	8,286.26	74.02	0.001	10.28
C x S	559.74	5	111.95			0.69
Targets (T)	888.41	3	296.14	2.94	0.10	1.10
T x S	1,510.04	15	100.94			1.87
A x B	2,731.11	4	682.78	9.66	0.001	3.39
A x B x S	1,413.33	20	70.67			1.75
A x C	767.63	2	383.81	17.10	0.001	0.95
A x C x S	224.37	10	22.44			0.28
B x C	480.96	2	240.48	2.26	(*a*)	0.60
B x C x S	1,061.70	10	106.17			1.32
A x T	1,243.04	6	207.17	2.52	(*a*)	1.54
A x T x S	2,467.19	30	82.24			3.06
B x T	551.04	6	91.84	1.33	(*a*)	0.68
B x T x S	2,075.19	30	69.17			2.58
C x T	315.37	3	105.12	1.88	(*a*)	0.39
C x T x S	837.74	15	55.85			1.04
All other interactions	12,033.46	180				14.93
Total	80,599.66	431				100.00

[a] Probability greater than 0.10

TABLE A-22. (Contd.)

Source of variance	SS	df	MS	F	<P	Eta^2
B. Orientation Range Data						
Subjects (S)	3,172.73	5	634.55	10.80	0.001	4.42
Errors	3,524.26	60	58.74			4.92
Aspect angle (A)	11,975.37	2	5,987.68	324.36	0.001	16.69
A x S	184.63	10	18.46			0.26
T/B contrast (B)	20,948.12	2	10,474.06	86.53	0.001	29.21
B x S	1,210.47	10	121.05			1.69
Contrast sign (C)	2,725.06	1	2,725.06	34.58	0.005	3.80
C x S	394.01	5	78.80			0.55
Targets (T)	3,330.01	3	1,110.00	12.12	0.001	4.64
T x S	1,373.65	15	91.58			1.91
A x B	4,390.77	4	1,097.69	17.91	0.001	6.12
A x B x S	1,225.56	20	61.28			1.71
A x C	287.23	2	143.61	3.43	0.10	0.40
A x C x S	418.33	10	41.83			0.58
B x C	433.78	2	216.89	7.79	0.01	0.61
B x C x S	278.36	10	27.84			0.39
A x T	1,036.93	6	172.82	3.77	0.01	1.45
A x T x S	1,375.96	30	45.87			1.92
B x T	493.46	6	82.24	1.27	(a)	0.69
B x T x S	1,945.85	30	64.86			2.71
C x T	879.06	3	293.02	6.51	0.01	1.23
C x T x S	675.03	15	45.00			0.94
All other interactions	9,431.14	180				13.15
Total	71,709.77	431				100.00

[a] Probability greater than 0.10.

DISCUSSION OF RESULTS

The results of this experiment are generally consistent with the results of a previous ship recognition experiment conducted by the author.* In that experiment it was found that the number of TV lines across the ship required for recognition varied from about 5 to 17 for 80% correct recognition of the same ship targets used in this experiment. The variability in the data was due mostly to ship aspect angle which varied from 10 to 90 degrees off the bow. The conditions were all high contrast. The number of TV lines required for 80% recognition in the present experiment varied from about 4 to 14 for the middle- and high-contrast conditions. Another NWC study has reported that 9 to 12 lines are sufficient for ship, vehicle, building, and aircraft recognition at 80% or better probability.[3]

In the previously cited study by the author* it was found that the probability of target recognition at a given range increased as the ship aspect angle increased from 10 to 90 degrees. In the present study, it was found that the probability of ship recognition increased when the ship aspect angle went from 20 to 45 degrees but there was little difference in performance for the 45- and 70-degree aspect angles. The results of the present study are probably more accurate, since a full factorial design was employed versus a partial factorial in the previous study.

Ship recognition was consistently better when the target was darker than the background than when it was lighter than the background. This was also true for the orientation responses, with the exception of one high-contrast condition. This finding could be a function of the particular formula used to compute T/B contrast (there are several). However, the T/B contrast at the low-contrast condition was about the same for both contrast signs no matter which equation is used. Since for all low-contrast conditions, correct ship recognition and orientation responses occurred at greater ranges for negative contrast targets than occurred at the positive contrast ones, it is safe to conclude that the difference is real; i.e., the difference was not due to a bias caused by the equation used to compute percent contrast.

The two analyses of variance revealed all of the main effects to be statistically significant with the exception of the target factor for the recognition range data. The small percent of the total sum of squares that target differences and subject differences accounted for was encouraging. Their inclusion in the regression equations would have had little effect on the ranges predicted. Subjects and targets together

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* See Experiment II, p. 36.

accounted for only 5.08% of the recognition data variation and 9.06% of the variation in the orientation data. On the other hand, the main effects of aspect angle, T/B contrast, and contrast sign combined accounted for 53.48% of the total recognition data sum of squares, while they accounted for 49.70% of the variation in the orientation data. Second- and third-order interactions among the three factors accounted for about 10% of the remaining variation. Other interactions, which also included targets and subjects, accounted for the rest.

One interaction which should be commented upon is the aspect angle x T/B contrast interaction. It accounted for 3.39 and 6.12% of the recognition and orientation data sum of squares, respectively. Simply stated, and this can be seen in Figures A-20 and A-21, it means that T/B contrast has a greater effect on response ranges when the ship's aspect angle is large than when it is small.

Both of the recognition range equations are fairly accurate predictors at all conditions with the exception of the low positive contrast one. Reference to Table A-7 shows Equation A-1 (log transformations) to be a better predictor at middle T/B contrast values for both positive and negative contrast conditions. At both low- and high-contrast values, the average error for the two equations is about the same.

Equation A-3 is a better predictor of orientation range at low T/B contrast values than Equation A-4. They both predict well at the medium T/B contrast values but neither predicts well at the high-contrast values.

These equations can be used for ship sizes different than the one simulated in this experiment (152 meters) by simply multiplying the predicted range by the actual ship length in meters and dividing by 152. If the HFOV is not the same, multiply the predicted range by 5.7 and divide by the system HFOV. If the HFOV is greater than about 15 degrees, tangents should be used. Also, the equation for computing T/B contrast must be the same as the one used in this study.

In view of the evidence that has been presented in this report, it can be concluded that the original objective of the experiment--to provide reasonably accurate predictors of recognition and orientation ranges--has been met.

Appendix A-1
INSTRUCTIONS TO THE SUBJECTS
(Experiment I)

This is an experiment in ship identification on television. The purpose of this experiment is to estimate the relative effects of several factors on observers' ability to identify ship targets.

Before the experiment begins, the four ships which you see on your reference card will be presented one at a time on the monitor and one feature of the ship which might help you identify it will be pointed out. The order in which the ships are presented will correspond to their assigned number on the reference card.

This is ship number one. It can be distinguished from the others by its low hull in the center area, here. Ship number two has three vertical structures here, here, and here. Ship number three has a triangular silhouette which may help you identify it. Most of ship number four's superstructure is slightly forward of center, in this area here.

The four ships you have just seen will be presented one at a time on the monitor under a variety of conditions. Your task will be simply to sit with your forehead against the pad in front of you, watch the monitor, and record on the scoresheet the number of the ship presented. You will have 15 seconds to make a response for each ship. After 10 seconds have elapsed, a tone like this will sound (tone sounds). This is your cue to respond immediately. During the first 32 trials, I will announce the ship number at the end of each 10-second period, but make a response anyway before I give you the number.

Now look at the scoresheet in front of you. You will see that there are six columns composed of 32 empty spaces. Trial numbers are to the left of the columns. When the first ship appears on the monitor, record what you believe to be the ship's number in column one, trial one, and continue down in this manner for 32 trials; then go to column two, trial one, and continue. Always make a response, even if it is only a guess. Don't leave blank spaces. I will announce the trial number occasionally so you can check to make sure the trial number on your scoresheet corresponds to the actual trial number. (Trial numbers 1, 8, 16, 24, and 32 were announced for each block of trials.)

If there are no questions, place your forehead on the pad and we will begin.

Appendix A-2
SUMMARY OF ANALYSIS OF VARIANCE
(Experiment I)

Source of variance	df	MS	F	P	Eta^2
Subjects (S)	7	0.536			1.52
Targets (T)	3	3.527	22.32	<0.001	3.94
TxS	21	0.158			
Aspect angle (A)	1	14.774	76.15	<0.001	5.97
AxS	7	0.194			
Wake (W)	1	10.767	23.25	<0.01	4.35
WxS	7	0.463			
Range (R)	1	5.790	23.63	<0.01	2.34
RxS	7	0.245			
Light position (L)	1	0.024	0.10	NS	0.01
LxS	7	0.230			
Depression angle (D)	1	0.048	0.12	NS	0.02
DxS	7	0.405			
TxL	3	3.220	14.44	<0.001	3.90
TxLxS	21	0.223			
AxL	1	1.485	22.50	<0.01	0.60
AxLxS	7	0.066			
AxD	1	0.712	7.42	<0.05	0.29
AxDxS	7	0.096			
WxL	1	0.413	5.82	<0.05	0.17
WxLxS	7	0.074			
RxL	1	0.610	6.63	<0.05	0.25
RxLxS	7	0.092			
LxD	1	3.400	21.52	<0.01	1.37
LxDxS	7	0.158			
TxWxL	3	1.027	3.88	<0.025	1.24
TxWxLxS	21	0.265			

Source of variance	df	MS	F	P	Eta^2
TxRxL	3	0.759	4.80	<0.025	0.92
TxRxLxS	21	0.158			
RxLxD	1	1.063	7.82	<0.05	0.43
RxLxDxS	7	0.136			
TxAxLxD	3	0.444	4.15	<0.05	0.54
TxAxLxDxS	21	0.107			
AxWxRxL	1	0.821	6.57	<0.05	0.33
AxWxRxLxS	7	0.125			
TxRxLxD	3	0.592	3.38	<0.05	0.72
TxRxLxDxS	21	0.175			
AxWxRxD	1	1.642	16.93	<0.01	0.66
AxWxRxDxS	7	0.097			
TxAxWxRxD	3	0.644	4.29	<0.05	0.78
TxAxWxRxDxS	21	0.150			

Appendix A-3

PHOTOGRAPHS OF ACTUAL VIDEOTAPED IMAGERY
(Experiment II)

A = 50 deg   0 = 90 deg
E = 38 deg   W = 50%


36 km


28 km


20 km


12 km

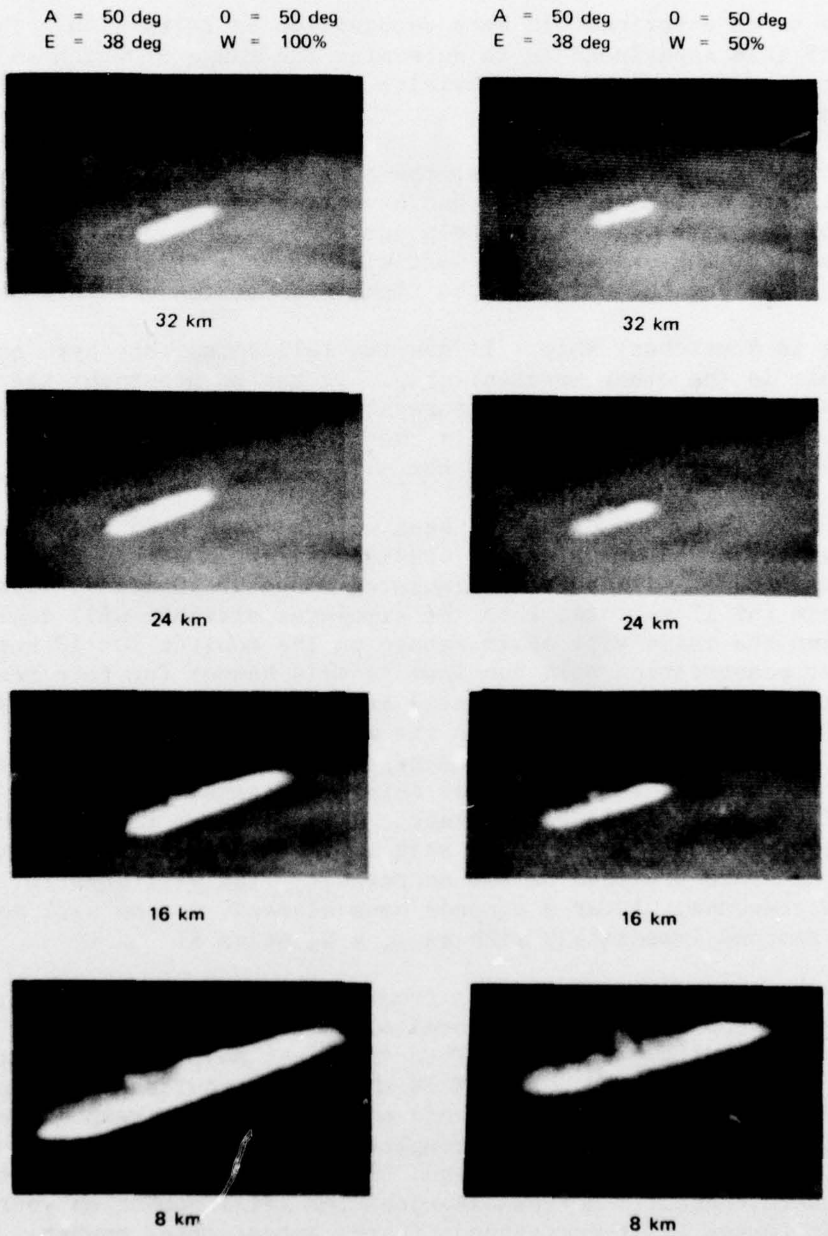
A = 50 deg   0 = 50 deg
E = 38 deg   W = None


36 km


28 km


20 km


12 km


A = 50 deg
E = 38 deg
0 = 50 deg
W = 100%
A = 50 deg
E = 38 deg
0 = 50 deg
W = 50%
32 km
32 km
24 km
24 km
16 km
16 km
8 km
8 km

Appendix A-4

INSTRUCTIONS TO SUBJECTS
(Experiment II)

This is an experiment in ship recognition on television. The purpose of this experiment is to determine the range at which ship targets can be recognized on television under several different conditions.

Before the experiment begins, the four ships which you see on your reference card will be presented one at a time on the monitor and one feature of the ship which might help you recognize it will be pointed out. As you can see, the ships on the left side of your reference card are merchant ships and the ships on the right side of the card are combatants.

This is a merchant ship. It has two tall booms, one here and one here. This is the other merchant ship. It has no prominent features. This is a combatant. It has two superstructures, here and here, which may help you recognize it. This is the other combatant. It has a tall superstructure near the center of the ship.

The four ships you have just seen will be presented one at a time on the monitor under a variety of conditions. When a ship first appears on the monitor, it will be at a simulated range of 20 miles. The image will remain for 12 seconds, then the simulated distance will decrease by 5 miles and the image will again remain on the monitor for 12 seconds. The target presentation will continue in this manner for four ranges. Then another target will be presented at the far range and the cycle will be repeated. Your task will be to sit with your forehead against the pad in front of you, watch the monitor, and record at the appropriate range on the scoresheet an M if you think the target is a merchant ship or a C if you think it is a combatant. If you cannot tell whether the target is a combatant or merchant ship in the time allotted, just enter an X in the space provided on the scoresheet. You will have 12 seconds to make a response. After 9 seconds have elapsed, a tone will sound. You must respond immediately with an M, a C, or an X.

Now look at the scoresheet in front of you. You can see that there are five columns, each composed of 32 empty spaces. Trial numbers are to the left of the columns. When the first ship appears on the monitor, record an M, a C, or an X in the space provided for column one, trial one, then continue down in this manner, making a response each time the range changes until you have completed the 32 trials in column one; then go to column two, trial one and continue. I will announce the trial number frequently so you can check the trial number on your scoresheet to see if it corresponds to the actual trial number.

Do you have any questions?

Appendix A-5

RANGE AT WHICH FIVE OF THE SIX SUBJECTS RECOGNIZED THE TARGET (Experiment II)

The range computed for each of the 25 conditions (25 conditions x four targets + replications) was the range at which five of the six subjects recognized the target as either a combatant or a merchant ship. This range was computed by first determining the z-score corresponding to the probability of recognition for a condition at each range tested. For example, if only one subject recognized the target at 32 kilometers for a particular condition, then the z-score paired with 32 was -0.97 (from a table of z-scores), and if three of the six subjects recognized the target at 24 kilometers the z-score was 0.00, and so on for the next two ranges under that condition. Then the z-scores corresponding to the probability of recognition at each of the four ranges for the next set of conditions were computed, and so on for all conditions.

Following these calculations, the relationship (least-squares fit)

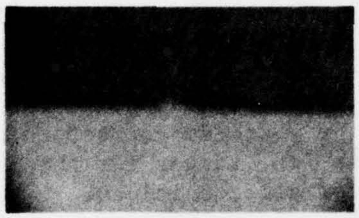
$$Y = \sigma Z + \mu$$

was used to compute the estimated standard deviation ($\hat{\sigma}$) and the estimated mean ($\hat{\mu}$) for the paired scores. It was then possible to insert the computed $\hat{\sigma}$ and $\hat{\mu}$ into the same equation along with the z-score for 5/6 and compute the range at which five of the six subjects recognized the target.

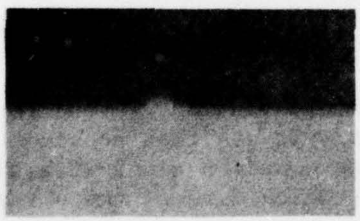
Appendix A-6

PHOTOGRAPHS OF ACTUAL VIDEOTAPED IMAGERY
(Experiment III)

CONTRAST = HIGH
SIGN = POSITIVE
ORIENTATION = RIGHT
TARGET = COMBATANT

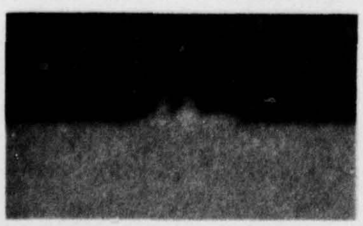


36 km



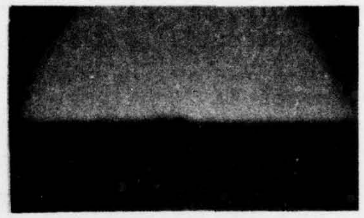
28 km

20 km

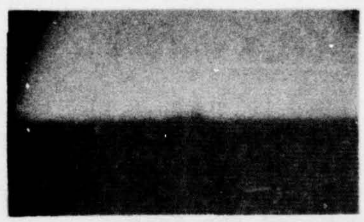


12 km

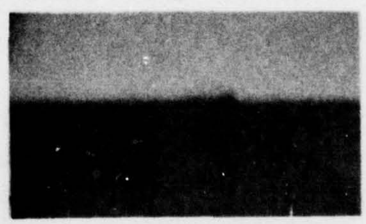
CONTRAST = HIGH
SIGN = NEGATIVE
ORIENTATION = LEFT
TARGET = MERCHANT



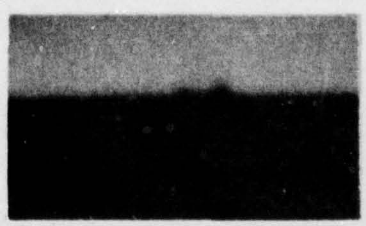
52 km



44 km

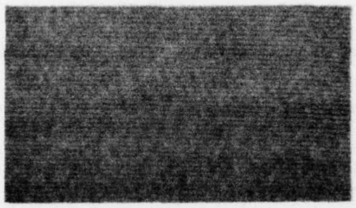


36 km

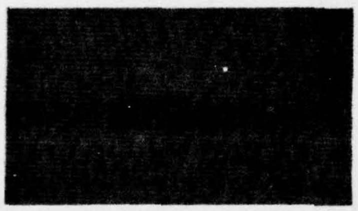


28 km

CONTRAST = LOW
SIGN = NEGATIVE
ORIENTATION = RIGHT
TARGET = MERCHANT



32 km

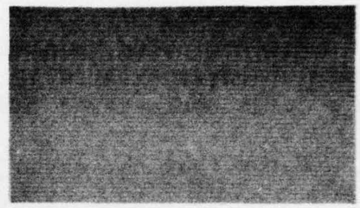


24 km

16 km

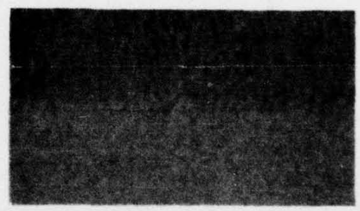
8 km

CONTRAST = LOW
SIGN = POSITIVE
ORIENTATION = RIGHT
TARGET = COMBATANT



16 km

12 km



8 km

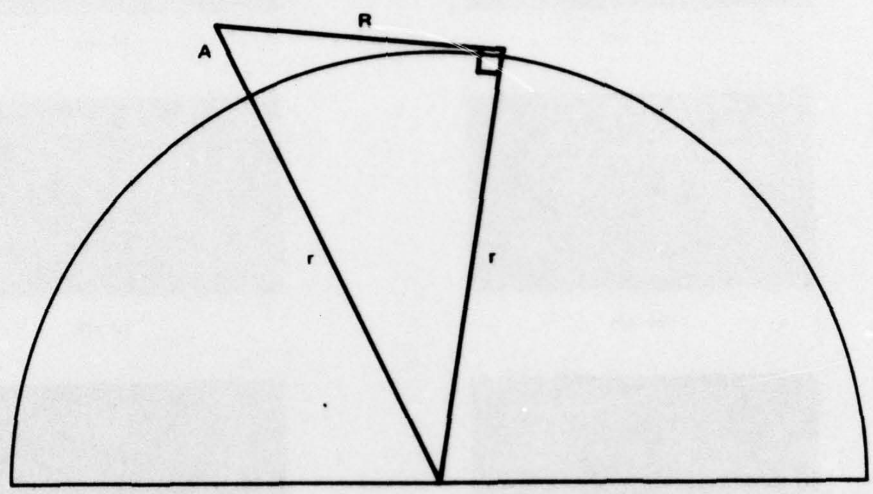
4 km

Appendix A-7

EQUATION FOR COMPUTING UNMASKED RANGE
(Experiment III)

The following equation can be used to compute the maximum range at which an observer at a given altitude has an unmasked view of a target on a large uncluttered land mass or body of water.

Given that the earth is a perfect sphere as shown below, then



$$R^2 = (r + A)^2 - r^2$$

which can be rewritten as

$$R^2 = r^2 + 2rA + A^2 - r^2$$

the r^2s sum to zero; therefore,

$$R^2 = 2rA + A^2$$

where

A = observer altitude
R = range to target
r = radius of the earth (3963.2 mi).

Appendix B
DERIVATION OF VISIBILITY CORRECTION

CONTRAST TRANSMITTANCE THROUGH THE ATMOSPHERE

Visible range, visibility, and meteorological range are all names given in meteorology for the horizontal distance to which the apparent detection contrast of a black object against the daylight horizon sky is reduced to 2%. To derive an expression for meteorological range, consider the general expression for the atmospheric contrast transmittance

$$\frac{B}{C_o} = e^{-\gamma R} \tag{11}$$

where

B = apparent contrast of a target object, located at a distance R from the observer

C_o = inherent contrast of the target at distance approaching zero

γ = average atmospheric extinction for the visible spectrum

R = optical path length, or range to the target.

Taking the natural logarithm and solving for R,

$$R = \frac{1}{\gamma} \ln \left(\frac{C_o}{B}\right) \tag{12}$$

If $C_o = 1$ and $B = 0.02$, the optical range is called the meteorological range, or visibility, V.

$$V = \frac{1}{\gamma} \ln \left(\frac{1}{.02}\right) = \frac{1}{\gamma} \ln 50 = \frac{3.912}{\gamma} \tag{13}$$

The units of V are determined by the units of γ. This formula assumes a circular black target with a diameter greater than 0.5 minute of arc (or 0.145 mrad).

It should be noted that the term visibility (meteorological range) applies to contrast transmittance in the visible portion of the electromagnetic spectrum (from 0.4 to 0.7 μm). This term does not apply to far infrared wavelengths (8 to 12 μm) because contrast at these longer wavelengths is dependent on temperature differences and is not a ratio of light levels.

Optical contrast requirements may be related to visibility by dividing Equation 2 by Equation 3, yielding

$$\frac{R}{V} = \frac{\ln [C_o/B]}{3.912} = 0.2556 \ln \left[\frac{C_o}{B}\right] = K_1 \ln \left(\frac{C_o}{B}\right) \tag{14}$$

Thus, knowing the visibility, assumed contrast requirements, and inherent contrast of the target enables one to estimate the range capability against a specific target.

Equation 14 can be rewritten as

$$\ln \frac{C_o}{B} = \frac{R}{VK_1} \text{, or} \tag{15}$$

$$\ln C_o - \ln B = \frac{R}{VK_1} \text{, or} \tag{16}$$

$$\ln B = \ln C_o - \frac{R}{VK_1} \tag{17}$$

Substituting

$$\text{Log } B/\text{Log } e \text{ for } \ln B, \tag{18}$$

$$\text{Log } B = \text{Log } e \left[\ln C_o - \frac{R}{VK_1}\right] \tag{19}$$

SHIP RECOGNITION

Equation 7 on p. 17 was obtained by fitting experimental data. It is rewritten with constants as shown below

$$R = [a \text{ Log } A + b \text{ Log } B - c\, C - d] f \frac{SL}{\tan (HFOV/2)} \tag{20}$$

where

a = 23.5
b = 15.5
c = 8.32
d = 33.1
f = tan (2.85°)/152 = 0.000327.

Substituting Equation 19 into equation 20,

$$R = \left[a \text{ Log } A + b\left(\text{Log } e\left[\ln C_o - \frac{R}{VK_1}\right]\right) - c\ C - d\right] f\ \frac{SL}{\tan\ (HFOV/2)} \quad (21)$$

solving explicitly for R,

$$R = \frac{[a \text{ Log } A + b \text{ Log } e \ln C_o - c\ C - d] f\ SL/\tan\ (HFOV/2)}{1 + f\ b \text{ Log } e\ SL/VK_1 \tan\ (HFOV/2)} \quad (22)$$

$$R = \frac{(a \text{ Log } A + b \text{ Log } C_o - c\ C - d) f\ K_1\ V\ SL}{VK_1 \tan\ (HFOV/2) + fb \text{ Log } e\ SL} \quad (23)$$

Substituting values into Equation 23 yields

$$R = \frac{23.5 \text{ Log } A + 15.5 \text{ Log } C_o - 8.32\ C - 33.1}{3058 \tan\ (HFOV/2)/SL + 26.33/V}$$

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14 August 1978

From: Head, Human Factors Branch, Survivability and Lethality, Surface Targets Division, Systems Development Department, Naval Weapons Center, China Lake, Calif. 93555

To: Distribution

Subj: NWC TP 5978, *Ship Acquisition on Television: Three Laboratory Experiments,* dated August 1977; errata for and addendum to

It is requested that the following errata and the attached addendum be placed with your copy of NWC TP 5978.

ERRATA

1. The last equation on page 85 should be assigned number (24).

2. The number 3058 in the denominator of equations (8), (10), and (24) should be 3053.

3. The use of equations (8) and (10) where visibility, V, is used implies the assumption of a video system with "unity" contrast rendition. That is, the contrast of the target at the sensor is the same as the contrast of the target as displayed on the monitor.

R. A. Erickson

R. A. ERICKSON

ADDENDUM

MULTIPLE REGRESSION ANALYSIS

Additional analyses were performed on the data collected in Experiment III. It was found that including the quadratic components of ship aspect angle and T/B contrast plus the interaction between the two factors resulted in an increase in predictive accuracy for both recognition and orientation ranges.

Thus, the multiple regression equation

$$\text{Range} = 22.49 + 6.23A' - 1.61A'^2 + 8.36B' - 0.93B'^2 + 3.43A'B' - 3.88C' \qquad (25)$$

is a better predicter of the experimental recognition range data given in this report (NWC TP 5978) than Equations 2 and 3 on page 14 and equations A-1 and A-2 on pages 66 and 67.

Orthogonal coding was used to conduct the analysis so the actual numbers inserted into the equation for each independent variable are as follows:

A	A'	A'^2	B or C_o	B' or C'_o	B'^2 or C'^2_o	C	C'	$A'B'$*
20 deg	-1	1	Low	-1	1	Pos	1	
45 deg	0	-2	Med	0	-2	Neg	-1	
70 deg	1	1	High	1	1			

* $A'B'$ is the product of A' and B'. If $A' = -1$ and $B' = 1$, then $A'B' = -1$. The nine possible permutations of A' and B' will always equal -1, 0, or 1.

The factors in the equation account for a combined total of 80% of the total variability (R^2) in the data. Both linear and quadratic components of Aspect Angle and T/B Contrast were statistically significant, while the Lack of Fit of the model was not (Table 1).

TABLE 1. Regression Analysis of Variance for Recognition Data.

Source	SS	df	MS	F	P<
Regression	7171.3	6			
Aspect Angle (A)					
Linear	1863.8	1	1863.8	73.35	0.001
Quadratic	373.3	1	373.3	15.29	0.001
T/B Contrast (B)					
Linear	3351.3	1	3351.3	137.29	0.001
Quadratic	124.3	1	124.3	5.09	0.05
Contrast Sign	1083.0	1	1083.0	44.37	0.001
A × B	375.6	1	375.6	15.39	0.001
Residual	1724.9	65			
Lack of Fit	406.5	11	36.95	1.51	(a)
Error	1318.4	54	24.41	...	...

[a] Probability greater than 0.10.

A multiple regression analysis was also performed on the orientation data. A very good least squares fit to the data ($R^2 = 0.73$) is provided by the equation

$$\text{Range} = 19.77 + 5.47A' - 1.40A'^2 + 7.77B' - 1.03B'^2 + 3.50A'B' - 2.32C' \qquad (26)$$

This equation provides better predictions of the experimental orientation range than Equations 4 and 5 on page 14 or Equations A-3 and A-4 on page 68.

Orthogonal coding was again used for the analysis and the coded values are the same as those used in the previous analysis.

Again, everything in the regression part of the analysis was statistically significant while the Lack of Fit was not (Table 2).

TABLE 2. Regression Analysis of Variance for Orientation Data.

Source	SS	df	MS	F	P<
Regression	5553.0	6			
Aspect Angle (A)					
Linear	1437.8	1	1437.8	46.68	0.001
Quadratic	281.8	1	281.8	9.15	0.01
T/B Contrast (B)					
Linear	2898.2	1	2898.2	94.10	0.001
Quadratic	154.1	1	154.1	5.00	0.05
Contrast Sign	388.5	1	388.5	12.61	0.001
A × B	392.6	1	392.6	12.75	0.001
Residual	2092.5	65			
Lack of Fit	429.3	11	39.03	1.27	(a)
Error	1663.2	54	30.80	...	...

[a] Probability greater than 0.25.

Recognition ranges can be predicted if Equation 25 is substituted into the numerator of Equation 8, page 18. The resulting equation is

$$R = \frac{22.49 + 6.23A' - 1.61A'^2 + 8.36C_o' + 0.93C_o'^2 + 3.43A'C_o' - 3.88C'}{\dfrac{3053 \tan\left(\frac{HFOV}{2}\right)}{SL} + \dfrac{26.33}{V}} \quad (27)$$

If Equation 26 is substituted into the numerator of Equation 10, page 19, it yields the equation

$$O = \frac{19.77 + 5.47A' - 1.40A'^2 + 7.77C_o' - 1.03C_o'^2 + 3.50A'C_o' - 2.32C'}{\dfrac{3053 \tan\left(\frac{HFOV}{2}\right)}{SL} + \dfrac{30.2}{V}} \quad (28)$$

It should be emphasized that the equations given in the report are empirical fits to the experimental data and should not be used for values outside those used in the experiments. The following bounds apply to Equations 27 and 28:

20 deg ≤ A(Aspect) ≤ 70 deg

7% ≤ B(Negative Contrast) ≤ 75%

7% ≤ B(Positive Contrast) ≤ 100%

A different set of limitations apply to the factors manipulated in the second experiment. Therefore, if Equation 6 is used, the values entered into the equation should fall within the following bounds:

10 deg ≤ A ≤ 90 deg

14 deg ≤ E(Light Elevation) ≤ 62 deg

0% ≤ W(Wake Size) ≤ 100%

T/B Contrast ≥ 100% and Positive

Remember to insert the appropriate coded values given on page 1 of this addendum when using Equations 27 and 28. Actual values are used in Equations 6, 8, and 10.

MINIMUM VISIBILITY

The following section presents a derivation of equations that can be used to insure that any calculations are within the proper bounds given in the section above.

The minimum contrast on the display, B, is equivalent to a minimum visibility, V. The minimum value for V that can be used in Equations 8, 10, 27, and 28 will be derived below.

$$R = \frac{V \ln\left(\frac{C_o}{B}\right)}{3.912} \tag{29}$$

Equation 29 can be substituted into Equation 8 to give

$$\frac{\ln\left(\frac{C_o}{B}\right)}{3.912} V = \frac{23.5 \text{ Log } A + 15.5 \text{ Log } C_o - 8.32C - 33.1}{\frac{3053 \tan\left(\frac{HFOV}{2}\right)}{SL} + \frac{26.33}{V}} \tag{30}$$

Solving for V,

$$V = \frac{23.5 \text{ Log } A + 15.5 \text{ Log } C_o - 8.32C - 33.1 - 15.5 \text{ Log}\left(\frac{C_o}{B}\right)}{\frac{1797}{SL} \tan\left(\frac{HFOV}{2}\right) \text{ Log}\left(\frac{C_o}{B}\right)} \tag{31}$$

The minimum visibility that can be used in the equations and still have a 7% contrast of the target on the display is given below.

$$V_{min} = \frac{23.5 \text{ Log } A + 15.5 \text{ Log } C_o - 8.32C - 33.1 - 15.5 \text{ Log}\left(\frac{C_o}{7}\right)}{\frac{1797}{SL} \tan\left(\frac{HFOV}{2}\right) \text{ Log}\left(\frac{C_o}{7}\right)} \tag{32}$$

or

$$V_{min} = \frac{23.5 \text{ Log } A - 8.32C - 20.0}{\frac{1797}{SL} \tan\left(\frac{HFOV}{2}\right) \text{ Log}\left(\frac{C_o}{7}\right)} \quad (33)$$

where

V_{min} = minimum visibility to be used, km

A = aspect off the ship's bow, degrees

C = 1 for a target lighter than the background
0 for a target darker than the background

SL = ship's length, meters

HFOV = horizontal field of view of the sensor, degrees

C_o = inherent contrast of the ship (contrast very close to the ship)

An example of the use of these equations is given below.

Given: A = 90 deg (broadside)

C_o = 100% and lighter than the background

HFOV = 4 deg

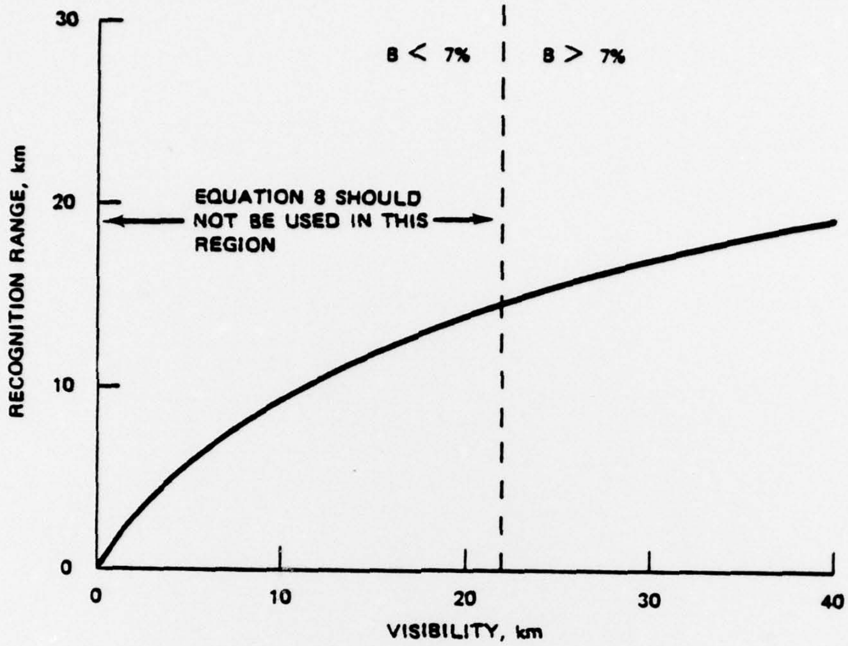
SL = 300 feet (91.4 meters)

Desired: Range at which a combatant ship can be differentiated from a merchant ship for a visibility of 5, 10, and 20 miles.

Using Equation 33,

$$V_{min} = \frac{23.5 \text{ Log } 90° - 8.32 - 20}{\frac{1797}{91.4} \tan 2° \text{ Log } \frac{100}{7}} = 22.2 \text{ km or } 13.8 \text{ miles}$$

Although recognition range is desired for 5- and 10-mile visibilities, these equations cannot be used to estimate it. The recognition ranges, as computed by Equation 8 for the conditions cited above are shown in the figure on page A-7.



We did not collect data in the region to the left of the dotted line in the figure (22 km). Extrapolation into the region would be risky. For example, the recognition range computed by Equation 8 for a visibility of 5 miles (8 km) is also 5 miles. By definition, the contrast at the visibility range is 2%. It is highly unlikely that a recognition could be made at what is usually assumed to be the limiting *detection* range.

Equations 8 and 27 can be used to compute recognition ranges for values of visibility greater than that computed by Equation 33. Equations 10 and 28 can be used to compute the range at which the direction of travel can be recognized for visibilities greater than that given by Equation 33. Other methods of estimation must be used for visibilities less than V_{min}.