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EFFECT OF SENSOR/DISPLAY, TARGET
AND SCENE CHARACTERISTICS ON DETECTION TIME IN
THE DEVELOPMENT OF A TARGET
ACQUISITION MODEL

BY

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THESIS

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PREFACE

This research was undertaken to develop a model that predicts time-to-detect military targets (in this case tanks) using various electro-optical devices displaying selected scenes. Television parameters of interest were display resolution (measured in terms of TV line pairs) and field of view. Inverted polarity images were used to simulate near-infrared sensors. Scene and target variables included scene complexity, target-to-background contrast, number of targets, and range of targets. Each of these variables was contained in a TV display showing a realistic terrain model. These displays were photographed and back-projected onto a ground glass screen.

All variables correlated highly with the time to detect. A basic model was derived using stepwise multiple regression. Using the coefficients in the model, the equipment designer need only multiply the coefficient in the equation by the equipment or scene parameter of interest. The result is the predicted number of seconds to detect the target. The effect on detection time of changing an individual parameter (e.g. resolution of the electro-optical equipment), can also be predicted.

For example, the coefficient derived for display resolution is -0.0227. Thus a 525 line system would result in a 6.2 second savings in target detection time, as opposed to a 250 line system (-11.9 seconds for the 525 line system versus -5.7 seconds for a 250 line

system). A 6 second difference in detection time might have real significance in an operational setting. Therefore, the design engineer can design target detection equipment for a particular operational setting.

Data derived from the performance of the twelve pilots who served as subjects are shown in Table 1. Display resolution is the parameter that contributes most to target detection time here.

TABLE 1
The Effect of the Model Variables on
Predicted Time-to-Detect

Variable	Value of Variable (and Contribution to Detection Time)	
(Y-intercept = 19.99)		
Equipment Variables		
Display Resolution (line pairs)	250 (-5.68 sec)	525 (-11.92 sec)
Field of View	6 degrees (0.87 sec)	33 degrees (4.78 sec)
Scene and Target Variables		
Target-to-Background Contrast	10 percent (-1.04 sec)	40 percent (-4.15 sec)
Scene Complexity	Simple (=1) (5.48 sec)	Complex (=2) (10.97 sec)
Target Size (milliradians)	10.4 (-7.51 sec)	5.4 (-3.75 sec)
Number of Targets	1 (-1.48 sec)	4 (-5.92 sec)
Total Detection Time	10.63 seconds	10.00 seconds

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INTRODUCTION

Target detection as a defined field of research had its beginning in the late 1940's. All of the early research on target detection addressed the problem of search in a structureless, basically uniform, visual field. It was more recently recognized that models of target search must also include the problems of recognition, masking (by terrain or vegetation), confusing objects, and cueing by patterns of land form or man-made structures and networks (Greening, 1976).

The major impetus behind target detection studies has been their military applications. In the "field," target detection involves a complex stimulus viewed against a complex background. Recently an attempt has been made to develop models of target detection taking into account a variety of stimuli and background characteristics. These models are reviewed in Greening (1976) and Scanlan (1976).

The Army Night Vision Laboratory (NVL), as well as a number of other military organizations, has been sponsoring target detection research using realistic stimuli and backgrounds. Johnson (1958) working under sponsorship of the NVL published average values and standard deviations of the number of "resolution elements" required to establish the identity of a variety of tactical targets, to various levels of specificity, using stimuli ranging from a single

infantryman to a tank. In this same area of target detection, Brainard (1965) at Rockwell International, performed a television study, using a terrain model with three simple, geometric shapes added as targets. The resulting finding of 3.2 line pairs for recognition has been incorporated into several current models.

In the usual target detection situation encountered in the field, the target object is usually one of a number of objects viewed against the background. Target acquisition requires searching among objects which have to be rejected as targets, to permit the search to proceed. Boynton (1955, 1957, and 1958) is widely cited in his work exploring the problem of recognizing one shape among many.

Greening (1976) states that the most significant elements in the geometry of the situation are those that establish the viewing angles and distance from the target area and/or search area. The visual scene provides the clues needed for target acquisition. It also provides the confusing nontarget patterns and textures which influence the target acquisition performance. Target size could be represented simply in angular subtense, as far as effect on the observed scene is concerned, and target shape has been shown to be, within broad limits, inconsequential in detection submodels.

Since ground targets do not appear in empty space, the effects of luminance target/background contrast is important. Apparent contrast at the observer's eye is a critical input to the detection submodel of many detection models. Scene characteristics which

appear most important include scene luminance, masking, clutter, and low-likelihood regions. These characteristics, with the exception of scene luminance, are often collectively referred to as scene complexity.

The Scanlan study (1976) breaks out scene complexity into many subfactors. Scanlan felt that there was a necessity to include the influence of backgrounds of varying complexity in a detection model in order that prediction and performance can be described more accurately. Background scene and the location of the target in the scene influence the method used and the time required to detect the target as well as the probability of detecting the target. Thus, any model used to predict the target detection performance must consider the contribution of the background scene.

Scanlan's experiment was conducted to examine the effect of background complexity on detection performance. The stimuli used in the experiment were aerial photographs of actual terrain with tactical vehicle targets photographically embedded. The experimental variables were as follows:

Target-to-background contrast	0.7 and 2.0
Target type	Armored personnel carrier, tank, and truck
Scene complexity	High and low
Display resolution	240 and 480 TV lines
Target subtense	0.178 and 0.356 arc grads (9.6 and 19.2 arc minutes).

The dependent variable was detection time. The analysis of variance showed significant main effects for all five variables. Significant interactions included display resolution by target-to-background contrast, target subtense by display resolution, target subtense by target-to-background contrast, scene complexity by target-to-background contrast, scene complexity by target type, and target-to-background contrast by target type.

The effects of display resolution and target subtense show that with a target subtense of 0.178 arc grads display resolution had no effect on detection time. However, with a target subtense of 0.356 arc grads, higher display resolution significantly reduced detection time.

Although detection time is higher when viewing stimuli with high scene complexity than with low scene complexity, the effects of display resolution show that higher resolution significantly reduces detection time in both high and low scene complexity stimuli.

Scanlan states that an attempt to fit a two parameter model such as the NVL model shown below, to his data clearly shows that this form cannot adequately describe the cumulative probability of detection as a function of time for realistic targets and scenes.

NVL Detection Model

$$P_D(t) = P_D(1 - e^{-t/T_1}) \quad \text{where:}$$

$P_D(t)$ = cumulative probability of detecting an object as candidate target as a function of time,

P_D = probability that an object will be detected as a candidate target in a single fixation,

t = elapsed time from beginning of search, and
 T_1 = time constant reflecting the influence of the
 scene on the search pattern.

In 1978, under NVL sponsorship, Kincaid, Silbernagel, O'Hara, Shirkey, and Cassidy developed a model to predict target detection time and probability using a linear regression model. Kincaid et al. (1978) differs from Scanlan (1976) in that Scanlan breaks out scene complexity into many subfactors. Kincaid (1978) was able to maintain tighter control over the levels of the experimental variables in his test stimuli due to the manner in which the test images were produced. The regression model developed in the Kincaid study takes into account various stimuli and background characteristics which are lacking in the NVL model.

The experimental variables used by Kincaid (1978) were as follows:

Resolution	525 and 1125 TV lines
Field of view	6 degrees and 33 degrees
Scene complexity	Low and high
Number of targets	1 and 4
Target-to-background contrast	Low and high
Video polarity	Regular TV picture and reversed polarity (to produce a FLIR-like image)
Viewing distance	12 inches and 24 inches.

The 128 test stimuli (64 positive polarity and 64 reverse polarity)

were photographs taken from a realistic terrain table.

Two experiments were conducted using different subjects. The first experiment used 60 college students as subjects and the second experiment used six fighter pilots as subjects. The pilots viewed only the positive polarity stimuli at a viewing distance of 24 inches. All other experimental variables were the same for both experiments.

The basic form of the models in the study are regression equations which allow analysis of the relative contributions of the various predictor variables to a criterion (detection time). The pilot data from the second experiment showed lower mean detection times than the student data (5.50 seconds for pilots and 9.05 seconds for students) and higher overall probability of detection for all test images (93.9 percent for pilots and 85.4 percent for students).

The variables correlating most highly with the time to detect were scene complexity, range, and target-to-background contrast. However, display resolution and display field of view were also important. The regression coefficients of the model variables using the pilots' data are:

<u>Variable</u>	<u>Coefficient</u>
Display resolution	-0.001
Field of view	0.005
Target-to-background contrast	-8.323
Scene complexity	3.516
Target size	-0.410
Number of targets	-0.449

Using these coefficients one can determine the number of seconds to be added to or subtracted from the predicted time to detect the target. For example, the coefficient derived for display resolution from the data of the six fighter pilots is -0.001 . Thus a 1000 line system would result in a 0.5 second savings in target detection time, as opposed to a 500 line system (-1.0 seconds for the 1000 line system versus -0.5 seconds for a 500 line system).

The best and most reliable data were derived from the six fighter pilots. Each had extensive experience in target detection, including target detection using TV displays. This use of high qualified subjects by Kincaid (1978) is also a major difference between his research and the research performed by Scanlan (1976).

The purpose of the present study is to extend the research completed in the Kincaid study (1978). The effect of resolution in the previous study by Kincaid (1978) was not found to be significant, however, it was felt that if lower levels of resolution were used, then resolution would have a significant effect on detection time. The present study also only uses reverse polarity test stimuli due to their simulation of near-infrared images. Like the Kincaid study, the present study also derives a target acquisition model that takes into account the effect of sensor/display, target, and scene characteristics on detection time.

Mathematical models of target acquisition have had several limitations; namely, they have concentrated on optical elements of target acquisition and have covered only a few variables. A regression equation (the basic form of the model in the present study)

allows analysis of the relative contributions of the various predictor variables to a criterion. In this case, the predictors are those variables affecting target acquisition, and time to acquire the target is the criterion. Keeping the equation as simple as possible is extremely important from the standpoint of its utility in the design process.

Another requirement of the experimental procedure is to use realistic imagery for derivation of the model. The most realistic imagery is that recorded in flight, but imagery taken from a detailed terrain board serves the same purpose, and allows more systematic work with the experimental variables.

METHOD

Subjects

The subjects were ten current USAF fighter pilots and two ex-Navy fighter pilots. All subjects were extremely familiar with target detection and had extensive experience in low-level attacks on tanks, using Maverick missiles that display a TV image on a head-down display in the aircraft cockpit. The subjects also had extensive experience in an aircraft simulator in which a simulated FLIR sensor is used for low-level terrain avoidance flying and target acquisition. All the subjects were volunteers and were tested at the Martin Marietta Simulation and Test Laboratory, Orlando, Florida.

Apparatus

Slides (35 mm color) were rear projected onto a commercially available 12 by 12 inch ground glass screen (Media Theater) through a GAF projector. Times for target detection were measured to the nearest second using a stopwatch.

A 1200 line 60 MHz high resolution TV system with an optical probe having infinity focus capability was used. The system has a variable line rate and bandwidth, and resolution is maintained up to 1200 lines with a linearity of less than 0.1 percent. Photographs were taken from a Conrac (Model RQB 14/C) black and white display monitor. This monitor can provide up to 1200 lines with linearity

and geometric accuracy of less than 1 percent of picture height. The overall resolution is 4 arc minutes per line pair. Photographs were taken using a Minolta 35 mm camera (Model SRT202) fitted with a lens having 35 mm focal length.

Target-to-background contrast values were measured using a Spectra Combi II light meter with a Spectra 1 degree Photospot. Contrast values were measured directly on the terrain table by reading the brightness of the tank targets and five points immediately around the target. The high contrast targets were coated with a nonreflecting black paint, resulting in a 40 percent contrast value. The low contrast targets were coated with a semi-gloss black paint, resulting in the 10 percent contrast value.

Two line rates were used, 250 and 525 line pairs. The vertical and horizontal line rates of the 525 resolution were calibrated using a RETMA Resolution Chart 1956 displayed in a Tele-Measurement Light Box. This resolution chart was photographed from the television display and the resulting slide was projected through the display mechanism. The 525 line resolution was achieved with the projector in focus. The 250 line resolution condition was achieved by defocusing the projector and determining resolution from the resolution chart. Resolution for the 525 line images was about 500 lines, measured both vertically and horizontally.

The photographs were taken on a very realistic 40 by 80 foot terrain table having a scale of 600:1 that represents a 4.5 by 9 mile area. The terrain is representative of that in northern Germany in that it has many small villages, rolling terrain covered with

vegetation, and a large number of prominent cultural features such as bridges, dams, roads, and railroad tracks.

Test Stimuli

Thirty-two test stimuli were used which was the result of a factorial combination of five of the six independent variables used in this study. Table 2 lists the experimental variables examined. Display resolution, which was held constant for each subject, was treated as a between subjects variable.

In the previous study Kincaid (1978) found no differences due to video polarity or to viewing distance which is the reason these variables were excluded from the present experiment. Although no difference was found due to display resolution, it was felt there would be a significant effect of display resolution if the resolution were reduced to levels approximating those of infrared detection devices. Resolutions of 250 to 500 lines is the range which can be expected of such equipment in the near future. The extremely high line rate tested in the Kincaid study (1125 line pairs) is far above what can be expected of infrared sensing devices for the near future.

Although the test stimuli were the same test images used in the Kincaid study, the number was reduced to 32 because of the elimination of the positive polarity stimuli and the elimination of test stimuli with 1125 TV line resolution. It was also decided that reverse polarity stimuli would be used due to its simulation of FLIR (forward looking infrared) like images.

The targets had a 225:1 scale and were 1.19 cm high, giving an apparent height of 2.68 meters in the test images. Samples of slides

are shown in Figures 1 and 2.

Procedure

A series of 20 trial slides and 32 test slides were presented individually to each subject. (The content of the slides correspond to the experimental variables shown in Table 2.) The twelve subjects were randomly assigned to one of two groups of six each. One group viewed the slides having a resolution of 525 TV lines. The second group viewed the slides with the display resolution reduced to 250 TV lines.

A standardized set of instructions, as shown in the Appendix, was read to each subject prior to viewing the trial slides. The subjects were given as much time as necessary to locate the targets on the trial slides, and feedback was given as to whether a response was correct or incorrect. The test slides were presented after completion of the trial slides. The experimenter started a stopwatch at the same time the test image was projected. When the subject located the target(s) he responded by stating "one" or "four" with respect to the number of targets detected. The time was recorded and the subject was asked to point to the target(s) to determine the correctness of the response. A time limit of 30 seconds was placed on each slide and missed detections were considered as having taken 30 seconds. Subjects were asked to be 80 percent confident that they had correctly located the target(s) prior to responding. The order in which the slides were presented was randomized to minimize effects due to learning or fatigue.

Table 2

Experimental Conditions

Resolution

250 lines

525 lines

Field of view

6 degrees

33 degrees

Scene complexity

Low

High - both subjectively measured.

Highly complex scenes tended to have more clutter around the targets. These required that more of the scene be scanned, since there was more area that a tank could be located. Also, the targets were typically located near foliage in the more complex scenes.

Number of targets (tanks)

1

4

Target-to-background contrast

Low - 10 percent

High - 40 percent

This measurement was done on the terrain model using a 1 degree spot photometer, according to the following formula:

Table 2 (Continued)

$$C = \frac{B_T - B_B}{B_B}$$

where B_T = target brightness, and

B_B = background brightness.

Range

Low

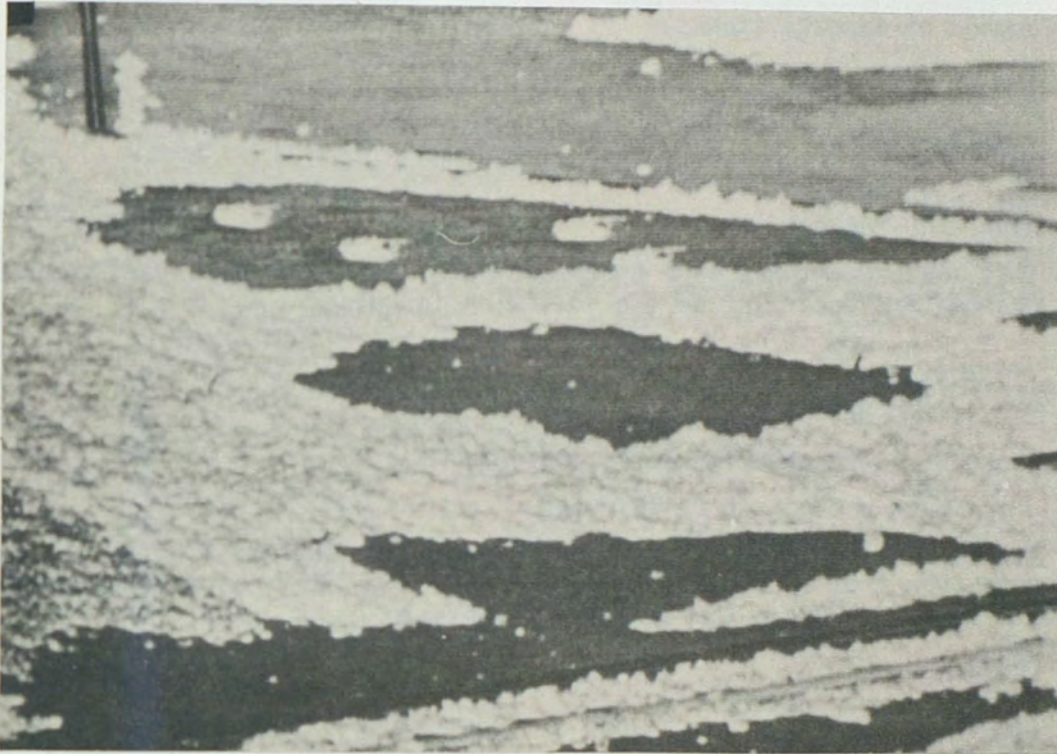
High

Ranges varied with the field of view (FOV). For the 6 degree FOV the low range was 1 kilometer and the high range was 4 kilometers. For the 33 degree FOV, range was reduced to produce the same image sizes on the TV monitor as the 6 degree FOV.

The experimental conditions listed in Table 2 resulted in the 32 photographs used as test stimuli. A factorial combination of variables 2 through 6 resulted in the 32 test images. The same test images were used for both levels of display resolution.

Figure 1

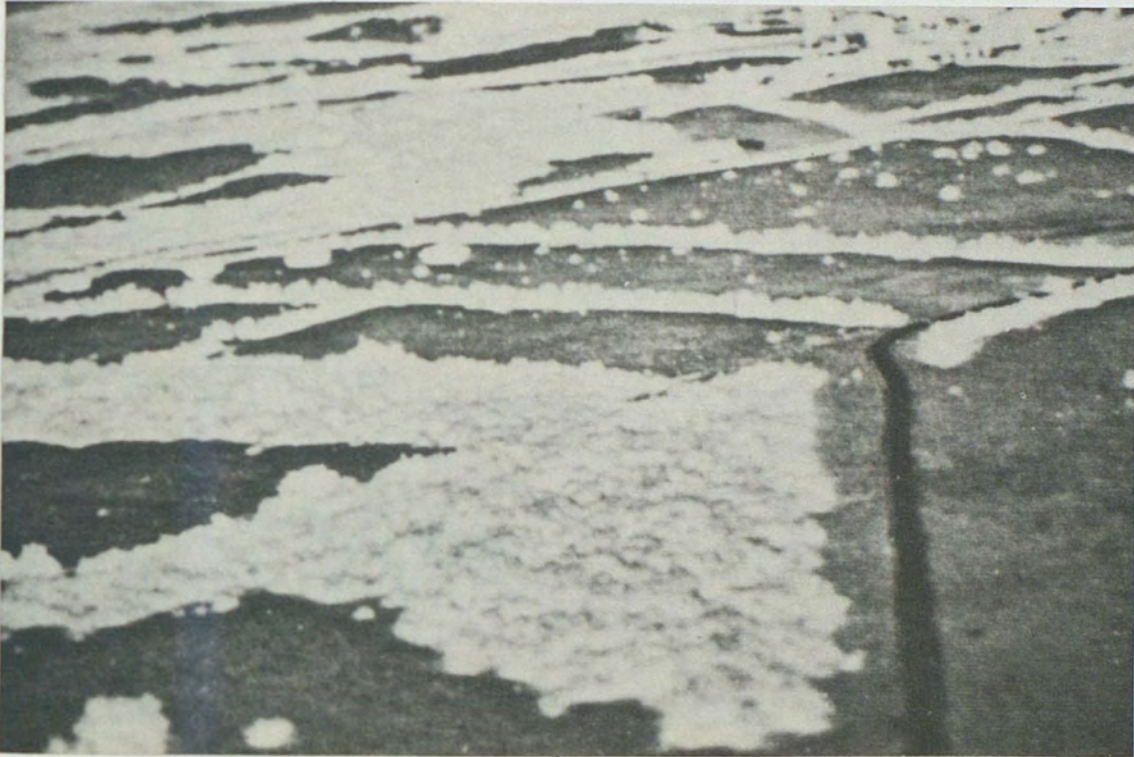
Sample of a Test Slide.



The test stimuli above resulted in very short detection times. It has the following characteristics: 525 lines, 6 degree field of view, low range for the four tank targets which have a 10 percent target-to-background contrast. The background scene is considered low in complexity because the tanks are not masked by foliage and, because much of the scene could not logically contain the targets, resulted in the observer not having to search the entire display.

Figure 2

Sample of a Test Slide



These high contrast targets (40 percent) appear to show up very well. The image is 525 line, 33 degree field of view. Tanks are at low range and appear against a complex background.

RESULTS

A repeated-measures analysis of variance was performed using the data generated from the twelve subjects. Resolution, a between-subject variable, was treated as a grouping factor in the analysis. The analysis was performed using the Biomedical Computer Program for analysis of variance (BMDP P2V, 1977). Table 3 is the summary table of the analysis of variance for detection time showing the main effects and most important interactions. The complete analysis of variance table is found in the Appendix.

Although significant higher order interactions were found, the practical significance of such interactions are not readily seen. Because these interactions do not lend themselves to interpretation, they are not presented here. Significant two way interactions were followed by post hoc comparisons (Tukey Method) in order to determine exactly where differences exist. As can be seen in Table 3 all main effects were found to be significant. Table 4 lists the average detection times and standard deviations of the different levels of the main effects. Standard deviations and average detection times of the two way interactions are given in Table 5.

The effect of increasing display resolution from 250 to 525 TV lines reduced detection time by nearly fifty percent as seen in Table 4. As discussed earlier, the previous study by Kincaid (1978) used levels of resolution that were so high significant differences

Table 3

Summary of Analysis of Variance of Detection
Time Showing Main Effects and
Most Important Interactions

Source	F	P
Display Resolution (DR)	20.4	0.001
Scene Complexity (SC)	69.9	0.000
Range (R)	22.2	0.001
Number of Targets (NT)	30.2	0.000
Target Contrast (TC)	46.0	0.000
Field of View (FOV)	60.4	0.000
DR X SC	15.3	0.003
SC X R	12.9	0.005
SC X NT	14.3	0.004
R X TC	33.6	0.000
FOV X R	11.8	0.008

Table 4

Mean Detection Times and
Standard Deviations for Main Effects

Variable	Mean (sec)	S.D. (sec)
Display Resolution		
250 lines	13.4	6.1
525 lines	7.1	4.7
Scene Complexity		
Low	7.5	4.6
High	13.0	6.1
Range		
Low	8.4	3.7
High	12.1	7.1
Number of Targets		
1	12.5	6.1
4	8.1	4.6
Target Contrast		
10 percent	11.9	5.3
40 percent	8.7	5.5
Field of View		
6 degrees	8.4	4.3
33 degrees	12.2	6.4

Table 5

Mean Detection Times and
Standard Deviations for Two Way Interactions

Interaction		Mean (sec)	S.D. (sec)
Resolution X Scene Complexity			
250	Low	9.4	5.4
250	High	17.5	6.8
525	Low	5.6	3.9
525	High	8.6	5.5
Scene Complexity X Range			
Low	Low	4.7	3.0
Low	High	10.3	6.3
High	Low	12.2	4.4
High	High	13.9	7.9
Complexity X Number of Targets			
Low	1	10.9	6.0
Low	4	4.0	3.3
High	1	13.9	6.2
High	4	12.2	6.0
Range X Target Contrast			
Low	10 percent	11.1	3.4
Low	40 percent	5.7	4.0
High	10 percent	12.6	7.1
High	40 percent	11.7	7.0

Table 5 (Continued)

Interaction		Mean (sec)	S.D. (sec)
Range X Field of View			
Low	6 degrees	5.4	3.4
Low	33 degrees	11.5	4.0
High	6 degrees	11.4	5.3
High	33 degrees	12.9	8.9

were not found. This was the major disadvantage of the detection model developed in that study. Display resolution was of primary interest in the present study and its effect was reliable beyond the 0.001 level of significance.

It was found that the target and scene characteristics also had a large effect on detection time. Table 4 shows that the mean detection time is reduced by 42 percent when viewing a scene of low complexity as compared to a highly complex scene. Range had a similar effect on detection time with the mean detection time of the low range test images being 30 percent lower than the detection time of the high range images.

The differences between the two levels of target-to-background contrast and the two levels of number of targets were also great enough to produce significant differences in detection time. A reduction in detection time of 35 percent occurs when viewing four targets as compared with one target and a reduction in detection time of nearly 27 percent occurs when detecting targets with a 40 percent contrast with the background as compared with targets having only a 10 percent target-to-background contrast.

When examining the remaining equipment variable, field of view, it is seen that detection time decreases nearly 32 percent when using the narrow field of view as contrasted with using the 33 degree field of view.

Table 5 indicates a significant two way interaction of display resolution by scene complexity. Post hoc comparisons found significant differences between 250 and 525 lines of resolution on both

high and low scene complexity. Significant differences were also found between high and low scene complexity for both 250 and 525 lines of resolution (see Figure 3).

When analyzing the range by scene complexity interaction, it was determined that significant differences exist between low and high scene complexity for both low and high range, however, only low scene complexity showed a significant difference between the two levels of range. In the interaction of range by target-to-background contrast a significant difference between the levels of contrast was seen only in the low range condition. High range tends to negate any differences that may exist between the two levels of target contrast. It was also found that targets with a 40 percent contrast with the background were significantly easier to detect at a low range than at a high range.

It is interesting to note that although field of view does not significantly affect detection time at high ranges, the 6 degree field of view does significantly reduce detection times at low ranges (see Table 5). Table 5 also shows that four targets are detected in significantly less time than one target when the scenes are of low complexity. Four targets were also located in less time in scenes of low complexity than in high complexity scenes.

Cumulative probability of detection as a function of time is presented in Figure 4. This figure illustrates the difference in probability of detection between 250 and 525 TV lines of display resolution. Also shown in this figure is the overall cumulative probability calculated by combining both levels of display resolu-

Figure 3

Interaction of Display Resolution by
Scene Complexity

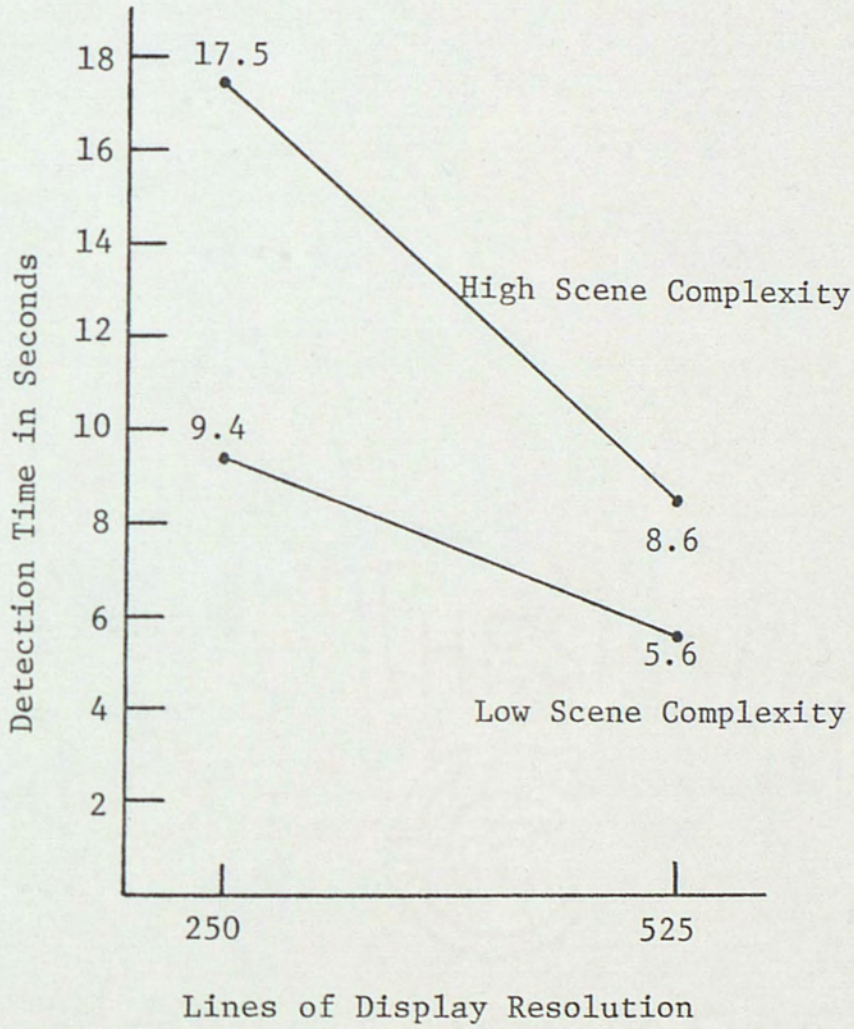
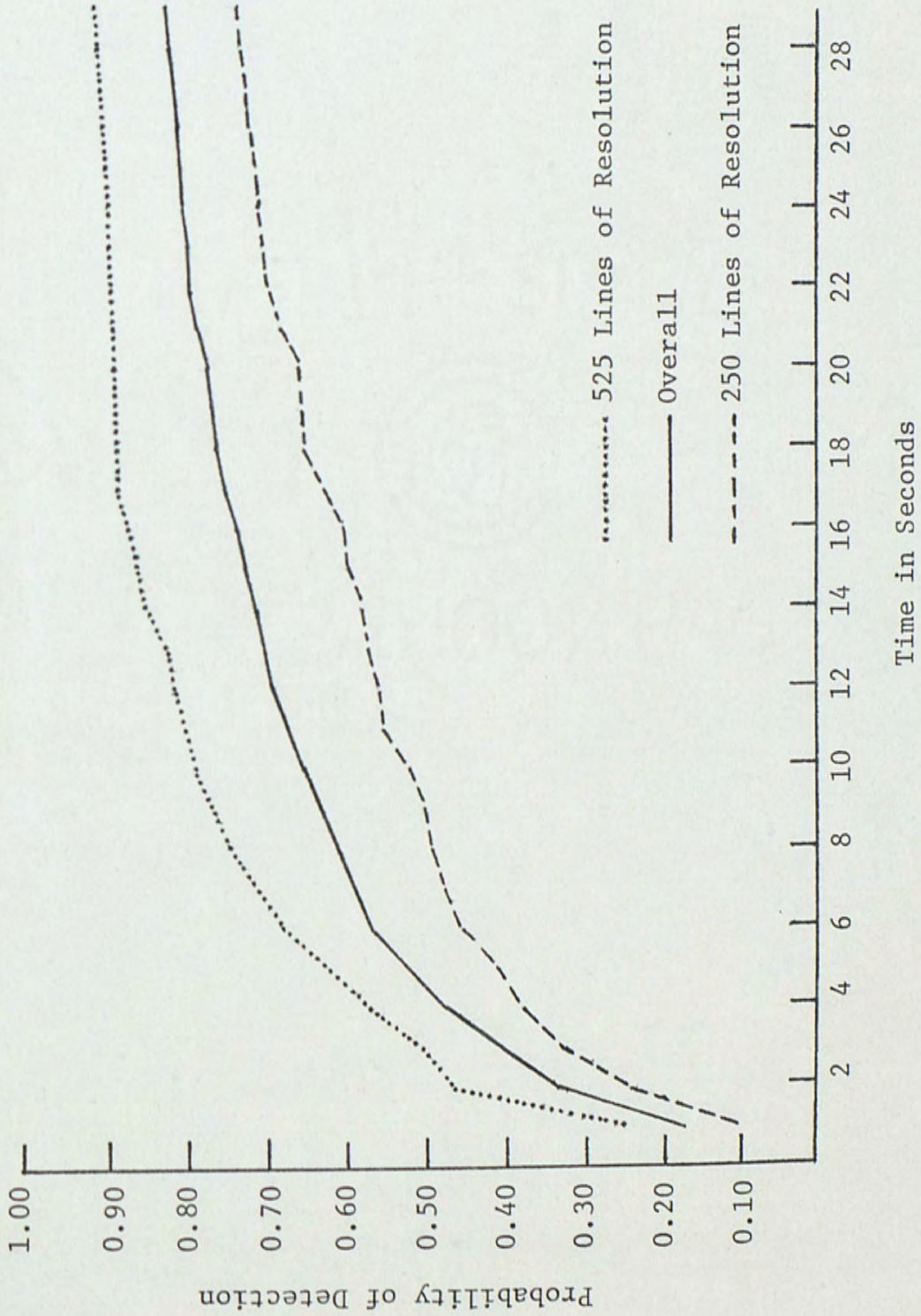


Figure 4
 Cumulative Probability of Detection as
 a Function of Time



Cumulative probabilities are shown for 250 lines of resolution, 525 lines of resolution, and overall probability.

Legend for Figure 4

<u>Seconds</u>	<u>250 Lines</u> <u>Probability</u>	<u>525 Lines</u> <u>Probability</u>	<u>Overall</u> <u>Probability</u>
1	0.104	0.250	0.177
2	0.245	0.427	0.336
3	0.328	0.505	0.416
4	0.380	0.573	0.476
5	0.412	0.641	0.526
6	0.458	0.682	0.570
7	0.479	0.714	0.596
8	0.490	0.750	0.620
9	0.500	0.776	0.638
10	0.531	0.797	0.664
11	0.557	0.802	0.680
12	0.568	0.823	0.696
13	0.583	0.844	0.714
14	0.588	0.854	0.721
15	0.615	0.870	0.742
16	0.615	0.875	0.745
17	0.635	0.880	0.758
18	0.651	0.885	0.768
19	0.662	0.885	0.774
20	0.667	0.891	0.779
21	0.693	0.891	0.792
22	0.703	0.896	0.800
23	0.708	0.896	0.802
24	0.724	0.911	0.818
25	0.724	0.911	0.818
26	0.729	0.911	0.820
27	0.729	0.911	0.820
28	0.740	0.917	0.828
29	0.745	0.917	0.831

tion.

In addition to the analysis of variance, a linear stepwise multiple regression (BMDP P2R, 1977) was also performed on the data generated in this study. Table 6 contains the regression coefficients of the experimental variables used in the experiment. The Appendix contains a table which describes the addition in variance predicted by each variable as it is included into the regression equation.

The regression equation showed the resolution factor to contribute 13.2 percent of the total variance, followed in order of contribution by scene complexity (an additional 10.2 percent), number of targets (an additional 6.7 percent), field of view (an additional 5.2 percent), target size (an additional 4.8 percent), and target-to-background contrast (an additional 3.3 percent). All six variables were retained in the regression equation and each of the variables contributed a significant amount to the total variance predicted.

The coefficients in Table 6 are the model which was the central purpose of this study. Using these coefficients, it is possible to predict detection time for a particular image. As an example, given a TV display with a 250 TV line resolution, a 33 degree field of view, and a scene with one target at long range seen against a complex background having a 40 percent target-to-background contrast, it is possible to predict target detection time. Using the coefficients from Table 6, the calculation of the predicted time is:

Table 6
Regression Coefficients of the
Experimental Variables

Variable	Coefficient
(Y-intercept = 19.9987)	
Display Resolution (TV lines)	-0.0227
Scene Complexity	5.4844
Target Size*	-0.7218
Number of Targets	-1.4802
Target-to-Background Contrast	-10.3855
Field of View	0.1448

*This is the angle (in milliradians) that the height of the target subtends when viewed on a TV screen from the 24 inch viewing distance. The values used in the regression analysis are 10.4 mils for the low range targets and 5.2 for the high range targets.

	Time Contributed (seconds)
Y-intercept	= 19.9987
250 Line Resolution	250 X -0.0227 = -5.6750
Complex Scene	2 X 5.4844 = 10.9688
Long Range (5.2 mils)	5.2 X -0.7218 = -3.7534
Number of Targets	1 X -1.4802 = -1.4802
Target-to-Background	
Contrast = 40 percent	0.40 X -10.3855 = -4.1542
Field of View = 33 degrees	33 X 0.1448 = <u>4.7784</u>
Total Predicted Time	= 20.6831

The actual mean time to detect the tank in this test image was 19.80 seconds.

DISCUSSION AND CONCLUSIONS

As with the Kincaid study, the most useful outcome of this research is the multiple regression equation that predicts target detection time given a series of different scene and electro-optical display values. This study provides an important extension of the results of the previous Kincaid study because it provides data more helpful to the engineer and systems analyst designing electro-optical detection equipment. This study also provides increased prediction accuracy with the target detection model generated. The experimental variables in the present study can account for 43.3 percent of the total variance in detection time whereas the model developed in the Kincaid study accounted for 18.3 percent of the variance (using the pilots' data from Experiment 2). This increase in predictability may be due in part to the three major differences which contrast these two studies.

- 1) The present study used much lower levels of resolution (250 and 525 TV lines) than the previous study (525 and 1125 TV lines) and found a significant effect due to resolution.
- 2) The present study tested subjects on reverse polarity (FLIR-like) images while the pilots in the Kincaid study were tested on positive polarity test stimuli. It may be questionable, however, that this difference

in test stimuli would have led to the difference in results obtained. In Experiment 1 of his study, Kincaid (1978) found no difference due to video polarity. It should be noted that the subjects in the experiment were 60 college students and that video polarity was not an experimental variable when testing the pilots. The subjects in the present study, all of whom were experienced fighter pilots, had extensive experience in target detection and, more importantly, all had recent experience in an aircraft simulator in which they viewed a simulated FLIR video monitor in low-level terrain avoidance flying and target acquisition.

- 3) The data in the study by Kincaid (1978) using pilots was obtained from only six subjects whereas the results of the present study are based on data obtained from twelve subjects.

The results of this study and of the study by Kincaid (1978) show that an increase in display resolution greatly aids target detection--however, only up to a certain level. (This level cannot be conclusively defined given the results of these two studies.) The results of the present study also show that there was present an important resolution by scene complexity interaction. The equipment by scene condition of 250 lines of resolution and high scene complexity resulted in very long detection times (see Table 5). Thus, if a near-infrared sensor is to be used in an area where scene complex-

ity would be high (e.g. northern Germany) then a higher resolution sensor would be desired. However, in a low complexity scene environment (e.g. Middle East) then a 250 line system would be acceptable.

The model developed in this study is considered valid and useful because the subjects are similar in their target detection capability to experienced Army combat troops. This is an important consideration since the present study is the extension of the study by Kincaid (1978) which developed its target detection model for purposes of generalizing to Army combat troops experienced in the detection process. It is possible, however, that the subjects' performance as seen in this study may be better in target detection than what one would expect to see if Army troops experienced in target detection had served as subjects.

Since the test images used in this study were taken from a terrain board which consisted of terrain typical of northern Germany, one should be careful about generalizing these results to other types of terrain (although one exception to this has already been made by the author).

A regression model of target detection, such as the one developed in this study, can consider a wide variety of factors, each of which can have a significant impact on target search time. Most current models cannot easily handle the effects of many factors. Also, since some electro-optical devices such as infrared do have low display resolutions, this model should be more useful to design engineers for this purpose than the model developed by Kincaid (1978).

Detection models, such as the one developed here, have much value due to the large effect of display resolution and field of view on target acquisition time. This model can provide considerable utility in aiding the designer of electro-optical detection devices for battlefield search use.

APPENDIX

DIRECTIONS FOR THE EXPERIMENT

You will be shown two sets of slides consisting of a variety of terrain scenes and targets, namely, military tanks. You are to locate the targets as quickly as possible, while still being approximately 80 percent confident that your response is correct. All the slides will have either one or four targets present. There are no cases in which no targets will be present. The first set of slides are trial slides. These will be used so that you may familiarize yourself with viewing the slides and with the targets. The tanks will be located at various angles and distances. If there are four tanks, they will be in some type of loose formation; typically there will be about five to seven tank lengths between the targets. After viewing the first set of slides, you will be shown the set of test slides. You will be timed on these slides for time of detection. Although time is important, remember that accuracy is also very important. When you locate all the targets in each particular slide, simply state the number of tanks seen, one or four. I will then stop the watch and ask you to point out the targets. If there are four tanks present, you should be able to point to all four. You will be given thirty seconds to locate the targets in each slide. These slides vary in difficulty and you are not expected to be able to correctly locate all the targets in all the slides.

Table 7

Raw Data from the Experiment

Slide Number	<u>250 Line Resolution</u>						<u>525 Line Resolution</u>					
	<u>Subject</u> 1	2	3	4	5	6	1	2	3	4	5	6
1	30"	30	30	30	30	30	30	30	30	30	30	30
2	9	30	21	28	30	30	2	14	30	13	5	10
3	30	30	13	17	11	10	8	30	13	28	30	1
4	30	9	30	21	30	6	10	11	5	6	7	7
5	30	29	15	13	11	8	5	4	5	15	5	3
6	6	2	4	5	11	4	6	1	1	3	4	2
7	2	12	4	4	3	3	5	1	2	6	2	2
8	1	1	3	2	1	2	1	1	1	1	1	1
9	1	1	1	3	1	1	1	1	1	1	1	1
10	1	6	7	3	3	3	4	2	5	4	1	1
11	4	12	5	30	6	6	30	2	1	2	30	3
12	10	30	18	7	30	21	2	3	4	3	1	2
13	1	10	2	3	2	1	4	1	1	1	5	1
14	1	18	30	30	30	3	8	6	30	12	8	6
15	30	30	30	30	30	30	9	4	2	15	22	5
16	6	24	22	20	18	17	8	2	2	16	24	2
17	4	30	19	22	15	30	10	1	10	4	12	13
18	3	2	5	3	2	3	2	1	2	3	2	1
19	1	2	5	2	2	2	2	1	3	7	2	1
20	30	30	26	30	30	30	20	12	13	8	30	9
21	30	23	30	6	8	6	3	6	24	15	2	4
22	1	15	21	11	4	2	2	3	2	7	4	1
23	2	19	17	5	2	5	5	1	2	8	2	1
24	2	30	14	15	30	2	4	17	24	18	5	7
25	2	4	13	7	3	2	2	1	2	5	2	1
26	2	1	3	2	2	2	1	1	1	2	2	1
27	3	28	10	10	6	21	3	1	2	3	2	12
28	24	30	30	30	24	30	6	2	9	9	30	1
29	2	15	11	7	3	2	6	1	4	4	3	1
30	2	17	30	10	30	30	30	3	8	14	30	2
31	1	1	1	2	1	1	1	1	1	1	1	1
32	4	30	30	30	4	30	5	2	3	9	7	3

Table 8
Analysis of Variance Table

Source	Sum Squares	Degrees Freedom	Mean Square	F	P
Resolution (R)	3837.97	1	3837.96	20.36	0.001
Error	1884.59	10	188.45		
Complexity (K)	2959.25	1	2959.25	69.95	0.000
KR	645.84	1	645.64	15.26	0.003
Error	423.02	10	42.30		
Range (G)	1320.16	1	1320.16	22.25	0.001
GR	80.66	1	80.66	1.35	0.271
Error	593.28	10	59.32		
KG	360.37	1	360.37	12.87	0.005
KGR	95.99	1	95.99	3.42	0.094
Error	279.99	10	27.99		
Number of Targets (T)	1828.75	1	1828.75	30.25	0.000
TR	21.09	1	21.09	0.34	0.568
Error	604.51	10	60.45		
KT	656.25	1	656.25	14.27	0.004
KTR	213.00	1	213.00	4.63	0.057
Error	459.60	10	45.96		
GT	80.66	1	80.66	1.42	0.261
GTR	32.66	1	32.66	0.57	0.465
Error	567.29	10	56.72		
KGT	522.66	1	522.66	7.06	0.024
KGTR	22.04	1	22.04	0.29	0.597
Error	739.41	10	73.94		
Contrast (C)	962.66	1	962.66	46.04	0.000
CR	84.37	1	84.37	4.03	0.072
Error	209.08	10	20.90		
KC	57.04	1	57.04	0.84	0.380
KCR	7.04	1	7.04	0.10	0.753
Error	675.28	10	67.52		
GC	472.59	1	472.59	33.65	0.000
GCR	90.09	1	90.09	6.41	0.030
Error	140.43	10	14.04		

Table 8 (Continued)

Source	Sum Squares	Degrees of Freedom	Mean Square	F	P
KGC	1046.75	1	1046.75	17.77	0.002
KGCT	58.59	1	58.59	0.99	0.342
Error	589.01	10			
TC	112.66	1	112.66	4.21	0.067
TCR	51.04	1	51.04	1.91	0.197
Error	267.16	10	26.71		
KTC	181.49	1	181.49	8.24	0.017
KTCR	192.66	1	192.66	8.74	0.014
Error	220.20	10	22.02		
GTC	956.34	1	956.34	17.24	0.002
GTCR	3.01	1	3.01	0.05	0.820
Error	554.51	10	55.45		
KGTC	846.09	1	846.09	9.91	0.010
KGTCR	36.26	1	36.26	0.42	0.529
Error	853.01	10	85.30		
Field of View (F)	1410.66	1	1410.66	60.43	0.000
FR	0.16	1	0.16	0.01	0.934
Error	233.41	10	23.34		
KF	15.04	1	15.04	0.48	0.504
KFR	10.66	1	10.66	0.34	0.572
Error	313.29	10	31.32		
GF	499.59	1	499.59	11.84	0.006
GFR	98.00	1	98.00	2.32	0.158
Error	421.89	10	42.18		
KGF	1033.59	1	1033.59	33.01	0.000
KGFR	0.26	1	0.26	0.01	0.930
Error	322.89	10	32.28		
TF	42.66	1	42.66	1.24	0.291
TFR	352.66	1	352.66	10.26	0.009
Error	343.41	10	34.34		
KTF	37.49	1	37.49	0.83	0.382
KTFR	176.04	1	176.04	3.92	0.076
Error	448.70	10	44.87		

Table 8 (Continued)

<u>Source</u>	<u>Sum Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Square</u>	<u>F</u>	<u>P</u>
GTF	688.00	1	688.00	38.29	0.000
GTFR	128.34	1	128.34	7.14	0.023
Error	179.64	10	17.96		
KGTF	58.59	1	58.59	0.81	0.387
KGTFR	21.09	1	21.09	0.29	0.599
Error	716.31	10	71.63		
CF	142.59	1	142.59	2.64	0.135
CFR	36.26	1	36.26	0.67	0.431
Error	539.14	10	53.91		
KCF	1127.50	1	1127.50	76.58	0.000
KCFR	23.01	1	23.01	1.56	0.240
Error	146.22	10	14.62		
GCF	1395.37	1	1395.37	21.92	0.001
GCFR	104.16	1	104.16	1.63	0.230
Error	636.45	10	63.64		
KGCF	0.16	1	0.16	0.01	0.940
KGCFR	42.66	1	42.66	1.52	0.246
Error	280.41	10	28.04		
TCF	1020.50	1	1020.50	24.05	0.001
TCFR	82.50	1	82.50	1.94	0.193
Error	424.22	10	42.42		
KTCF	128.34	1	128.34	3.03	0.112
KTCFR	195.50	1	195.50	4.62	0.057
Error	422.89	10	42.28		
GTCF	176.04	1	176.04	3.22	0.103
GTCFR	368.16	1	368.16	6.75	0.027
Error	545.04	10	54.50		
KGTCF	495.04	1	495.04	8.55	0.015
KGTCFR	459.37	1	459.37	7.93	0.018
Error	578.83	10	57.88		

Table 9
Correlation Matrix of Dependent and Independent Variables

	1	2	3	4	5	6	7
Resolution	1.0000						
Scene Complexity	0.0000	1.0000					
Target Size	0.0000	0.0000	1.0000				
Number of Targets	0.0000	0.0000	0.0000	1.0000			
Contrast	0.0000	0.0000	0.0000	0.0000	1.0000		
Field of View	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	
Detection Time	-0.3636	0.3189	-0.2182	-0.2582	-0.1812	0.2273	1.0000

Table 10

Summary of Stepwise Multiple Regression

Step Number 1

Variable Entered - Resolution
 Multiple R 0.3636
 Multiple R-Square 0.1322
 Std. Error of Est. 8.1387

<u>Variable</u>	<u>Coefficient</u>	<u>Std. Error of Coeff.</u>	<u>Std. Reg. Coeff.</u>	<u>F to Remove</u>
(Y - Intercept = 19.122)				
Resolution	-0.023	0.007	-0.364	9.445

Step Number 2

Variable Entered - Complexity
 Multiple R 0.4836
 Multiple R-Square 0.2339
 Std. Error of Est. 7.7094

<u>Variable</u>	<u>Coefficient</u>	<u>Std. Error of Coeff.</u>	<u>Std. Reg. Coeff.</u>	<u>F to Remove</u>
(Y - Intercept = 10.896)				
Resolution	-0.023	0.007	-0.364	10.527
Complexity	5.484	1.927	0.319	8.097

Step Number 3

Variable Entered - Number of Targets
 Multiple R 0.5482
 Multiple R-Square 0.3006
 Std. Error of Est. 7.4274

<u>Variable</u>	<u>Coefficient</u>	<u>Std. Error of Coeff.</u>	<u>Std. Reg. Coeff.</u>	<u>F to Remove</u>
(Y - Intercept = 14.596)				
Resolution	-0.023	0.007	-0.364	11.341
Complexity	5.484	1.857	0.319	8.724
Number of Targets	-1.480	0.619	-0.258	5.719

Step Number 4

Variable Entered - Field of View
 Multiple R 0.5935
 Multiple R-Square 0.3522
 Std. Error of Est. 7.0281

Table 10 (Continued)

Step Number 4 (Continued)

<u>Variable</u>	<u>Coefficient</u>	<u>Std. Error of Coeff.</u>	<u>Std. Reg. Coeff.</u>	<u>F to Remove</u>
(Y- Intercept = 11.773)				
Resolution	-0.023	0.007	-0.364	12.041
Complexity	5.484	1.802	0.319	9.263
Number of Targets	-1.480	0.601	-0.258	6.072
Field of View	0.145	0.067	0.227	4.706

Step Number 5

Variable Entered - Size of Target

Multiple R	0.6323
Multiple R-Square	0.3999
Std. Error of Est.	6.9977

<u>Variable</u>	<u>Coefficient</u>	<u>Std. Error of Coeff.</u>	<u>Std. Reg. Coeff.</u>	<u>F to Remove</u>
(Y - Intercept = 17.402)				
Resolution	-0.023	0.006	-0.364	12.777
Complexity	5.484	1.749	0.319	9.828
Number of Targets	-1.480	0.583	-0.258	6.443
Field of View	0.145	0.065	0.227	4.994
Size of Target	-0.722	0.336	-0.218	4.602

Step Number 6

Variable Entered - Contrast

Multiple R	0.6578
Multiple R-Square	0.4327
Std. Error of Est.	6.8631

<u>Variable</u>	<u>Coefficient</u>	<u>Std. Error of Coeff.</u>	<u>Std. Reg. Coeff.</u>	<u>F to Remove</u>
(Y - Intercept = 19.999)				
Resolution	-0.023	0.006	-0.364	13.283
Complexity	5.484	1.716	0.319	10.217
Number of Targets	-1.480	0.572	-0.258	6.698
Field of View	0.145	0.064	0.227	5.192
Size of Target	-0.722	0.330	-0.218	4.785
Contrast	-10.385	5.719	-0.181	3.297

REFERENCE LIST

- Boynton, R. M., & Bush, W. R. Laboratory studies pertaining to visual air reconnaissance, Part I (TR 55-304). Dayton: Wright Air Development Center, 1955.
- Boynton, R. M., & Bush, W. R. Laboratory studies pertaining to visual air reconnaissance, Part II (TR 55-304). Dayton: Wright Air Development Center, 1957.
- Boynton, R. M., Elworth, C., & Palmer, R. M. Laboratory studies pertaining to visual air reconnaissance, Part III (TR 55-304). Dayton: Wright Air Development Center, 1958.
- Brainard, R. W., Hanford, E., & Marshall, R. Resolution requirements for identification of targets in television imagery (NA63H-794). Columbus, Ohio: North American Rockwell, 1965.
- Greening, C. P. Mathematical modeling of air-to-ground target acquisition. Human Factors Journal, 1976, 18(2), 111-148.
- Johnson, J. Analysis of image forming systems. In Proceedings of the Image Intensifier Symposium. Fort Belvoir, Virginia, October 6-7, 1958.
- Kincaid, J. P., Silbernagel, B. L., O'Hara, J. W., Shirkey, E. C., & Cassidy, T. W. Development of a target acquisition model: effect of sensor/display and scene characteristics (OR 15,052). Fort Belvoir, Virginia: Night Vision Laboratory, 1978.
- Scanlan, L. A. Target acquisition model development: effect of realistic terrain (D4977, P76-484). Culver City, CA: Hughes Aircraft Co., 1976.