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DETECTING TACTICAL TARGETS WITH MOTION PICTURES FROM LOW SLOW AIRCRAFT

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FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Aerospace Medical Research Laboratory

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Finding and recognizing small unbriefed tactical targets with a narrow-angle forward-looking airborne sensor was examined at a simulated aircraft speed of 60 knots, in the helicopter and hovercraft speed range. A motion picture camera depressed 7° downward flown near noon on sunny days at 340 feet above the terrain along country roads in Florida collected black-and-white pictures, with a narrow field of view of 6° 4' high and 8° 21' wide. Displayed scene resolution for observers in the laboratory was (Contd)

degrees minutes

minutes

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20. Abstract

about 1-3/4 minutes of arc. Fourteen university students searched the motion picture screen for heavy construction equipment, trucks, cars, and people.

Performance measures were correlated with each other and with target characteristics. Acquisition ranges, percentage of targets detected (%D), and response accuracy increased with target size. Acquisition range and response time varied significantly with response accuracy only for cars, and with contrast only for trucks. Average contrast of detected targets was, except for trucks, unrelated to %D, accuracy, and reaction time. Relative ranks of observers on %D were not maintained across target types, and neither was rank on accuracy, but reaction time had some consistency across target types. Observer selection was discussed.

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SUMMARY

This study examined the ability of observers to find and recognize small unbriefed tactical targets with a narrow-angle forward-looking airborne sensor. A motion picture camera flown at 340 feet above the terrain and depressed 7° downward from the horizontal collected black-and-white pictures with a 6° 4' high by 8° 21' wide field of view. All targets were in the open in near noon sunlight. Projection rate simulated an aircraft speed of 60 knots. Image scale varied from 1/1200 at the top to 1/470 at the bottom of the display. For high contrast objects the total number of resolved picture elements on the display was approximately equal to that on home TV sets, while displayed scene resolution was about 1¾ minutes of arc. The moving scene was searched individually by 14 university students for people, cars, trucks, and heavy construction equipment.

Average target acquisition slant range, percentage of targets detected, and response accuracy all increased with increase in target size. At the extremes in size, heavy construction equipment and people, these measures yielded, respectively, 3460 versus 2680 feet; 82 versus 46% recognized; and 84 versus 59% of responses were to real targets. The equation, Sum(%D) = A Log (X) + B, was found to relate cumulative percentage of targets detected to distance down the display when detected, i.e., to slant range.

Detection probability varied significantly with contrast only for trucks. Rapidity of detection was related to: (1) accuracy only for cars, (2) contrast only for trucks. It was not related to percentage of targets detected. Average contrast of detected targets was, except for trucks, unrelated to: (a) %D, (b) accuracy, (c) reaction time and (d) position on the display screen when detected. Targets detected, on the average, at larger distances were also more likely to be detected.

Observers did not maintain their rankings on %D from one type of target to another. For most types of targets, accuracy on one type was of little or no value in predicting accuracy with another type of target. There was some consistency in observers in reaction time with different types of targets. The problem of observer selection was discussed.

PREFACE

This report was prepared in the Human Engineering Division of the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed under Project 7184, "Man-Machine Integration Technology." This study was originated and conducted at the request of and in support of Project Shedlight. The authors wish to express their gratitude to Mr. Donald L. Beam, Systems Integration Section of the Advanced Systems Analysis Division (ASB), for his many hours of superb assistance and direction in the collection of the film which made this study possible. Thanks are due to Captain Donald Thurman, the project officer and pilot from the directorate of flight test (AST), for his diligent care in the image collection flights, and to Mr. Ken Arnold for his skill in setting up and maintaining the movie camera. Special thanks are also extended to MSgt Don Coones from the Reconnaissance Applications Branch (AVRS) for the care and ingenuity that he displayed in the picture-taking flights. The help given in preparing this manuscript by Mrs. Betty F. Reid and Mrs. Dorothy M. Chouinard is greatly appreciated.

INTRODUCTION

This study was initiated in response to requests from a number of U.S. Air Force organizations for data on target acquisition ranges and detection probabilities from low-flying aircraft. The types of targets of interest were small tactical targets of opportunity, including people and vehicles. The sensors of particular interest were closed circuit television and direct view night vision devices of the intensifier type. The aircraft speed simulated was 60 knots, which is in the speed range of helicopters and hovercraft.

A forward-looking motion picture camera was used to collect imagery for the study. It was flown over various areas of the southeastern United States. The equipment available to the experimenters for displaying the motion pictures on a television monitor was found to be inadequate in image quality, particularly in resolution of small details in the pictures. Therefore, it was decided to use a standard motion picture film projector to optically project pictures onto a rear-projection screen. Measurements made on the display screen with this equipment showed that display resolution was approximately the same as that provided by commercial television stations to Americans' homes.

Future research may indicate a requirement to modify the results of the present study because of the characteristics of other sensors. However, some of the results, such as the influence of target size and contrast and findings relative to observer selections, may require little modification.

PROCEDURE

IMAGE COLLECTION

The motion pictures were taken between 1000 and 1400 hours from the nose of an RB-47 aircraft flying at an altitude of approximately 340 feet above the terrain. The aircraft speed was about 240-260 knots. The imagery was collected over various areas of the southeastern part of the United States, the majority of it over generally wooded areas in northern Florida. The picture collection flights took place in March of 1967. There were some trees of types that have no leaves this time of year. However, a large portion of the trees were not of those types. Pine trees were particularly common in the pictures. The ground was covered in most areas with grass, in some places grass and weed growth was massive; dense vegetation was frequent. Examination of the pictures in the Appendix shows the heavy foliage in some areas. Most of the motion picture film was collected while following country roads.

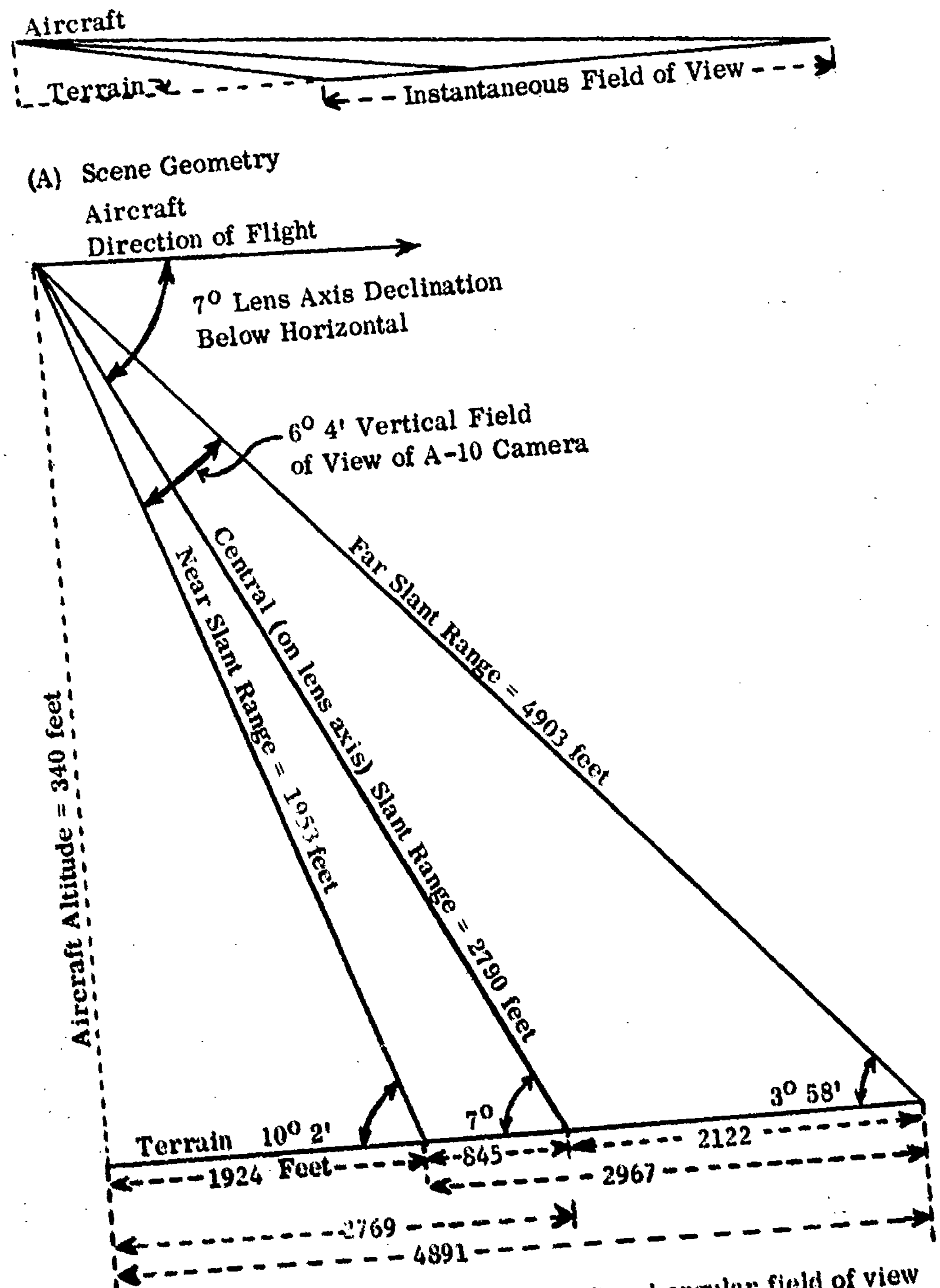
Filming was done with an Air Force A-10 camera*. Initial experiments with a 4-inch focal length lens yielded pictures with images of people that were too poorly resolved. It was judged that the probability of detecting people on the ground from film made with this lens would be unacceptably low. Therefore, it was necessary to substitute a 6-inch focal-length lens for the 4-inch lens even though this substitution resulted in a field of view that was only 6° 3' high and 8° 20' wide. Pictures were taken at 96 frames (pictures) per second since pilot tests with slower frame rates resulted in projected pictures that, due to the high speed (240 knots) of the aircraft, appeared jumpy or jerky when projected. Motion over the terrain between pictures at slower frame rates than 96 per second simply did not allow enough overlap of successive pictures to allow the motion on the displayed pictures to give the illusion to the viewer that motion over the terrain was smooth and continuous. The film used to take the pictures, Kodak Plus-X film, yielded black-and-white pictures without objectionable amounts of photographic grain, as would have been the case with some of the faster (more light sensitive) films often used for taking motion pictures. Low graininess helped to maintain an illusion of looking at moving terrain rather than at a motion picture display.

The pictures were taken through an optically flat photographic window located in the nose of the RB-47 aircraft. The camera was mounted so that, when the aircraft was flying at a 340 foot altitude at 240 knots, the lens axis of the camera was at 0° azimuth (stright forward), but was inclined downward by 7°. Objects on a line down the center of the flight path thus came into view at the scene top while at a ground range of approximately 4890 feet (slatt range 4900 feet), and went out at the scene bottom while at a ground range of approximately 1920 feet (slant range 1950 feet). The scene geometry and the ground and slant ranges are shown in figure 1.

The forward looking camera's declination, with consequent variation in slant range from the top to the bottom of the scene, yielded an imaged width of terrain that increased from the bottom to the top of the display. Thus, though the displayed image was rectangular, the territory on display was somewhat wedged-shaped, as shown in figure 2. This meant, also, that the center of the display was not the center of the displayed terrain.

The variation in slant range as a function of distance down from the top of the display is shown in figure 3. Note that the relationship is not linear. Figure 3 also shows the time in seconds that the images of objects have been on the display for various screen positions and slant ranges.

*The A-10 is a half-frame 35 mm motion picture camera with a nonstandard picture format of 16.1 mm high by 22.2 mm wide. The half-frame designation applied to 35 mm motion picture cameras because they take pictures that are only half the height (along the film) of pictures taken with ordinary (or "full frame") 35 mm still cameras.



(B) Ranges and ground coverages (height of aircraft and angular field of view distorted by 15X enlargement of the vertical scale for ease of illustration and labeling).

Figure 1. Scene geometry and ground and slant ranges at the top, center, and bottom of the scene on display.

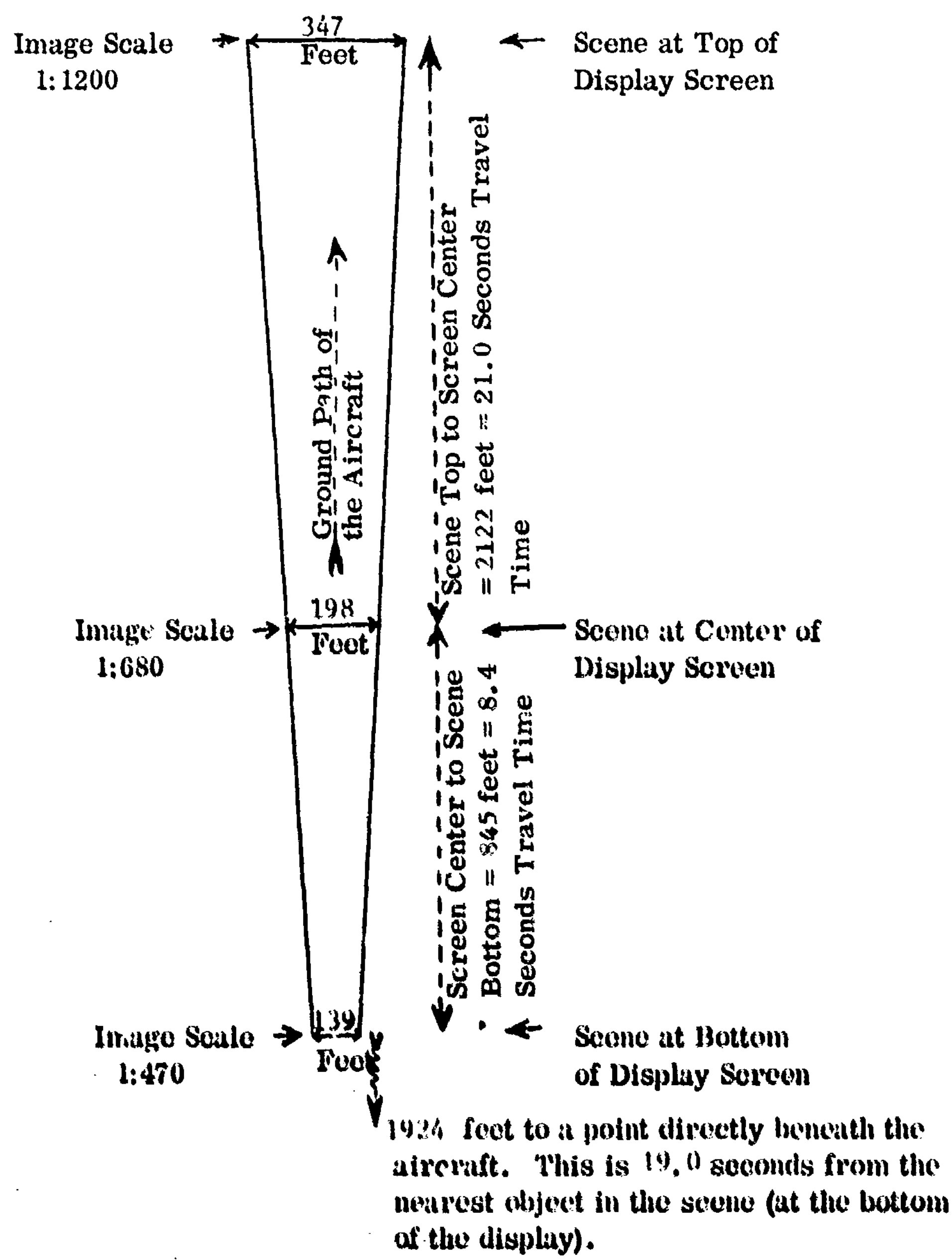


Figure 2. The shape and dimensions of the wedge of terrain whose image fills the 130 by 180 millimeter rectangular screen at any one moment.

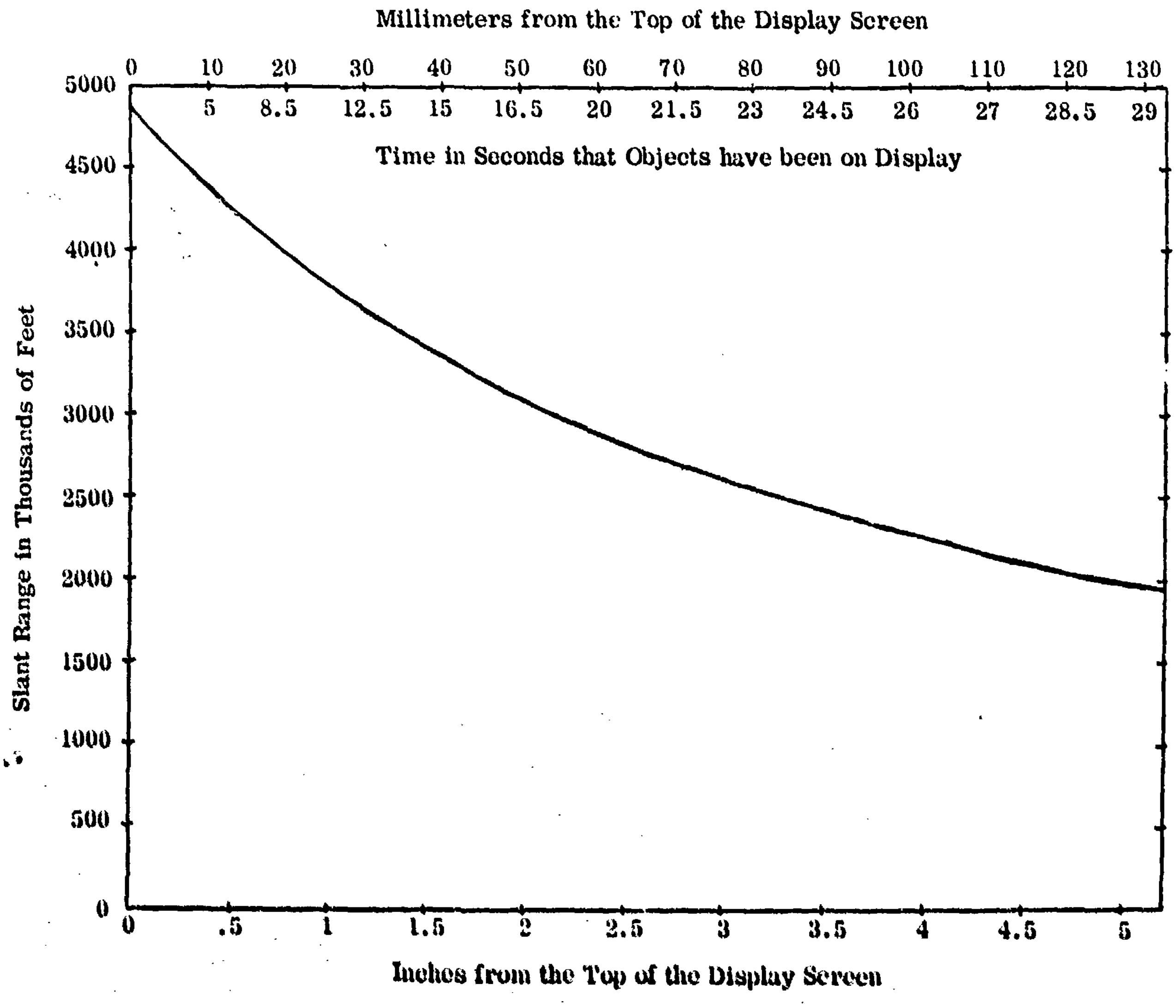


Figure 3. Slant range to the terrain and time that objects have been on the display for various image positions on the screen for a line down the center of the display. Time is rounded to the nearest half second.

The pilot of the aircraft was instructed to fly at a constant barometric altitude and attempted to do so. The strips or runs of film that were used in this study appeared to represent fairly level terrain. However, the terrain was not always flat and level even though it appeared to be in the narrow field of view of the camera. Gradual slope of the terrain was not apparent. The terrain was not always at the same altitude above sea level. The actual map location of the terrain on the runs that were used in testing was known only approximately. The aircraft altitude above the terrain was calculated from the size on the film of the images of automobiles. This procedure yhielded an average altitude of 340 feet. At times, the actual altitude could have varied from this value by as much as 20% or more. This would influence the size of the ground swath on display, acquisition slant range, etc., all of which were calculated with the average value of 340 feet for aircraft altitude above the terrain.

THE MOTION PICTURES

The nature of the motion picture scenes that were used is best visualized and understood by examination of enlargements made from single frames (or pictures) of the motion picture film. Figures 4 through 10 were selected to illustrate both easy and difficult targets. The targets are circled in the pictures. Keep in mind that the printed pictures will have some loss in resolution of fine details and a considerable loss in dynamic range as compared to the projected transparent film viewed on the display screen by the observers. Also, due to the 24 frames or pictures per second of the motion pictures, observers did not see the "grain" that is apparent in a static enlargement of a single picture or frame. Loss of grain in projection makes the scene look more "natural" than single static pictures.

PROJECTION SYSTEM FOR IMAGE DISPLAY

Since a standard 35 mm projector was not available, the original film was printed as a positive transparency at a reduced scale on 16 mm film. A Bell and Howell stop motion variable speed motion picture projector and a large screen were used to examine the film to find and identify all of the imaged targets. The same projector was used at a frame rate of 24 pictures per second to present the motion pictures to the test subjects. Since the ground scene was originally filmed at 96 frames second, but was played back to observers at only 24 frames second, the aircraft speed simulated in this study was 60 knots. Thus, the study simulates motion pictures taken from slow moving aircraft such as helicopters or hovercraft.

A small rear projection Polacoat® display screen was used during subject testing. Its 133 mm height and 180 mm width, or about 5½ x 7 inches, is consistent with the size of displays used in typical cockpits; cockpit dimensions usually preclude the use of large displays. The brightness of the screen varied with the terrain and with the objects on the terrain. It ranged from approximately 3 to 20 foot-lamberts for relatively dark terrain (such as grass and other dense vegetation), to about 130 to 150 foot-lamberts for bright white sand coral roads. The screen was divided by horizontal and vertical grid lines into a three by three matrix to facilitate recording the observer responses. This can be seen by examining the subject's display screen in figure 11. It turned out that this grid was not necessary in scoring since there were no malfunctions in the data scoring camera.

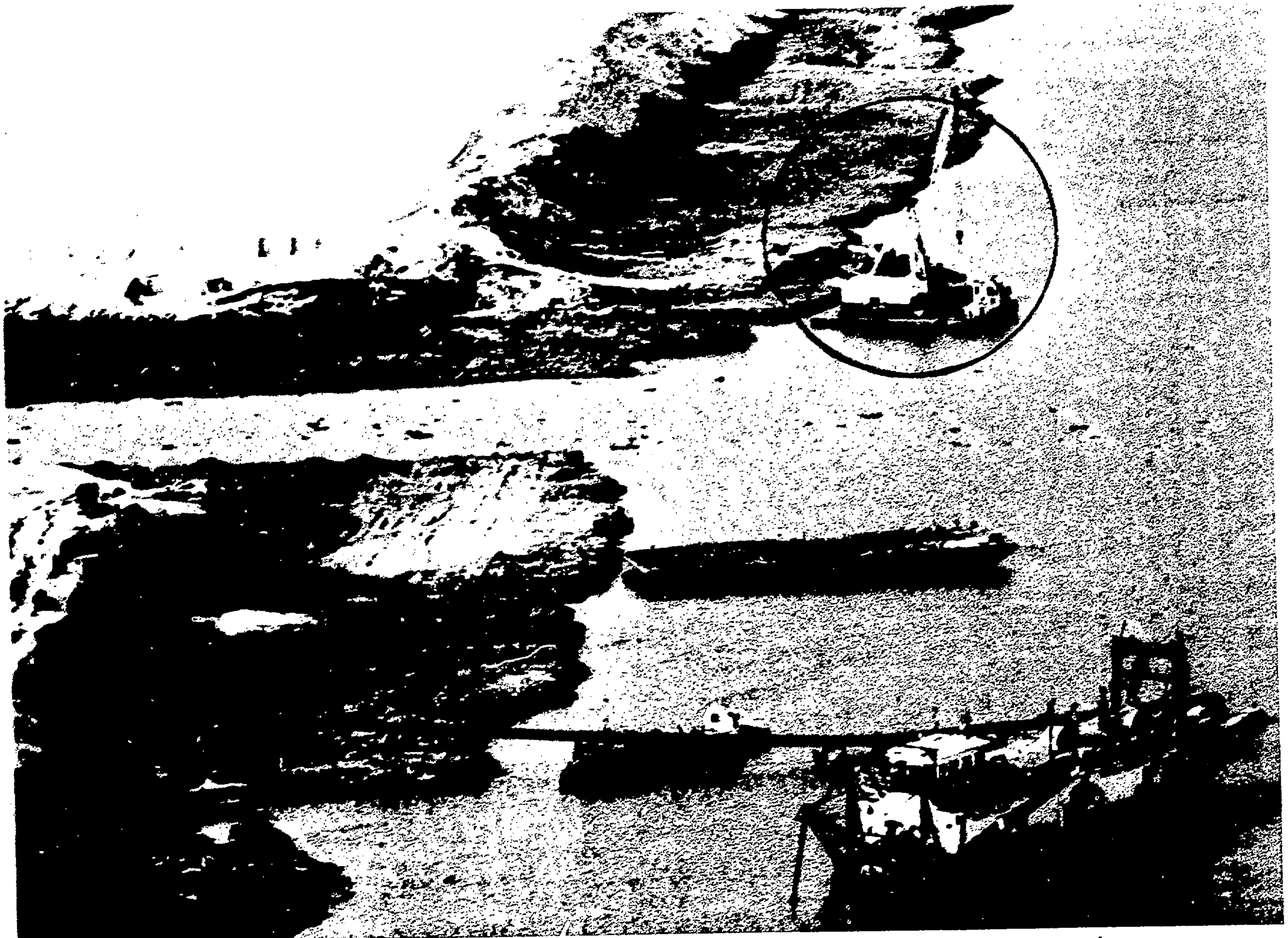


Figure 4. Example of heavy construction equipment that was easily detected and recognized (Target 49, average screen travel 33%, detection probability 1.00).

Figure 5. Example of heavy construction equipment that was difficult to detect and recognize (Target 54, average screen travel 98%, probability of detection of .071).

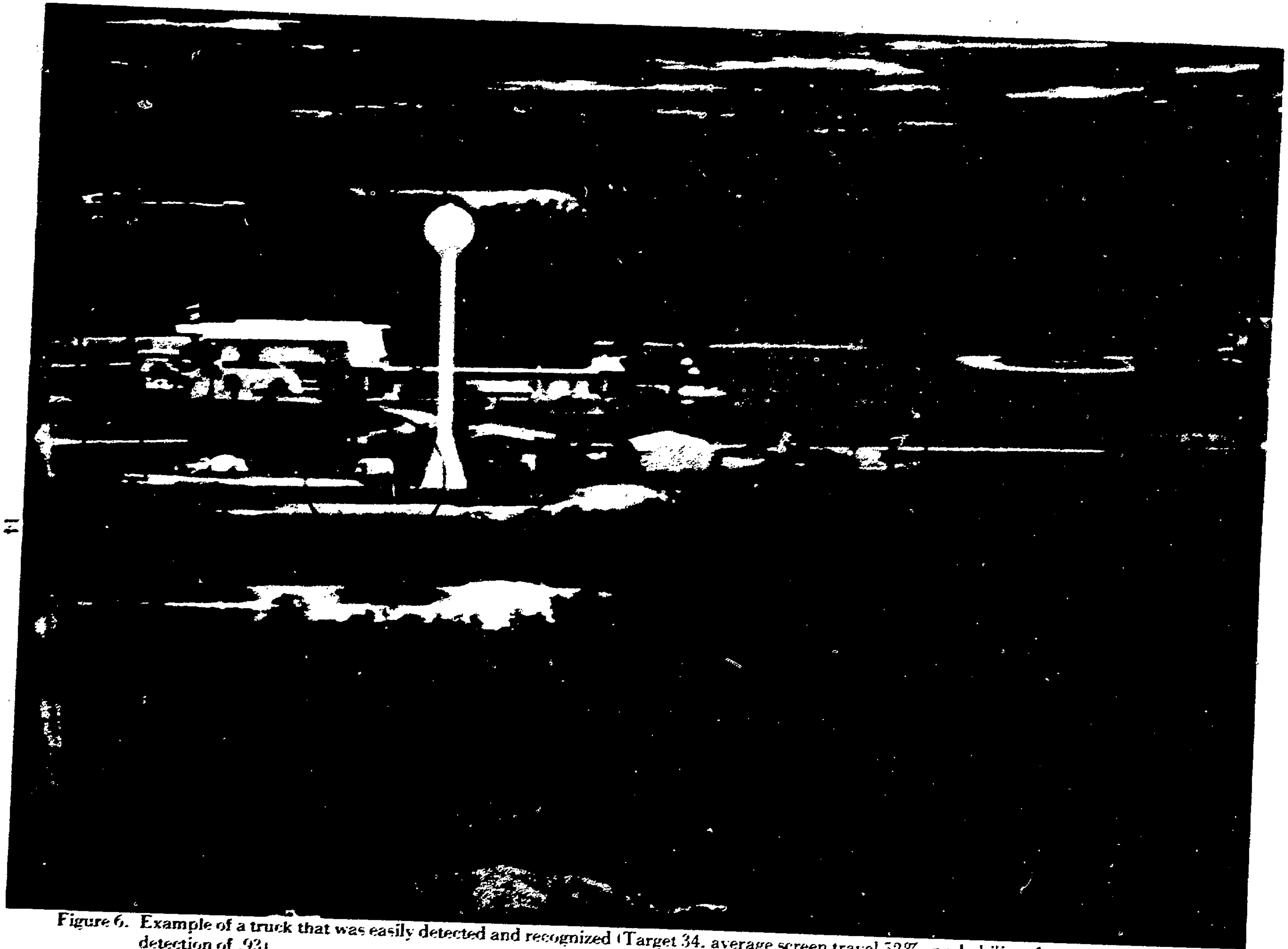


Figure 6. Example of a truck that was easily detected and recognized (Target 34, average screen travel 52%, probability of detection of .93).

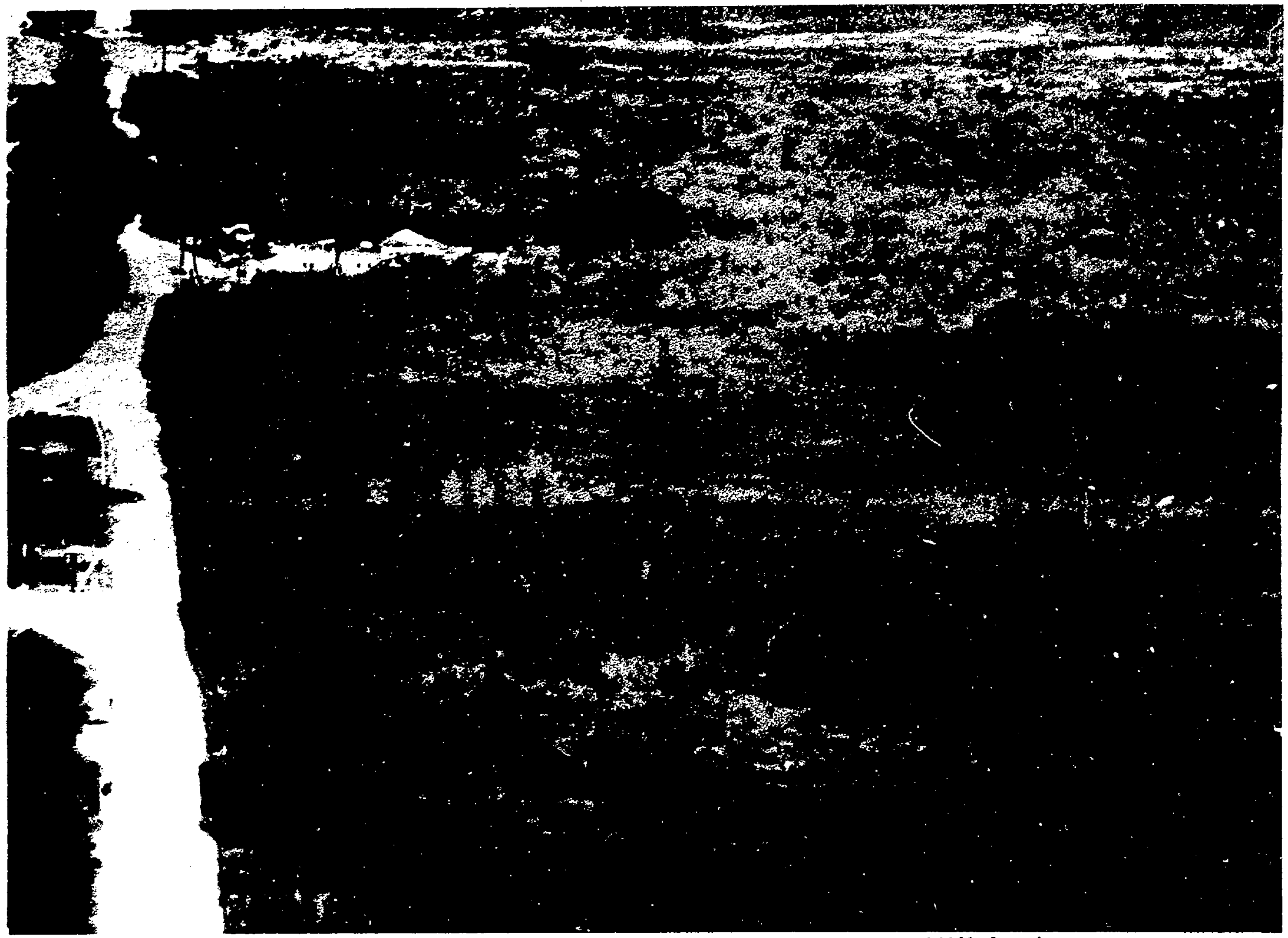


Figure 7. Example of a truck that was difficult to detect and recognize (Target 31, average screen travel 23%, detection probability .14).

Figure 9. Example of an automobile that was difficult to detect and recognize (Target 24, average screen travel 90%, detection probability .071).

Figure 10. Example of humans who were difficult to detect and recognize (Target 78 and 79, travel 90% and 82%, detection probabilities of .971 and .21, respectively.

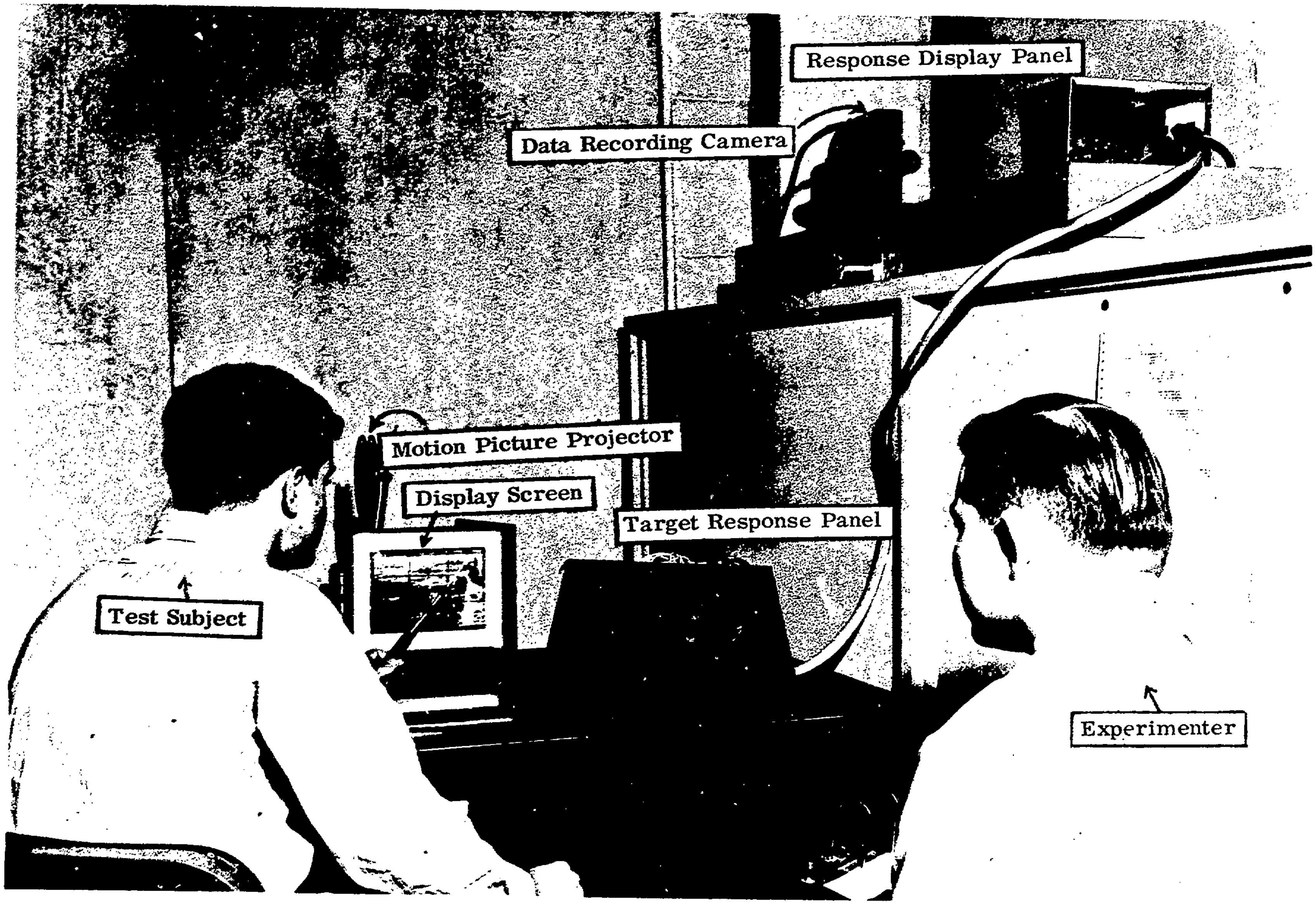


Figure 11. Laboratory test set-up for measuring observers.

IMAGE SCALE ON THE DISPLAY

Image scale is defined as the ratio of the linear size of the images of objects on the displayed image to the linear size of the corresponding objects on the terrain. Figure 1 shows that the slant rante to objects at the top of the field of view was 4903 feet, while at the bottom of the field it was only 1953 feet. Thus, it is clear that the image scale on the film and on the display screen increased from the top to the bottom of the scene. The displayed image scale, as shown in figure 2, was 1/1200 at the top, 1/680 at the display center (not the center of the terrain on display), and 1/470 at the bottom of the display. Thus, the image of any object coming into view at the top of the display increased 2.5 times in linear size (maximum dimension) and about 6.5 times in area by the time that it reached the bottom of the display screen.

The effect upon image size of variation in slant range is shown for objects from 6 feet tall to 15 feet tall in figure 12. Note that a 6-foot-tall object is displayed at the top of the screen as only 1.5 millimeters tall. The ability of an observer to discern details depends, in part, on how many minutes of visual angle are subtended at the observer's eye by the viewed image. Figure 13 shows, for a 20-inch viewing distance, the angular size subtended at the eye of an observer by the displayed image on the screen of objects that are 6, 10, and 15 feet tall, respectively. Note that the curves are almost straight lines, and that the image of a 6-foot-tall object seen at the top of the display subtends about 10 minutes of arc at an observer's eye.

DISPLAY AND TERRAIN RESOLUTION

To determine the approximate resolution of details (minimum separable resolution) of the display screen, the RB-47 aircraft was flown over high-contrast three-bar resolution test patterns at Wright-Patterson Air Force Base. The 35 mm film was printed at a reduced image size on 16 millimeter film, with the same films, development, printing, etc., used on the terrain films with which observers were tested. The 16 mm film was projected onto the same small 133-by-180 millimeter screen that was used in testing subjects. The images of the resolution test patterns on the screen were examined with a 10 power (1 inch focal length) hand-held magnifier to find the smallest vertical and horizontal 3-bar patterns that were resolved. The criterion of resolution was the usual one in optical testing: A "resolved" pattern is one in which the three bars can be seen as three, even though not sharply defined. This is a minimally-discernable criterion. The separation in inches between the centers of all the test "bars" in the array of patterns on the ground was known. Thus, knowledge of which patterns were just resolved, lens focal length on the camera, display magnification, camera declination angle, and aircraft altitude allowed a variety of types of resolution to be computed. These included vertical and horizontal resolutions on the terrain and on the ground, and on the terrain for upright objects. The resolution data are given in table 1. Since cameras resolve finer details with high contrast objects than with low contrast objects, the resolution of ground objects that were low in contrast would be less than the values given in the table.

The very narrow field fo view (6° 3' high by 8° 20' wide) of the motion picture camera resulted in pictures whose resolution in the image (not on the terrain) varied very little across the display. This was also true for angular resolution. Image resolution on the film in terms of which 3-bar test pattern on the terrain was resolved was very close to that on the display. This was found by examining the film on a light table with a magnifier. At no part of the picture did projection cause more than a 10% loss in resolution, and in some parts of the scene no loss was discernable.

Inspection and study of the values in the resolution table reveal some interesting facts. Note that the average angular resolution is given as 1.75 minutes of arc. This value is for the angle subtended between the centers of the resolution test pattern bars. Visual resolution is usually given in terms of the angle subtended by one bar or

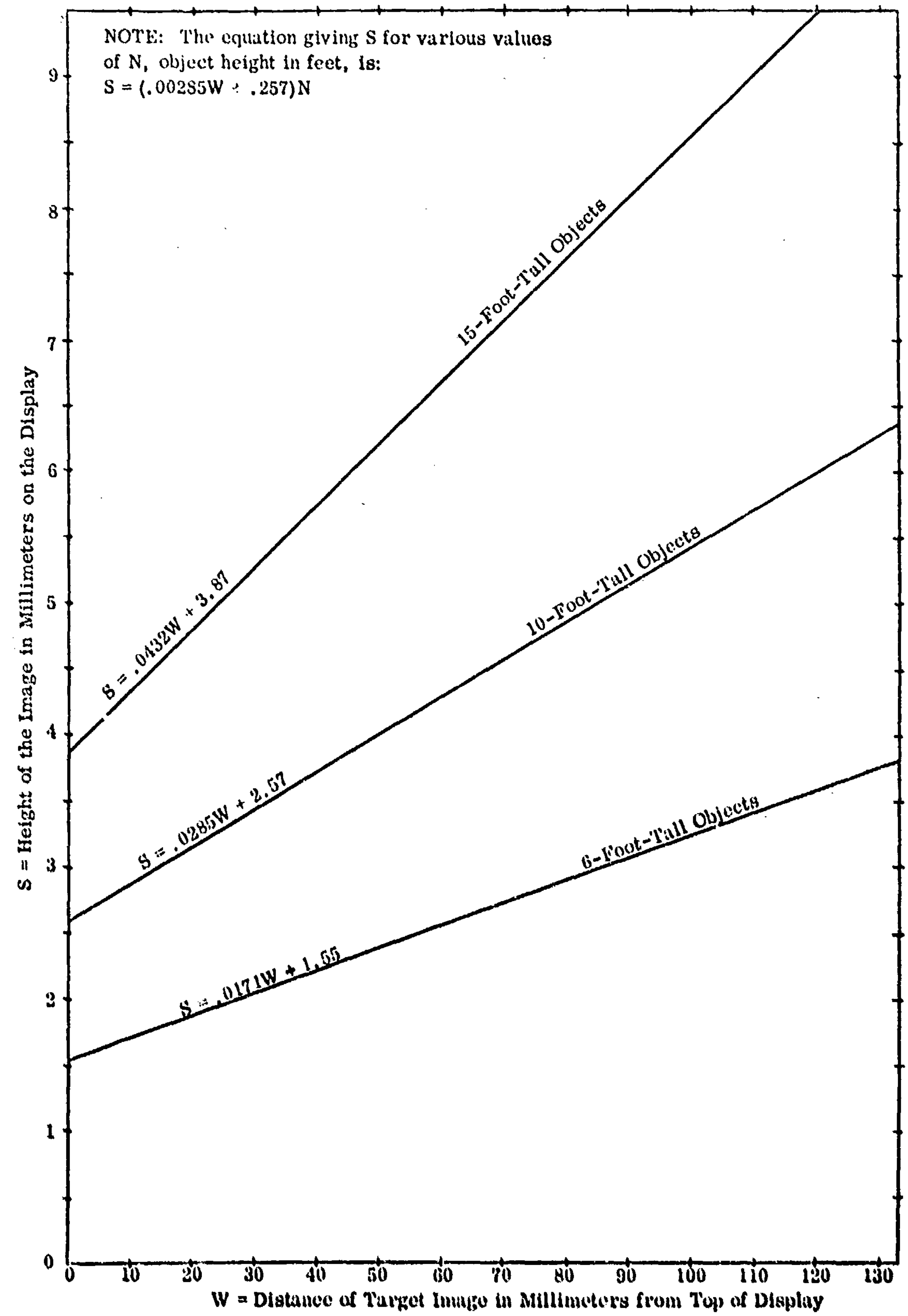


Figure 12. Height of the image on the display for objects on the terrain of various heights plotted against distance down from the top of the display to the bottom of the object.

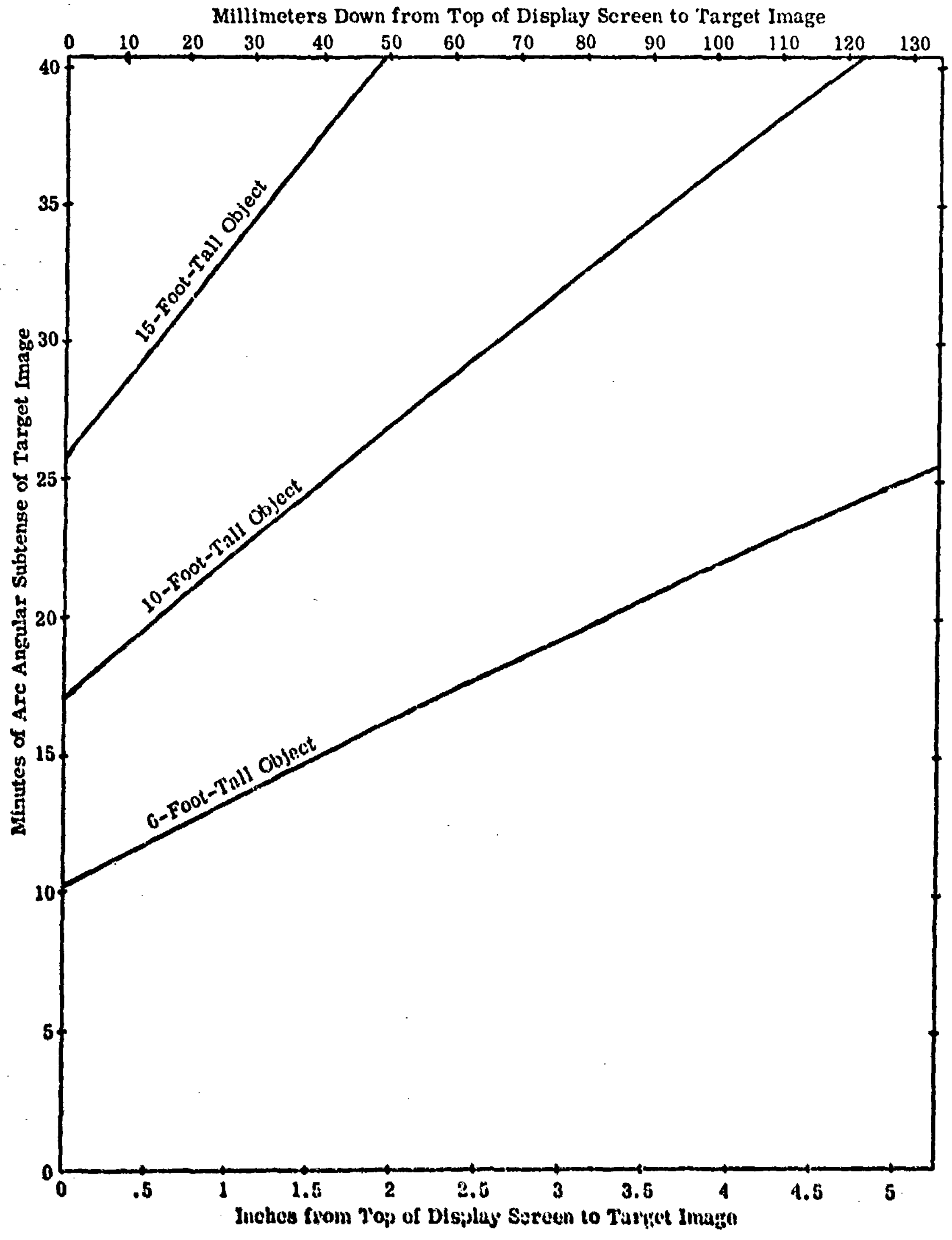


Figure 13. Angle subtended by target image height as the target image moves down the display screen for various sizes of targets. A 20-inch viewing distance with the observer's eye on a perpendicular through the center of the display is assumed.

space, so that the display resolution of 1.75 minutes of arc becomes .88 minutes of arc when computed as it is for the eye. The average unaided eye in bright sunlight and with a clear atmosphere (the conditions under which the pictures of this study were collected) in a laboratory situation is nominally quoted as having a resolution capability of about one minute of arc for Snellen letters. For a bar grid pattern, normal visual resolution is slightly superior to one minute. In an aircraft the vibration plus optical imperfections would limit visual acuity to not better than around two minutes of arc. Thus, test subjects could see the details of high contrast objects in the displayed scene somewhat better than they could have had they been using unaided vision from the aircraft itself.

An observer with average separable visual acuity (resolution) of 1 minute of arc per line can just resolve about 4 high contrast optical line pairs per millimeter or about 2 lines at a two foot viewing distance under good viewing conditions. The resolution table shows that the average display resolution, in optical line pairs, was only 1.6. Thus, there was an appreciable amount of "empty" display magnification. It should be kept in mind, then, that in the present study the observers were not examining displayed details that were too small to be easily discerned.

The 1.77 optical line pairs per millimeter average vertical resolution shown in table 1, in conjunction with the 133 millimeter height of the display screen yields 235 optical line pairs of vertical resolution. Similarly, the 1.39 line pair average horizontal resolution plus the 180 mm screen width yields 250 horizontal optical resolution elements (line pairs). Doubling the optical line pair values to obtain television resolution elements (TV lines) yields 470 vertical TV lines and 500 horizontal TV lines. This is about one-third better than the resolution capability of a well-adjusted commercial television set receiving a good quality TV broadcast which yields about 350 resolved vertical TV lines. Thus, it should be kept in mind that the present study used a display whose total amount of resolved picture details was only slightly better than that on a common household TV set.

PHYSICAL MEASUREMENTS OF TARGET IMAGES

The following measurements were taken to examine the relationships between physical characteristics and various performance measures:

Target Size: The size of a target image is defined as the diameter of the smallest circle that can be drawn around the image. It is the same as the maximum dimension of the target. For example, the maximum dimension or size of a target imaged as a rectangle is the diagonal of the rectangle. It should be kept in mind that the size of objects on the terrain can be found by multiplying the maximum dimension of the displayed image by the reciprocal of the image scale at the screen position where the image appears. Table 2 gives the average size of the four types of targets and the average size of their images at the center of the display screen. The former were determined from measurements of the latter. Note that the average truck, at 12.9 feet, was shorter than the average car at 15.1 feet. This happened because most of the trucks were pick-up trucks and delivery trucks which are quite short, rather than the larger varieties usually brought to mind by the term "truck." Since vehicles are often viewed from the front or back, rather than broadside, average sizes are somewhat less than average lengths. Note that the average person's "size" was six feet. This included shoe heels and hats, if worn. Since the filming was done along country roads, people were standing up and, likely, frequently wore both shoes and hats or caps. Probably most of the people were males; not many females are seen along country roads.

Target Image Contrast: The image contrast of concern here is brightness contrast, which is one measure of how the image of the target stands out from its surround (or background) due to the brightness difference between them. To avoid both negative values of contrast and very high numerical values, and to express values in percentage form, the formula used was $C = 100x(T\text{-}B)/T$ for target images brighter than their background and $C = 100x(B\text{-}T)/B$ when less bright. This is a $C = 100x(MAX\text{-}MIN)/MAX$ formulation. The brightness of the target was averaged over the entire target. Background brightness was the average of the brightness of

TABLE I

RESOLUTION OF THE SENSOR-DISPLAY SYSTEM MEASURED+ AT THE DISPLAY

Type of Resolution Measured	Direction+ of Resolution	Location on the Display: Top	Center	Bottom	Mean
Angular Ground Resolution: Angle subtended at the aircraft by the centers of just-resolved+++ bars in the resolution test patterns* on the terrain.		Minutes of Arc			
	Forward	1.67	1.44	1.53	1.55
	Sideways	1.86	2.05	1.98	1.96
	Mean	1.76	1.74	1.76	1.75
Linear Vertical Object** Ground Resolution: Vertical distance on the terrain between the centers of just-resolved vertical++ bars in the resolution test patterns on the terrain.		Inches			
	Forward	28.7	14.2	10.6	17.8
	Sideways	31.9	20.0	13.5	21.8
	Mean	30.3	17.1	12.1	19.8
Display Space Resolution: Spacing on the display between the centers of just-resolved bars in the image of the resolution test patterns on the terrain.		Millimeters			
	Forward	.61	.56	.53	.57
	Sideways	.68	.75	.73	.72
	Mean	.64	.66	.63	.64
Display Line Pair Resolution: Number of optical line pairs/millimeter in just-resolved bars in the image of the resolution test patterns on the terrain.		Line Pairs/Millimeter			
	Forward	1.63	1.89	1.78	1.77
	Sideways	1.46	1.33	1.38	1.39
	Mean	1.54	1.61	1.58	1.58

+ All values are for a line down the center of the display and flight path.

++ *Direction of Resolution:* "Forward" is in the direction of flight, which is the up-down display dimension, while "sideways" is across the flight path or display.

+++ *Just-Resolved:* A pattern of three bars was "just-resolved" if that pattern was the smallest on for which the three bars could be counted on the display using a 10-X magnifier.

*The test patterns were on the standard Air Force 3-bar configuration, and were painted on the runway at Wright Field, Ohio.

***Vertical Object:* The resolution test patterns if stood up vertically instead of lying horizontally. Resolution was calculated from values obtained with the patterns painted on the flat runway.

NOTE: In comparing system angular resolution with that of the eye it must be kept in mind that human angular visual resolution (minimum separable), as usually stated, uses the separation or space between the bars, not the distance between bar centers tabled above.

TABLE 2

THE SIZES+ OF TARGETS AND TARGET IMAGES

Type of Target	Average Size of Target	
	At Display Center, in Millimeters	On the Terrain, in Feet
People	2.67	6
Trucks	5.77	12.9
Cars	6.76	15.1
RCE	42.7	95.3

+Sizes are diameters of smallest circle that can enclose the target image on the display. "Actual" target sizes are calculated by dividing the size at the display center by 304.8 to convert to feet and then multiplying by 680, the image scale factor at the center of the display. There is no correction for perspective, head on view of cars, etc. People are outdoors and are standing, and their size includes hats, if worn. Sizes are averages of targets available, not average size of detected targets.

four circular areas three millimeters in diameter immediately adjacent to, but not including, the target. Due to the small sizes of some of the target images, brightness measures for calculating target contrast were obtained by projecting pictures at high magnification by increasing the projection distance. This was done with the motion picture projector used for testing subjects and with the same type of screen material used in testing subjects. Contrast at the screen as viewed by the observer was then calculated from the measurement data.

To obtain target contrasts, the brightness of areas on the display screen were measured with a Spectra Brightness Spot Meter, Model 1505 UB 1/2, with an S/L-10 reducing lens. The sensitivity and narrow angle of view of this photomultiplier equipment allowed precise brightness measures to be made on minute areas. However, the images of people were small and were not well-resolved, so that the reliability and accuracy of contrast measures on the images of people were judged as not acceptable. Thus, contrast measurements were made only on the three larger types of targets.

PICTURE PRESENTATION PROCEDURE

A small part of the total footage of film was selected as the most suitable and was spliced into four rolls, with no area of terrain duplicated on different rolls. Each roll of film contained 10 nautical miles of terrain and contained all four types of targets, but, for ease of scoring subjects and to simplify the task for subjects, they were told to search the display for only *one* type of target on each roll. In terms of targets of interest on each roll, roll A contained 28 cars; roll B, 15 trucks; roll C, 19 pieces of heavy construction equipment; and roll D, 21 people, for a total of 83 target objects.

The four films were projected sequentially, with the order of presentation randomized across subjects. Each subject saw all four rolls. The motion picture projector frame rate of 24 pictures per second simulated a ground speed of approximately 60 knots at a 340-foot aircraft altitude. The running time for each of the four 10-nautical-mile film strips was 10 minutes, so that the total viewing time per test subject was 40 minutes.

At the simulated aircraft speed of 60 knots, an object appearing at the top of the display took 21 seconds to move down to the center of the display (see figure 2), and in 8.4 more seconds the object moved down to the bottom of the display. Thus, the total time of 29.4 seconds to move from top to bottom of the display meant that images on the display moved at a leisurely pace. This point is important in visualizing the subject's observing task.

TEST SUBJECTS AND THEIR INSTRUCTIONS

Fourteen University of Dayton students served as subjects. Each became thoroughly familiar with the equipment that he had to use before he was tested. Immediately before being tested, each subject was given a practice trial with a short strip of imagery. This was done so that he would know how to respond during the later test runs and to let him know what to expect about the image characteristics of the targets. After this trial run, each subject read the test instructions (Appendix I) which asked him to identify targets as quickly as he could. They were told by the test administrator to spend most of the time searching the upper part of the display where targets usually first came into view so as to detect targets at longer distances. They were also cautioned to not respond to nontarget objects. They were also given an instruction sheet.

DATA RECORDING

When a subject wished to indicate that an object was a target, he placed the tip of the stylus upon it with his left hand and verbally described it to the test administrator sitting behind him. With his right hand the subject depressed the appropriate switch in a 3 X 3 array of switches to indicate the section of the screen containing the target. This switch caused a data camera to take a picture of a data panel containing digital indicators for the switch-indicated screen position and a counter giving the frame number of the picture on the screen when the data camera was activated. As a point of interest, a sprocket wheel with a microswitch pulsed the counter once for every picture on the roll of film to indicate which picture was on the display screen when the subject depressed the switch. As a back-up in case of camera malfunction, the test administrator did part of the scoring during test runs. Since the data camera did not malfunction during tests, the target location in the 3 X 3 screen matrix was not used for measuring screen position, hence recognition slant range, data. For false positives the experimenter estimated the screen position at the time the response was made, recording a false positive as being in the top, middle or bottom third of the display screen.

PERFORMANCE MEASURES

Number and Correctness of Responses: Each time that a subject placed the point of his stylus upon one of the 83 targets and depressed one of the nine screen position-indicating switches, he was credited with detecting a target, i.e., with making a correct response. A false positive or false positive response was a response in which the object designated by the subject was not one of the 83 targets. A false positive is thus a nontarget object that is mistaken for a target.

Reaction Time: The time that a target image was visible in a detectable form on the display prior to being designated by the observer's depressing the data camera record switch. Note that it is not the interval between the appearance of the image at the top of the display (often it is never there) and its designation by the observer with his stylus. The reaction time or response time was obtained by using the picture of the digital counter recorded by the data camera. This counter started at zero for each film run, so that the picture showed the experimenters the exact picture (or "frame") being projected when the data camera activation switch was depressed. At a later time, in the laboratory, this picture was located on the film, and the counter set on zero. A projector that could run backward, either rapidly, slowly, or a frame at a time, played the film backwards until a frame was found where the target was not detectable. The number of prior-to-detection frames plus the 24 frames/second rate of the projector when used with the observers, permitted calculation of the reaction time. Reaction time was not measured for nontargets mistaken for targets.

Screen Position: The distance down the display screen of the target when a response (switch depression) was made to it. Screen position and reaction time are not always directly convertible, one to the other, when using motion pictures taken in flight. This is partly due to variations in pitch and yaw of the aircraft. Thus, a bend in the flight path causes the images on the film to move sideways while a downward dip influences vertical image motion. Some targets appeared first at the edge and partway down the display, instead of at the top, and a few target images, for short periods of time, stood still on the display or even moved upward on it when the nose of the aircraft dipped. Also, the images of moving vehicles on roads intersecting with the flight path moved down the display screen at an angle to the vertical. It must also be kept in mind that there was extensive vegetation in the form of trees and brush. This caused "masking" or covering up of targets, especially when roads turned, even slightly. Terrain masking and vegetation masking were especially severe for heavy construction equipment, because it was off the roads, frequently in low areas or water. Many of the roads are raised above the surrounding terrain so that objects beside the roads may be up to several feet below the road. Targets of all types were frequently well down the display before being revealed by unmasking due to aircraft motion. From Appendix V it may be noted that only 41 of the 83 targets were available on every vertical tenth of the display, seven were available on 9 of the tenths, etc. From this discussion, it is clear that recognition slant ranges and screen position are not highly correlated and may differ by a factor of up to two or more for some targets.

RESULTS

Appendix II lists the image characteristics and gives the observer performance data for each of the 83 individual targets. The image characteristics and performance data of this table are summarized by target type in Appendix III. Individual target data permit some interesting comparisons between types, characteristics, and performance measures. This will be done later on in this report in connection with analyses done on the performance data of individual observers.

PERCENTAGE OF TARGETS DETECTED AND DETECTION PROBABILITY

The percentage of targets detected by each observer for each of the four types of target is derived from the numbers detected given in table 3. The percentage detected is simply 100 times the number detected divided by the number available. This ratio, without the factor of 100 to convert to a percentage, is an estimate of detection probability using the relative frequency definition of probability.

The percentages detected given in table 4 for the four types of targets is plotted in figure 14 against the average size of available target as given in Appendix III. Note that the detection probabilities range from a low of .46 for the smallest type of target, people, to a high of .82 for the largest type, heavy construction equipment. In more easily remembered terms, detection probability varied from slightly less than 1/2 to slightly over 4/5ths in going from the smallest to the largest type of target object. As a point of interest, the two most conspicuous people targets were each detected by 93% of the observers, while one person target was not detected by any of the 14 observers.

As noted earlier, the camera lens and film were selected by theoretical calculations followed by image-collection trial flights to make sure that an appreciable fraction of the targets of every one of the four types of targets would be found and recognized. The data show that this goal was attained.

With the test conditions used in the present study, the average human target was almost as likely to be missed as to be detected. However, it must be kept in mind that most people were either on or adjacent to roads, and were frequently in close proximity to vehicles or equipment. Also, their civilian clothing was not the drab low-visibility attire of soldiers. It is not unlikely that very low contrast objects would, especially in rapid search, be less detectable than the target objects used in the present study. Similarly, military vehicles have coloration not favorable for detection and are often in fields or on tree lined foliage-overhung poor quality roads. In a military field situation both people and vehicles would probably be less detectable than they were in the present study.

ACCURACY

The accuracy score for an individual observer is the percentage of his responses that are correct. Operationally, it is 100 times the number of targets that he designates as targets, divided by the total number of objects that he designates as targets. Accuracy scores for the 14 individual observers are given in table 5. The means and standard deviations of the accuracy scores for the four types of targets are plotted against target size in figure 15.

The figure shows that the average observer was the least accurate for people (58.6%) and was the most accurate (84.1%) for heavy construction equipment (HCE). Thus, with the conditions of the present study, about 3 out of every 5 objects that observers called people were people, and about 6 out of every 7 objects that were designated as HCE really were HCE. Observer accuracy for trucks and cars were between these extremes. In line with what was hypothesized about detection probability in a military situation, it is likely that the attire and locations of people and the color and locations of vehicles in military rather than civilian situations will result in lower observer accuracy, given similar conditions of image collection and display, than was the case in the present study.

If the graph of accuracy versus target size in figure 15 is examined again, it is apparent that there is an increase in accuracy from people to heavy construction equipment, the mean for each target type being at a higher point on the graph than the next smaller target type. Now, it is clear that average shape, contrast, location in the scene context, and other factors than average size differ for the four types of targets. Hence, one must be cautious about attributing the obtained increase in average accuracy to the increased average size of targets in a category or type. Also, it should be remembered that, with only four pairs of scores, a statistical test is quite insensitive to rather large amounts of genuine relationship between the variables.

TABLE 3

NUMBER OF TARGETS DETECTED AND NUMBERS OF OBJECTS MISTAKEN FOR TARGETS BY INDIVIDUAL OBSERVERS

Observer	(a) Number of Detected Targets						(b) Number of Objects Mistaken for Targets+						Total No. of Responses (a) plus (b)
	People	Trucks	Cars	HCE	Sum	Mean	People	Trucks	Cars	HCE	Sum	Mean	
a	9	8	13	17	47	11.75	9	9	10	2	30	7.50	77
b	12	9	17	18	56	14.00	8	7	7	4	26	6.50	82
c	10	5	19	16	50	12.50	15	6	3	9	33	8.25	83
d	7	5	21	16	49	12.25	14	0	7	1	22	5.50	71
e	7	8	15	12	42	10.50	6	5	5	4	20	5.00	62
f	10	9	21	15	55	13.75	6	2	6	0	14	3.50	69
g	12	10	26	17	65	16.25	6	6	6	2	20	5.00	85
h	8	5	17	16	46	11.50	10	1	5	3	19	4.75	65
i	12	8	21	17	58	14.50	0	5	0	0	5	1.25	63
j	7	8	17	16	48	12.00	6	8	5	5	24	6.00	72
k	14	7	21	18	60	15.00	13	20	16	17	66	16.50	126
l	7	7	19	10	43	10.75	3	0	1	0	4	1.00	47
m	10	5	16	14	45	11.25	10	5	0	3	18	4.50	63
n	10	9	21	17	57	14.25	2	3	2	2	9	2.25	66
Sum	135	103	264	219	721	180.25	108	77	73	52	310	77.50	1031
Mean	9.64	7.36	18.86	15.64	51.50	12.88	7.71	5.50	5.21	3.71	22.14	5.54	73.64
S.D.	2.27	1.74	3.20	2.28	6.99	1.75	4.46	5.05	4.25	4.52	15.24	3.81	18.13

+Objects mistaken for targets are usually referred to in the present report as "false positives."

TABLE 4

PERCENTAGE OF TARGETS DETECTED

Observer	Percent of Targets Detected = (No. Detected/No. Available)x100						Mean/ Target+
	People	Trucks	Cars	HCE	Sum	Mean	
a	42.86	53.33	46.43	89.47	232.09	58.02	56.63
b	57.14	60.00	60.71	94.74	272.59	68.15	67.47
c	47.62	33.33	67.86	84.21	233.02	58.26	60.24
d	33.33	33.33	75.00	84.21	225.87	56.47	59.04
e	33.33	53.33	53.57	63.16	203.39	50.85	50.60
f	47.62	60.00	75.00	78.95	261.57	65.39	66.26
g	57.14	66.67	92.86	89.47	306.14	76.54	78.31
h	38.10	33.33	60.71	84.21	216.35	54.09	55.42
i	57.14	53.33	75.00	89.47	274.94	68.74	69.88
j	33.33	53.33	60.71	84.21	231.58	57.90	57.83
k	66.67	46.67	75.00	94.74	283.08	70.77	72.29
l	33.33	46.67	67.86	52.63	200.49	50.12	51.81
m	47.62	33.33	57.14	73.68	211.77	52.94	54.22
n	47.62	60.00	75.00	89.47	272.09	68.02	68.67
Sum	642.85	686.65	942.85	1152.62	3424.97	856.26	868.67
Mean	45.92	49.05	67.35	82.33	244.64	61.16	62.05
Median	47.62*	53.33*	67.86	84.21*	232.56	58.14	59.66
S.D.	10.83	11.58	11.79	9.00	33.22	8.31	8.42

* This is the mode and is close to the 50th percentile; there is no definable median in this column.

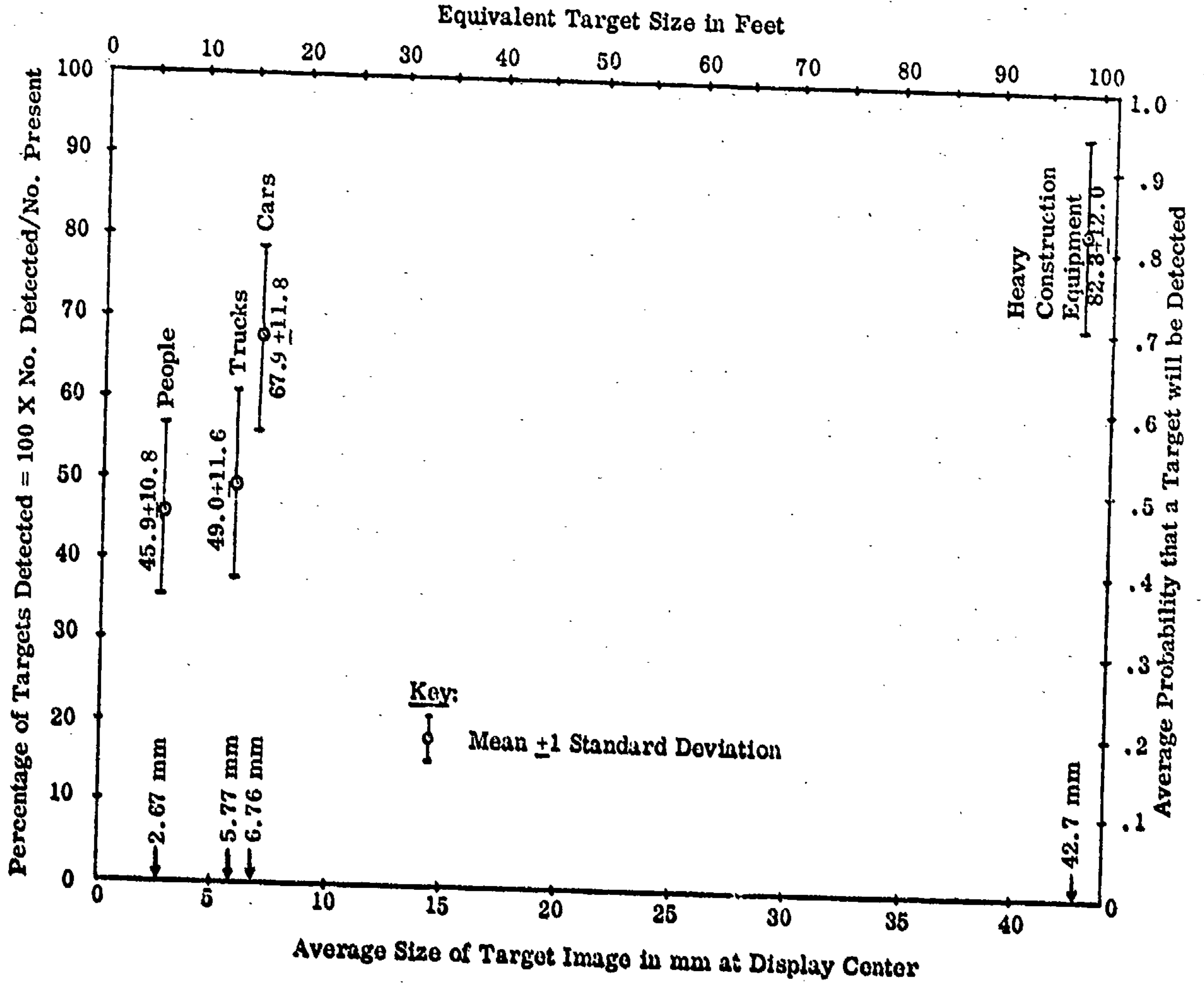


Figure 14 Percentage of targets of each of the four types detected by the average observer plotted against target size. The corresponding average probability of detection is also shown for each type. Target size is defined by the diameter of the smallest circle that can enclose it.

TABLE 5

RESPONSE ACCURACY+ AS A PERCENTAGE

Observer	Accuracy+ = (No. of Targets Found/No. of Objects Called Targets) X 100						Mean/ Target++
	People	Trucks	Cars	HCE	Sum	Mean*	
a	50.00	47.06	56.52	89.47	243.05	60.76	61.04
b	60.00	56.25	70.83	81.82	268.90	67.22	68.29
c	40.00	45.45	86.36	64.00	235.81	58.95	60.24
d	33.33	100.00	75.00	94.12	302.45	75.61	69.01
e	53.85	61.54	75.00	75.00	265.39	66.35	67.74
f	62.50	81.82	77.78	100.00	322.10	80.52	79.71
g	66.67	62.50	81.25	89.47	299.89	74.97	76.47
h	44.44	83.33	77.27	84.21	289.25	72.31	70.77
i	100.00	61.54	100.00	100.00	361.54	90.38	92.06
j	53.85	50.00	77.27	76.19	257.31	64.33	66.67
k	51.85	25.92	56.76	51.43	185.96	46.49	47.62
l	70.00	100.00	95.00	100.00	365.00	91.25	91.49
m	50.00	50.00	100.00	82.35	282.35	70.59	71.43
n	83.33	75.00	91.30	89.47	339.10	84.78	86.36
Sum	819.82	900.41	1120.34	1177.75	4018.10	1004.51	1008.90
Mean**	58.56	64.32	80.02	84.11	287.01	71.75	72.06
Median	53.85	61.54	77.52	86.84	285.80	71.45	69.89
S.D.	17.46	21.39	13.70	13.96	49.97	12.49	12.38

+ Accuracy is the same as the percentage of all objects called targets by the observer that are targets: A = 100 X (number of targets detected)/(number of targets detected + number of nontargets called targets).

* Mean = Sum/4

** Mean = Sum/14

++ Mean/Target = 100 X (sum of detections for all types of targets)/(sum of detections for all types of targets + sum of false positives of all types). This is not a mean of the means for different types of targets.

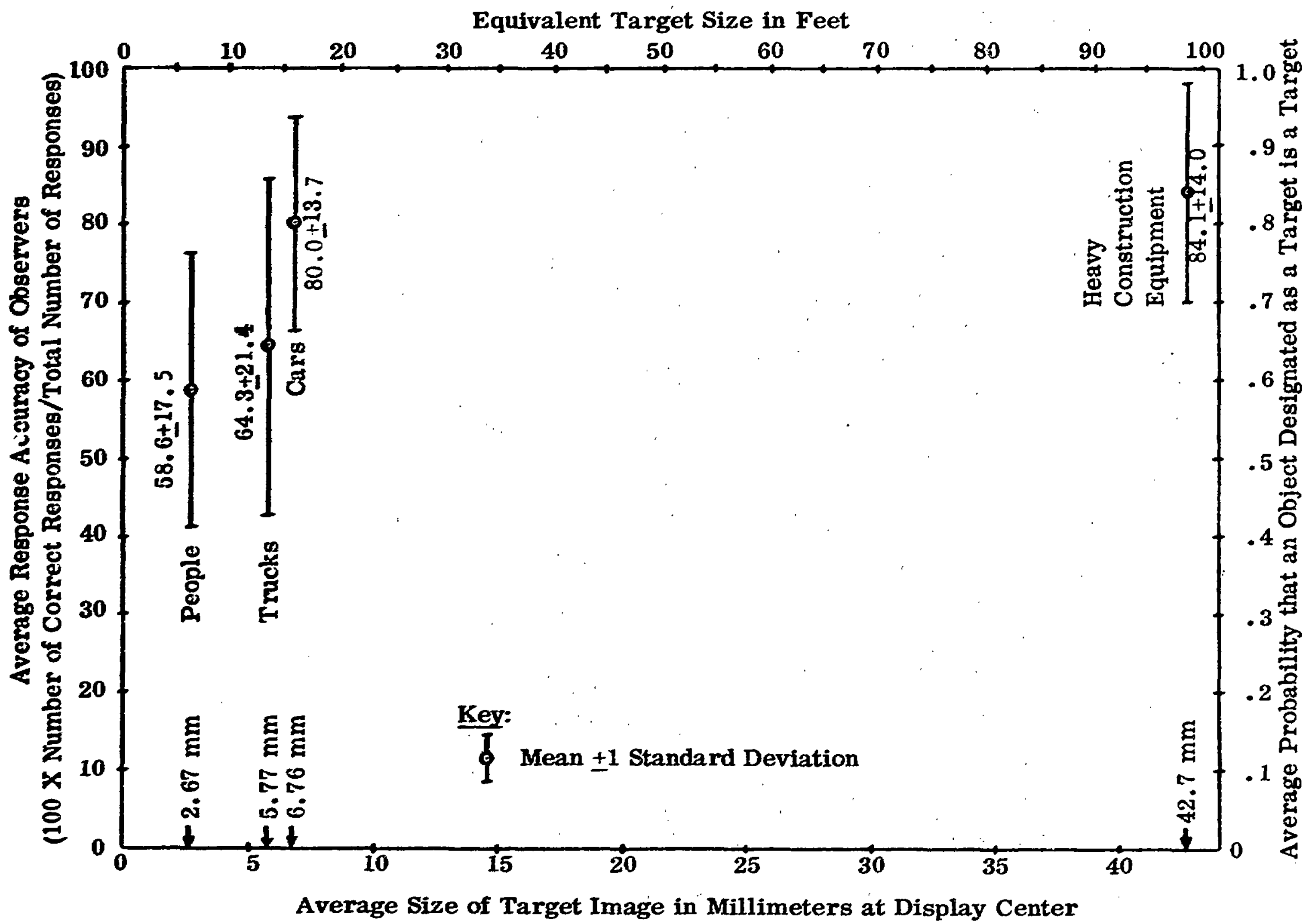


Figure 15 Response accuracy of the average observer for the four types of targets plotted against average target size. The corresponding average probability that an object designated as a target is truly a target is also shown. Target size is defined by the diameter of the smallest circle that can enclose it.

SCREEN POSITION AND SLANT RANGE WHEN DETECTED

As explained previously, most targets enter the display at the top of the screen and move down it. Hence, distance down the screen, expressed as a percentage of the total height of the display, is a meaningful way of designating screen position at the time that an object is designated as a target by the observer. The average value of this position at the time of detection is given in Appendix II for each of the 83 targets and means for target types are given in Appendix III.

The average positions for individual observers for the 4 classes of target objects are of more interest. These values are given in table 6 and are plotted against the mean size of target for each target class in figure 16. The values are 54.7% for people, 54.7% for trucks, 44.3% for cars, and 27.5% for heavy construction equipment. Note that people, cars, and trucks were, on the average, detected about halfway down the display. However, the comparatively very large heavy construction equipment (average size at the display center of 43 mm) was detected, on the average, when it was only about one-fourth of the way down the display.

Table 7 lists for individual observers, and for classes or types of target, the mean position on the display of false positives when designated as targets. The mean values, by target type, are 55.3% for people, 67.7% for trucks, 33.8% for cars, and 50.5% for heavy construction equipment. Thus, the average false positive person target or heavy construction target was responded to at about the center of the display, the average false positive (F.P.) truck at two-thirds of the way down the screen, while the average F.P. car was responded to when it was only one-third of the way down. Comparing genuine and false positive targets, it may be noted that the real targets were, on the average, detected at about the same position as the F.P. targets for people, detected later for trucks and HCE and, responded to more quickly in the case of cars.

The screen position when detected is, from an applications point of view, of less interest than the slant range when detected, sometimes called acquisition slant range or detection slant range. The mean acquisition slant ranges, calculated from the mean screen positions when detected, are plotted against the mean size of available targets in figure 17. The mean acquisition slant ranges, in feet, for the targets are: people, 2,680; trucks, 2,660; cars, 2,630; and heavy construction equipment, 3,460. Note that images of people, although only half of the size (maximum dimension) of truck images, were detected at essentially the same distance. Cars, only slightly larger than the trucks in the present study, were detected at about 10% (270 feet) greater slant ranges. Particularly interesting is the fact that heavy construction equipment was detected, on the average, at only 1.3 times greater slant ranges than trucks. This is of interest because, on the average, heavy construction equipment is about 6.3 times as large in maximum dimension as trucks so that their image area is about 40 times as large. Even keeping in mind that the images of the two target categories differ in several ways, it is clear that target acquisition range increases at a much slower rate than does target size.

DISTRIBUTION ON THE DISPLAY WHEN DETECTED

In the preceding section means for individual observers and for types of targets were examined. A more thorough examination of position down the display at detection requires an investigation of the distribution down the display of detected targets. This is done by pooling the detections of all observers for each of the four types of targets and cumulating (adding) the percentages in successive steps, each step being 5% of the distance down from the top to the bottom of the display. The data are given in table 8 and are plotted in figure 18. Note that in the first or top third of the display, the increase in percentage of targets detected is approximately linear with screen position. For people and trucks it is approximately linear all the way down the display, but for cars and heavy construction equipment the rate of increase after the top third of the screen decreases. Fall off is greatest for heavy construction equipment. Note the closeness of the curves for people and trucks and the large separation of the car and HCE distributions from each other and from the curves for trucks and people.

The shapes of the curves of cumulative percentage of targets detected permit speculation about the adequacy of the vertical field of view. Some types of target may be being acquired at an appreciable rate at the bottom of

TABLE 6

AVERAGE POSITION* OF TARGET IMAGES ON THE DISPLAY SCREEN WHEN DETECTED

	People		Trucks		Cars		HCE		Combined Means	Combined Targets++	
S	n	mean	n	mean	n	mean	n	mean	(mean of means)	N	mean
A	9	52.67	8	42.50	13	40.00	17	31.18	41.59	47	39.66
B	12	53.33	9	31.67	17	36.18	18	19.44	35.16	56	33.75
C	10	59.80	5	60.80	19	52.89	16	33.12	51.65	50	48.74
D	7	35.00	5	48.00	21	40.71	16	25.31	37.26	49	35.61
E	7	45.00	8	45.62	15	42.67	12	25.83	39.78	42	38.81
F	10	48.00	9	52.78	21	31.43	15	25.67	39.47	55	36.36
G	12	37.50	10	50.00	26	28.85	17	25.00	35.34	65	32.69
H	8	72.37	5	86.80	17	57.29	16	37.81	63.57	46	56.35
I	12	67.00	8	75.50	21	64.76	17	41.76	62.26	58	59.97
J	7	42.14	8	40.62	17	45.29	16	15.62	35.92	48	34.17
K	14	58.93	7	45.71	21	33.33	18	27.50	41.37	60	39.00
L	7	56.43	7	47.71	19	34.21	10	12.50	37.71	43	34.98
M	10	73.00	5	70.00	16	65.88	14	42.14	62.76	45	60.53
N	10	65.00	9	67.78	21	46.67	17	21.47	50.23	57	45.70
Sum	135	766.17	103	765.49	264	620.16	219	385.35	634.07	721	596.32
n	14	14	14	14	14	14	14	14	14	14	14
mean	9.64	54.73	7.36	54.68	18.64	44.30	15.64	27.52	45.29	51.50	42.59
S.D.		12.21		15.36		11.96		8.77	10.73		9.96

* Positions are distances down from the top of the display expressed as a percentage of the total 133 m.m. height of the display screen. To convert to millimeters, multiply the tabled values by 1.33.

+n = number of detections; N = sum of targets for all four types combined.

++ mean for combined targets = mean/target = (sum of positions of all targets)/(total number of targets).

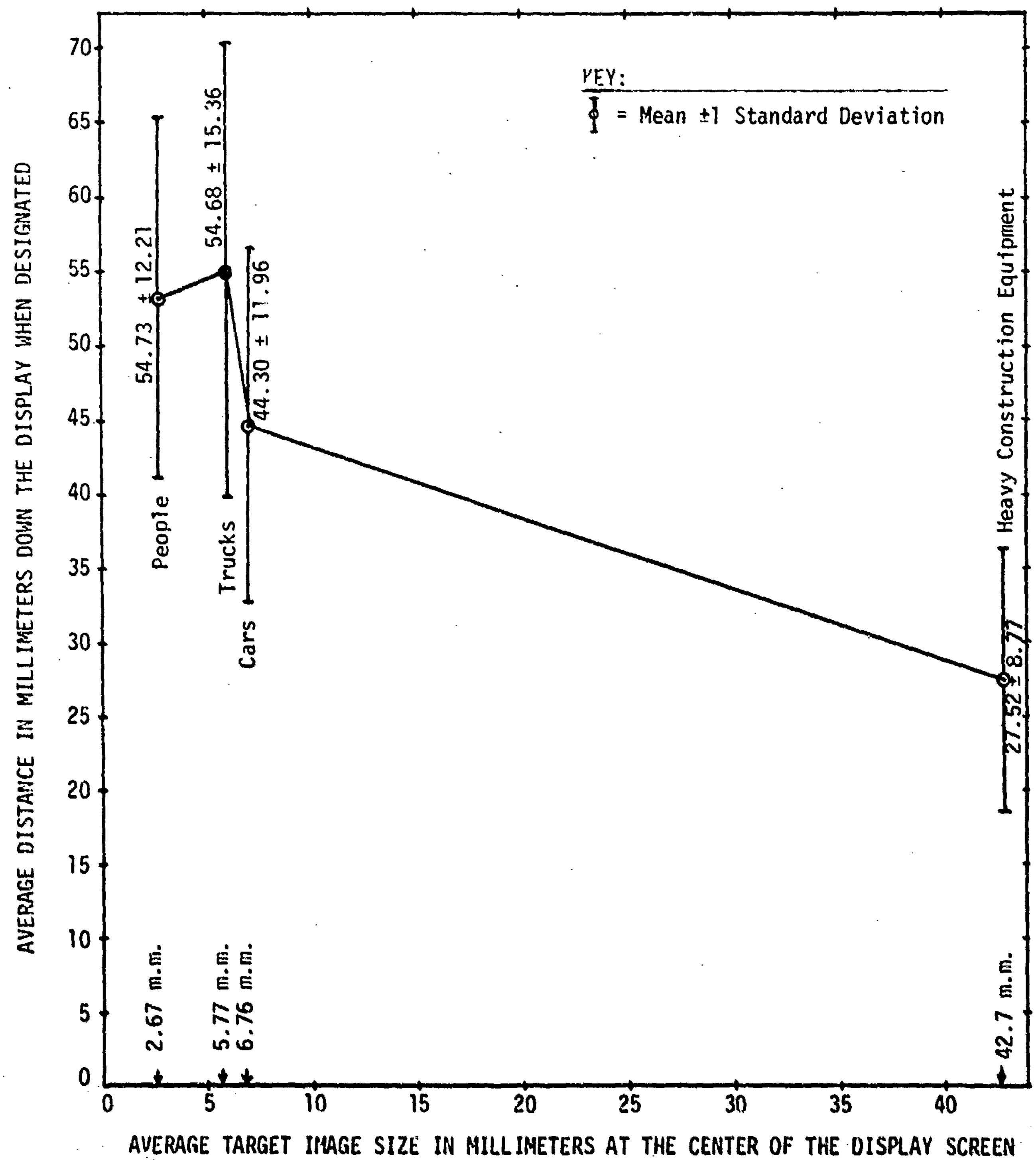


Figure 16 Average Distance down the display when detected of the four types of targets plotted against the average size of the target image when at the center of the display. Size is defined as the diameter of the smallest circle that can enclose the target image.

TABLE 7

AVERAGE POSITION* OF FALSE POSITIVES ON THE DISPLAY SCREEN WHEN DETECTED

	DISTANCE DOWN DISPLAY SCREEN WHEN DETECTED AS A PERCENTAGE OF SCREEN HEIGHT											
	People		Trucks		Cars		HCE		mean of means+		FP means++	
OBSERVER	n	mean	n	mean	n	mean	n	mean	N	mean	n	mean
A	9	42.7	9	72.0	10	43.4	2	66.5	4	56.15	30	53.50
B	8	54.1	7	64.1	7	17.0	4	33.5	4	42.18	26	43.65
C	15	63.2	6	66.5	3	61.0	9	57.3	4	62.00	33	62.00
D	14	47.6	NONE		7	35.9	1	50.0	3	44.50	22	44.00
E	6	55.5	5	50.0	5	50.0	4	33.5	4	47.25	20	48.35
F	6	28.0	2	83.0	6	17.0	NONE		3	42.67	14	31.14
G	6	39.0	6	72.0	6	44.5	2	50.0	4	51.38	20	51.65
H	10	69.8	1	83.0	5	43.4	3	61.0	4	64.30	19	62.16
I	NONE		5	56.6	NONE		NONE		1	56.60	5	56.60
J	6	66.5	8	78.9	5	36.8	5	63.2	4	61.35	24	63.75
K	13	65.2	20	45.0	16	23.2	17	46.1	4	44.88	66	44.00
L	3	28.0	NONE		1	17.0	NONE		2	22.50	4	25.25
M	10	76.4	5	69.8	NONE		3	61.0	3	69.07	18	72.00
N	2	83.0	3	72.0	2	17.0	2	33.5	4	51.38	9	53.67
Sum		719.0		812.9		406.2		555.6		716.21		711.52
n		13		12		12		11		14		14
observer mean		55.31		67.74		33.85		50.51		51.16		50.82
S.D.		17.52		12.13		15.24		12.00		11.91		12.80
F.P. Sum	6126		4807		2429		2600				15,962	
n Sum	108		77		73		52				310	
F.P. mean		56.72		62.43		33.27		50.00				51.49

*The position of individual false positives was known only to the nearest third of the screen height, i.e., it was known in which third they occurred. Values were taken as the center of the third, namely, 17, 50, or 83% of the distance down the display screen.

+This is the average of the means for the types of targets = sum of means/N. It is an observer mean for false positives.

++This is the sum of the distances down the display at detection of all false positives divided by the number of false positives. It is a false positive mean for a type of false positive rather than an observer mean.

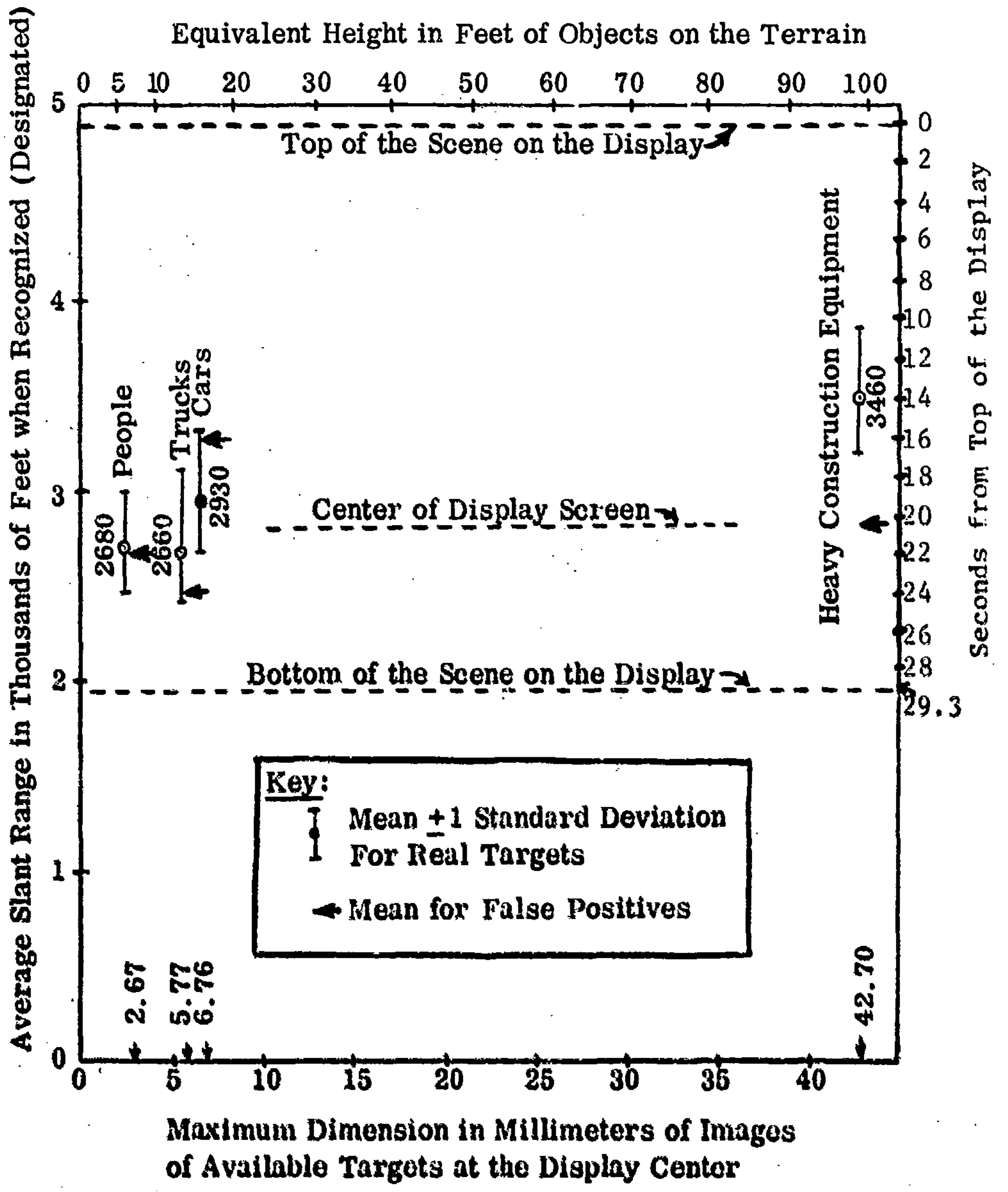


Figure 17 Average Slant Ranges When Recognized for Targets and for False Positives. The horizontal dimension of the graph, object size, applies only to the real targets. The slant ranges are calculated from the average distances down the display screen when images were designated as targets. The standard deviations are not symmetrical about the means, one standard deviation above the mean in screen position corresponding to more slant range than one standard deviation below the mean. Seconds from the top of the display are not reaction times. Average reaction times are considerably less than seconds from the top.

TABLE 8

DISPLAY SCREEN POSITION IN TERMS OF NUMBERS OF TARGETS DETECTED AND CUMULATIVE PERCENTAGE OF TARGETS DETECTED BASED ON POOLING NUMBERS OF DETECTIONS

N* Targets	294 People			210 Trucks			329 Cars			266 Heavy Const. Equip.			1162 Targets Combined		
Screen Position	n+	Sum n	Sum %	n	Sum n	Sum %	n	Sum n	Sum %	n	Sum n	Sum %	n	Sum n	Sum %
5	0	0	0	0	0	0	7	7	1.79	22	22	8.27	29	29	2.50
10	4	4	1.36	7	7	3.33	13	20	5.10	28	50	18.80	52	81	6.97
15	10	14	4.76	4	11	5.24	21	41	10.46	28	78	29.32	63	144	12.39
20	14	28	9.52	5	16	7.62	32	73	18.62	36	114	42.86	87	231	19.88
25	4	32	10.88	4	20	9.52	12	85	21.68	16	130	48.87	36	267	22.98
30	4	36	12.24	5	25	11.90	17	102	26.02	32	162	60.90	58	325	27.97
35	10	46	15.65	7	32	15.24	14	116	29.59	3	165	62.03	34	359	30.90
40	8	54	18.37	3	35	16.67	22	138	35.20	11	176	66.17	44	403	34.68
45	6	60	20.41	3	38	18.09	21	159	40.56	4	180	67.67	34	437	37.61
50	3	63	21.43	20	58	27.62	26	185	47.19	10	190	71.43	59	496	42.69
55	3	66	22.45	5	63	30.00	7	192	48.98	7	197	74.06	22	518	44.58
60	6	72	24.49	5	68	32.38	9	201	51.27	11	208	78.20	31	549	47.25
65	6	78	26.53	2	70	33.33	4	205	52.30	0	208	78.20	12	561	48.28
70	11	89	30.27	4	74	35.24	13	218	55.61	1	209	78.57	29	590	50.77
75	8	97	32.99	3	77	36.67	10	228	58.16	2	211	79.32	23	613	52.75
80	11	108	36.73	8	85	40.48	13	241	61.48	2	213	80.08	34	647	55.68
85	5	113	38.44	5	90	42.86	3	244	62.24	0	213	80.08	13	660	56.80
90	9	122	41.50	1	91	43.33	12	256	65.31	4	217	81.58	26	686	59.04
95	6	128	43.54	8	99	47.14	6	262	66.84	2	219	82.33	22	708	60.93
100	7	135	45.92	4	103	49.05	2	264	67.35	0	219	82.33	13	721	62.05
Sum	135			103			264			219			721		

n+ = number detected = all observer detections added together
N* = the total number of targets available = (the number of observers) x (the number of targets per mission)
Sum % = 100 x (cumulative number detected)/(total number available) = 100x(Sum n)/N

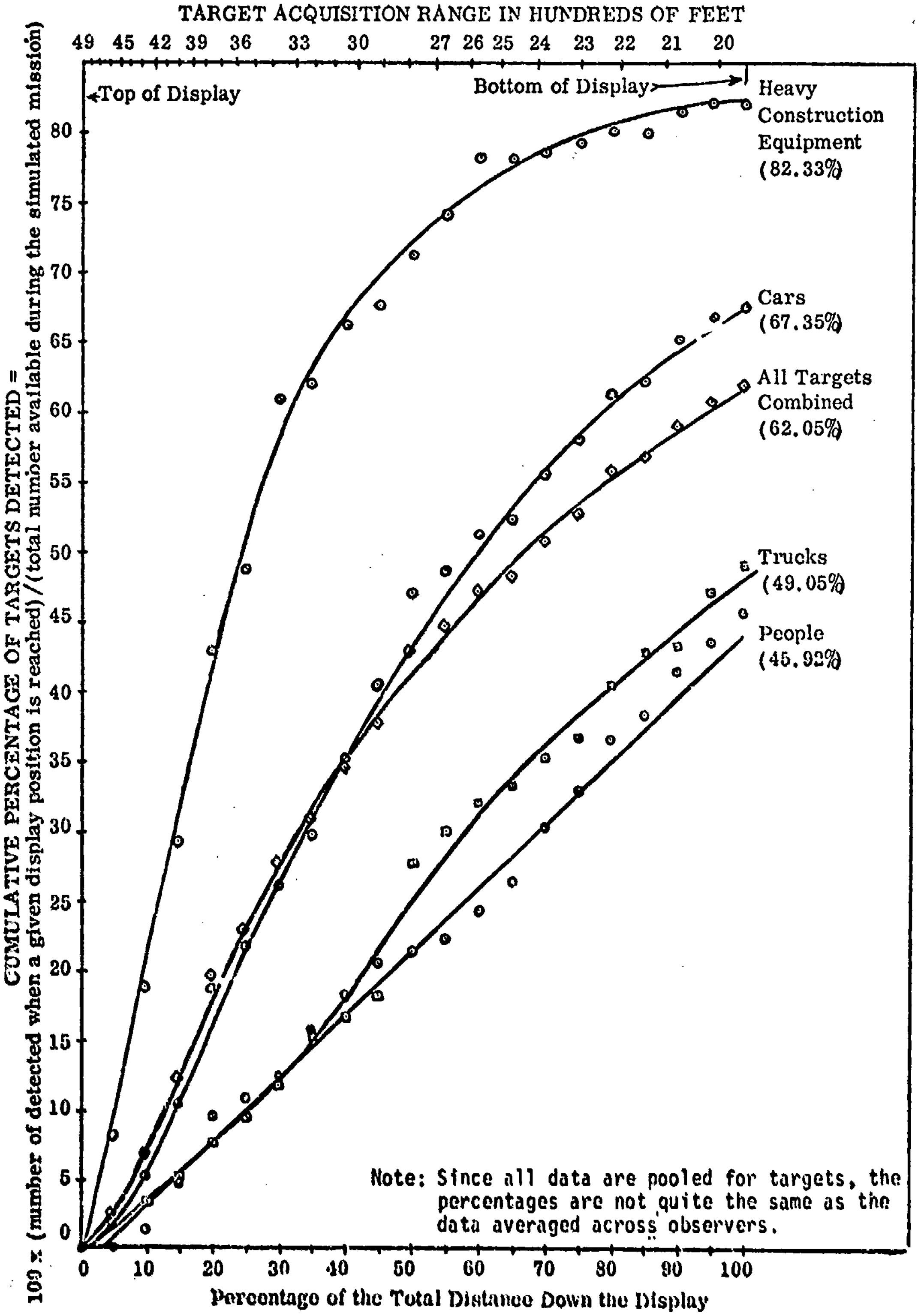


Figure 18 Variation in percentage of targets detected with display screen position and slant range. The curves are computed for all detections of all observers combined before percentages are taken. They are not the means of percentages for individual observers, hence the numbers at the 100% distance do not quite agree with the mean screen distance for individual observers.

the display just before they pass out of the field of view. If this is true, then a field of view that extended downward further would very likely lead to the detection of more targets. Keep in mind that at the bottom of the field of view the target images on the display are of maximum size and that, here, resolution of details is also maximum. In earlier discussion, it was noted that the rate of detection of heavy construction equipment "fell off" or decreased near the bottom of the display, i.e., at the top of the Sum (%D) Graph. For these large objects, it would appear that increasing the vertical field of view would have little or no effect on target detection. However, car, truck and people detections were not decreasing, making it highly likely that a field of view extended downward further would increase target detections.

To look into this matter further, Sum (%D) was plotted against the logarithm of screen position. From the curves so obtained in figure 19, it is apparent that all four distributions have two linear portions or branches. Each linear portion may be described by a mathematical equation of the form Sum (%D) = A Log (X) + B, where X is screen position and A and B are constants. The constants are different for the two linear branches and for different types of targets. The values of the constants are given in table 9, while table 10 gives obtained Sum (%D) and Sum (%D) calculated from the formulas. Note the close agreement of obtained and calculated values. This is in line with the close fit of the data points to the straight lines seen on the logarithmic plots. It may be noted that only the heavy construction equipment curves show a low value of the inclination or slope of the second branch of the curve. For the other three types of target, the second branch has an increased slope relative to the first branch. Clearly, a field of view that extends further downward would be expected to be beneficial for these types of targets. The actual values of the constants will vary considerably with camera inclination, field of view, type of targets and terrain, etc. The values in the table are provided only to illustrate the fit of the Sum (%D) data to logarithmic functions.

RECOGNITION OR ACQUISITION TIME

When the images of targets first appear on the display, the actual targets are quite some distance away. Due to the forward motion of the aircraft, distance to targets decrease with time, resulting in larger and more clearly resolved target images. Detection and recognition become easier. Even if image size and resolution were both excellent when targets first appeared in the field of view, almost instant detection and recognition would not be possible; people take time to search and to react. The earlier discussion of the target acquisition slant range data clearly indicated that acquisition takes an appreciable amount of time. Since not all targets first appeared at the top of the display, slant range at acquisition and time on display do not correlate perfectly. A look at average target reaction time in seconds for individual observers is illuminating. The data are given in table 11 and the means and standard deviations for the four target types are plotted in figure 20.

Not surprisingly, the relatively huge heavy construction equipment was found and acquired (designated), on the average, significantly ($P \leq .01$) quicker than were any of the other three types of targets: only 6.74 seconds after appearance on the display. Cars, the second largest target in the present study, came second with an average time of 10.89 seconds. This is significantly ($P \leq .05$) quicker than reaction to people and to trucks. The reaction (designation) time to people, 12.48 seconds, was not significantly shorter than to trucks, 14.09 seconds. This is somewhat surprising when the large difference in size of trucks and people is noted. Note that detection times for trucks were significantly longer than for cars though their average sizes differed but little. Clearly, other factors than size are exerting an influence.

Standard deviations, as displayed in the table and on the graph, were rather small, even for trucks where it was about twice as large as for the other three types of targets. The small standard deviations reflect the small differences between observers in the time taken to find the designate targets.

PREDICTING AN OBSERVER'S SCORE ON ONE PERFORMANCE MEASURE FROM HIS SCORE ON ANOTHER PERFORMANCE MEASURE.

Various tables in the present report give the scores of individual observers on 7 different measures of performance for each of the 4 types of targets. This allows correlation coefficients to be calculated between

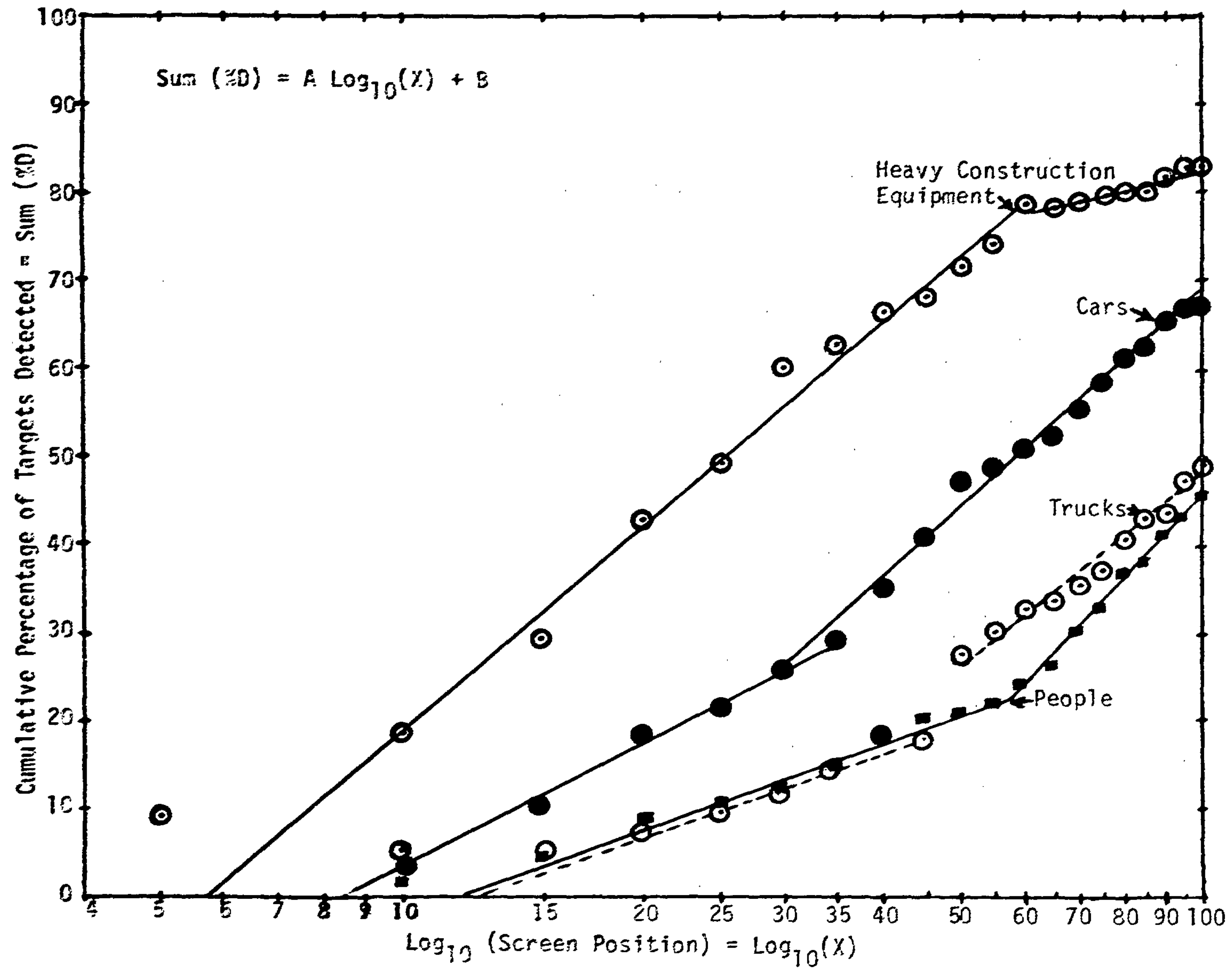


Figure 19 Cumulative Percentage of Targets Detected Plotted Against the Logarithm of Screen Position

TABLE 9

CALCULATION OF CUMULATIVE PERCENTAGE OF TARGETS DETECTED, SUM (%D)

Computational Formula: Sum (%D) = A $Log_{10}(X)$ + B			
Target Type	Range of X	A	B
Heavy Construction Equipment	10-60 65-100	76.89 20.64	-58.70 +40.72
Trucks	10-45 50-100	29.15 72.16	-29.77 -96.92
Cars	10-35 40-100	45.77 81.85	-42.38 -94.91
People	10-55 60-100	32.37 98.20	-34.33 -150.41

X = Position of Target on Display Screen.
Sum (%D) = Cumulative Percentage of Targets Detected.
A, B are Constants in the Equation.

TABLE 10

OBTAINED AND CALCULATED* VALUES OF CUMULATIVE PERCENTAGE OF TARGETS DETECTED

Screen Position, X	Heavy Const. Equipment		Trucks		Cars		People	
	Obtained	Formula	Obtained	Formula	Obtained	Formula	Obtained	Formula
5	8.27		.0		1.79		.0	
10	18.80	18.19	3.33		5.10	3.39	1.36	
15	29.32	31.73	5.24	4.51	10.46	11.45	4.76	3.37
20	42.86	41.34	7.62	8.16	18.62	17.17	9.52	7.78
25	48.87	48.79	9.52	10.98	21.68	21.60	10.88	10.92
30	60.90	54.88	11.90	13.29	26.02	25.23	12.24	13.48
35	62.03	60.02	15.24	15.23	25.59	28.29	15.65	15.65
40	66.17	64.48	16.67	17.53	35.20	36.22	18.37	17.53
45	67.67	68.41	18.09	18.42	40.56	40.41	20.41	19.18
50	71.43	71.93	27.62	25.67	47.19	44.15	21.43	20.67
55	74.06	75.12	30.00	28.66	48.98	47.54	22.45	22.01
60	78.20	78.02	32.38	31.39	51.27	50.63	24.49	24.20
65	78.20	78.14	33.33	33.89	52.30	53.48	26.53	27.62
70	78.57	78.80	35.24	36.22	55.61	56.11	30.27	30.78
75	79.23	79.42	36.67	38.38	58.16	58.91	32.99	33.72
80	80.08	80.00	40.48	40.41	61.48	60.86	36.73	36.47
85	80.08	80.54	42.86	42.31	62.24	63.01	38.44	39.06
90	81.58	81.06	43.33	44.10	65.31	65.04	41.50	41.50
95	82.33	81.54	47.14	45.79	66.84	66.97	43.54	43.80
100	82.33	82.00	49.05	47.40	67.35	68.79	45.92	45.99

*Calculated from the formula Sum (%D) = A $Log_{10}(X)$ + B

TABLE 11

AVERAGE TARGET REACTION TIME IN SECONDS FOR INDIVIDUAL OBSERVERS

	Mean Reaction Time in Seconds				Summary Measures		
OBSERVER	People	Trucks	Cars	HCE	Sum of Means	Average Means*	Mean per Target**
A	10.4	12.8	10.3	7.2	40.7	10.18	9.62
B	14.7	6.0	9.6	4.7	35.0	8.75	8.54
C	12.0	13.1	14.3	8.5	47.9	11.98	11.86
D	9.8	13.2	10.6	6.2	39.8	9.95	9.31
E	10.4	14.2	11.2	6.8	42.6	10.65	10.38
F	10.4	9.6	7.9	6.6	34.5	8.62	8.28
G	9.4	13.1	6.4	5.7	34.6	8.65	7.80
H	13.8	25.2	14.0	9.3	62.3	15.58	13.55
I	14.8	19.3	14.8	10.3	59.2	14.80	14.10
J	11.3	8.8	10.5	4.0	34.6	8.65	8.17
K	13.1	11.7	7.7	6.3	38.8	9.70	9.03
L	15.8	11.6	8.4	3.8	39.6	9.90	9.06
M	16.8	22.1	14.8	9.9	63.6	15.90	14.53
N	12.0	16.6	11.9	5.1	45.6	11.40	10.63
Sum	174.7	197.3	152.4	94.4	618.8	154.71	144.84
Mean+	12.48	14.09	10.89	6.74	44.20	11.05	10.35
S.D.	2.38	5.20	2.78	2.10	10.35	2.59	2.29

* Average of Means = (Sum of Means)/4

** Mean/Target = (Total of Reaction Times/(Total Number of Detected Targets)= (Number of Targets Per Target Type)(Mean for Target Type)/(Total Number of Targets Detected by the Observer). Not exactly equal due to rounding of values.

+Mean = Column Total/14 = Average Observer Reaction Time.

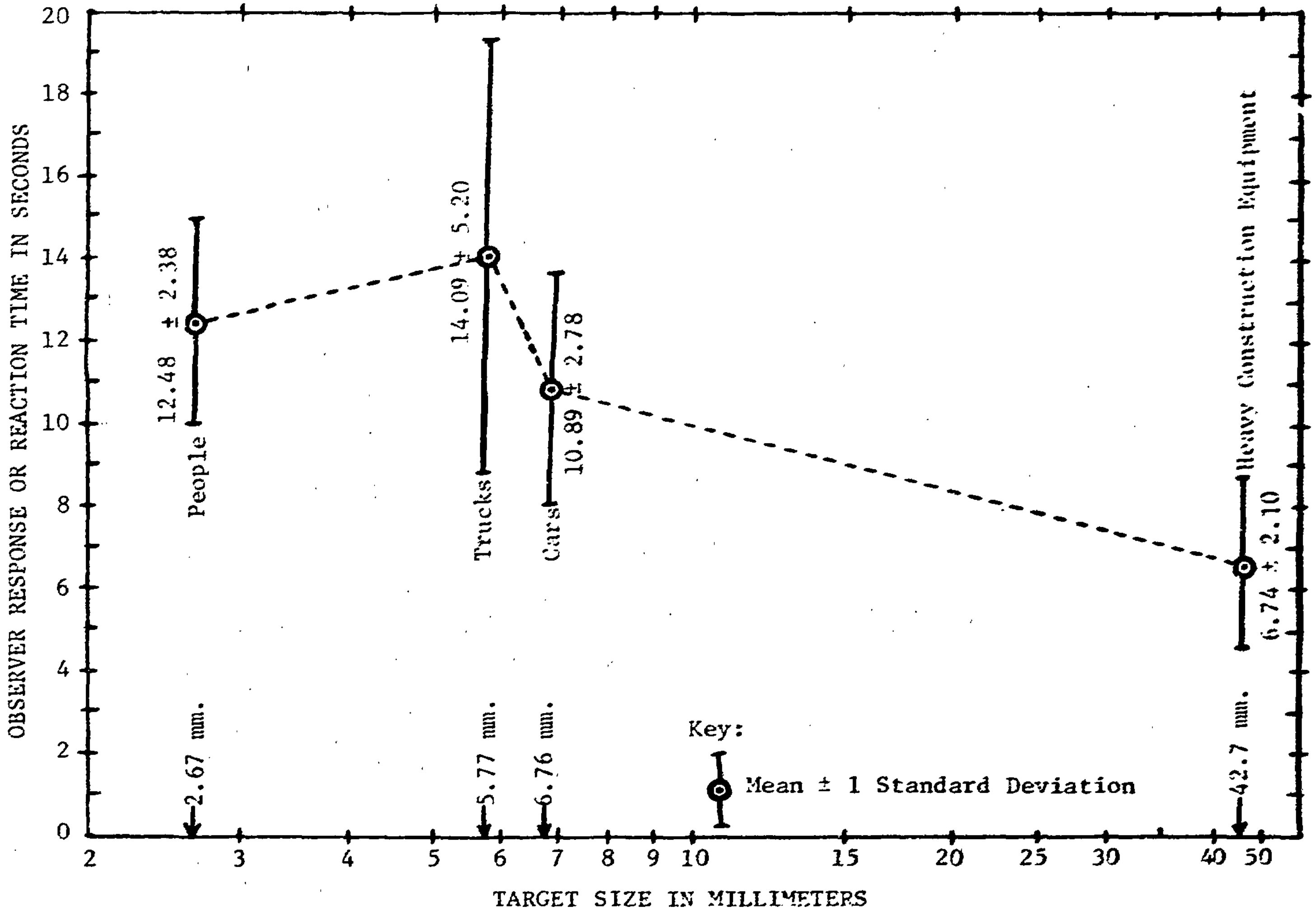


Figure 20. Observer reaction time plotted against target size. Size is plotted on a logarithmic scale.

scores. For example, there are 14 scores, 1 for each observer, on percentage of trucks detected (%D) and on the average contrast of the targets that were detected. Thus, individual observer "A" detected 53.33% of the trucks and the average contrast of the trucks that he detected was 51.00. Individual observer "A" and the 13 other observers supply 14 data pairs for the computation of a correlation coefficient, r. Suppose that the r is statistically significant (larger in absolute value than expected by chance alone one time in 20) and negative in sign. This would indicate that the average contrast of trucks detected by observers who detect a higher (or lower) percentage of targets than does the average observer tends to be lower (or higher) than average. Presumably, at least part of superior %D performance in this case would be achieved by detecting more of the low contrast targets.

Table 12 gives correlation coefficients between scores on the 7 performance measures: percentage of targets detected (%D), accuracy, average target position on (distance down) the display when detected, average false positive (F.P.) position on (distance down) the display at detection, average response time (detection times), average size of targets detected, and average contrast of detected targets. The first statistically significant r in the table, -.5310 for trucks, indicated by an asterisk, is the one corresponding to the hypothetical example above. Since the Table has 21 cells, each containing either 4 or 5 correlation coefficients, it is not feasible to discuss in detail each individual r. The correlation table shows that:

1. The percentage of targets detected (%D) by individual observers varies significantly with the average size of targets detected for three of the four target categories. For trucks only, %D also varies significantly with the average contrast of detected targets and with reaction time.

2. %D does not appear to be related to accuracy scores nor to the average distance down the display (position at detection) of either targets or of objects mistaken for targets (F.P.'s).

3. Only for trucks is observer *accuracy* significantly related to: average contrast of detected targets, average size of detected targets, and average display position of false positives at detection. Only for cars is accuracy related to average display position of detected targets and to reaction time.

4. Average *reaction time* is significantly related to average position on (distance down) the display of targets when detected. As expected, the correlations are all high and positive. For trucks, average reaction time is significantly related to the average size and contrast of detected targets.

5. Average *target position* on the display when detected appears to be unrelated to: (a) average contrast of detected targets (except for trucks), (b) average size of detected targets, (c) average position of false positives (except false positive people targets), (d) accuracy (except for car targets), and (e) %D.

6. However, as expected, average *target position* is highly and significantly related to average reaction (or detection) time.

7. Average *false positive position* is, significantly and positively, related to the average contrast of detected targets for trucks, heavy construction equipment, and to the means for trucks, cars and heavy construction equipment.

8. The *averge size* of detected targets is positively and significantly related to %D for cars, HCE, and means (all torgets combined), but is unrelated to: accuracy (except for trucks), reaction time (except for trucks) average target position when detected, and to average false positive position when detected.

9. The average *contrast* of detected targets is, except for trucks, unrelated to: %D, accuracy, reaction time, target position when detected, and average size of detected targets (except for heavy construction equipment). However, average contrast of detected targets is related to false positive position at detection for trucks, heavy construction equipment, and all targets combined. Note that, for trucks, average contrast of detected targets is

TABLE 12

CORRELATIONS BETWEEN OBSERVER SCORES
ON DIFFERENT MEASURES OF PERFORMANCE

Measure	Target	Target Contrast	Target Size	F. P. Position	Target Position	Reaction Time	Accuracy
%D	People		-.3390	.1076(11)	.2547	.1804	.3518
	Trucks	-.5310*	-.4050	-.0048(10)	-.4208	-.5017*	-.0939
	Cars	.4086	.5440*	-.2147(10)	-.3147	-.3920	.2392
	HCE	.0885	-.9662**	.0126(9)	.1800	.1228	-.2629
	Means+	-.2000	-.7226**	-.5064(7)	-.1503	-.3130	-.0248
Accuracy	People		-.3325	-.0791(11)	.2551	.2632	
	Trucks	.5041*	.5422*	.6093*(10)	.1903	.1280	
	Cars	-.1780	-.0614	-.0851(10)	.5626*	.4952*	
	HCE	-.2072	.2317	-.0127(9)	-.1135	-.0265	
	Means+	.1588	.3234	.1371(7)	.1791	.1850	
Reaction Time	People		.2137	.2650(11)	.7618**		
	Trucks	.5288*	.5206*	.1134(10)	.9139**		
	Cars	-.2822	-.4119	.4985*(10)	.9397**		
	HCE	.0027	-.0997	.4799(9)	.9559**		
	Means+	.2946	.1479	.5545(7)	.9814**		
Target Position	People		.0519	.5434*(11)			
	Trucks	.4783*	.3870	.2416(10)			
	Cars	-.3229	-.4202	.4960(10)			
	HCE	-.3439	-.2747	.4741(9)			
	Means+	.2722	.0121	.5814(7)			
F. P. Position	People		.4744(11)				
	Trucks	.6086*(10)	-.0143(10)				
	Cars	-.0129(10)	-.3573(10)				
	HCE	.5565*(9)	-.0239(9)				
	Means+	.8646**(7)	-.0191(7)				
Target Size	People						
	Trucks	.3718					
	Cars	.4130					
	HCE	-.4828*					
	Means+	.0856					

*, **Statistically significant, by a directional or one-tailed test; one asterisk at the .05 level two asterisks at the .01 level.

+ The means are the data for all of the targets combined before correlations are computed.

Note: Numbers in parentheses are degrees of freedom, which are data pairs minus 2. When no parenthesis is present, data pairs are 14 and degrees of freedom is 12.

related to 5 of the 6 performance measures.

When the absolute sizes of the statistically significant correlations are examined, it is apparent that most of them are not large: most of them are smaller than .7. Thus, even the majority of the significant ones are of marginal or doubtful utility for predicting one performance measure (or score) from another. The exception is the correlations of reaction time to targets with target position on the display when detected: these correlations are high. They are not perfect since some targets did not enter the display at the top. However, here there is a relationship largely due to measuring for most targets the same quantity in different ways so that prediction of one from the other is only of academic interest.

For observer selection purposes, the most useful performance measures are %D, accuracy, and target position on the display at detection. The latter is a simple mathematical transformation of target acquisition range. The correlations between these three measures of scores clearly indicate that they are unrelated or independent. This implies that observers were not uniformly excellent or inferior on the most important measures of mission success. To the extent that the results are generalizable, it may be said that one can't select observers who are excellent on multiple criteria or eliminate those who are not since there are no such individuals. On the other hand, individual observers often differed greatly on specific scores so that selection or rejection for specific performance is another matter.

PREDICTING THE AVERAGE OBSERVER'S SCORE ON ONE TYPE OF PERFORMANCE FROM THE AVERAGE SCORE ON ANOTHER TYPE OF PERFORMANCE

A further look at the relationship between scores on different performance measures is obtained by using as data pairs the averages (means) of target categories, rather than the scores of individual observers. Thus, since there are 4 types of targets, there are 4 accuracy means and 4 screen position means, yielding 4 data pairs to correlate accuracy for types of targets with screen position for types of targets. Here it must be kept in mind that with only 3 or 4 data pairs, the value of r must be quite high to attain statistical significance. Stated differently, in such cases appreciable degrees of true relationship may not be shown to be significantly different from zero; tests are rather insensitive with only a few data pairs.

Table 13 lists the correlations between performance measures when the means for target types are used as data pairs. Looking down the %D column, note that %D is correlated significantly with position, reaction time, and accuracy, but not with size. In the accuracy column none of the r's are significant. Reaction time is significantly correlated with %D, average size of target detected, and average position on the display when detected. Looking across the contrast row reveals that the average contrast of detected targets is not significantly correlated with any of the other variables. Even the size — contrast r of .93 is not statistically significant since there are only 3 types of targets for which contrast data were available.

Even though different types of targets have different sizes and contrasts, it is clear from the above that there are appreciable correlations between several of the performance measures, particularly between %D, reaction time, and position at detection. However, accuracy correlated significantly only with %D, and average contrast of detected targets did not correlate significantly with any of the other performance measures.

PREDICTING AN OBSERVER'S SCORE ON ONE TYPE OF TARGET FROM HIS SCORE ON A DIFFERENT TYPE OF TARGET.

It has been shown that one cannot expect to find individuals who will be outstandingly efficient or inefficient on a mission-related (but not mission-specific) combination of several important performance measures. Can one expect to be able to make reliable observer selections for only one or two types of performance? This is a question concerning the repeatability of performance, not just the magnitude of the differences in scores. The present study has not repeatedly tested the same observers, nor were they intensively trained. Thus the question cannot be completely answered.

TABLE 13

CORRELATIONS BETWEEN PERFORMANCE MEASURES ON TARGETS AND CHARACTERISTICS OF TARGETS, USING MEANS OF TARGET CATEGORIES AS DATA PAIRS

	TARGET CHARACTERISTICS				PERFORMANCE MEASURE					
	Mean Displayed+ Image Size		Mean Displayed Target Contrast		Detection Probability		Screen Position++		Reaction Time	
Performance Measure	r	d.f.	r	d.f.	r	d.f.	r	d.f.	r	d.f.
Detection Probability	.8661	2	.0547	1			-.9528*	2	-.9557*	2
Screen Position++	-.8501	2	-.8862	2	-.9528*	2			.9869*	2
Reaction Time	-.9235*	2	-.9266	1	-.9557*	2	.9869*	2		

+ When located halfway down the display.
++ Screen Position = Distance down from the top of the display when detected.
Note that acquisition range is measured from the bottom of the display, not from the top.
* Significantly different from zero at the .05 level of significance by a directional or one-tailed test.

However, it is answered in part by examining the scores of observers on different types of targets. For example, is there any relationship between %D score on truck targets and heavy equipment targets? Do the rankings of observers on a given measure of performance show little change from one target type to the next, or do they change radically? The answere to these questions, as revealed by data analysis, would concern within-test measures of consistency or reliability, rather than a day-to-day measure.

Table 14 lists the correlations between the scores of individual observers on various performance measures for different types of targets. This table also contains graphical information in the form of "bars" extending part of the way across the cells in the matrix of correlations. The length of these bars is proportional to r^2, so that a quick glance of the table indicates to the reader the degree of predictability of a performance measure on one target from the same type of score (e.g., %D, etc) on another type of target.

Note that the first starread entry in the table is an r of .6481 between %D scores for people targets and %D scores for heavy construction equipment. This correlation is statistically significant, i.e., is larger than would be expected one time in twenty by chance alone. However, it is not a high correlation so that individual observers are not highly consistent on the two types of targets. Note that the length of the bar below the .6481 is not very long, which indicates a not-very-high degree of predictability of one score from the other. The other 5 possible correlations between types of targets for %D are low and do not reach statistical significance. Clearly, observers were not maintaining their rankings on %D from one type of target to another.

Looking down the accuracy column, it is apparent that accuracy across target types came out somewhat better than did %D: 3 of the 6 different correlation coefficients achieved statistical significance. However, two of them were below .5 and the third was only .75. For most types of targets, accuracy on one type was of either little value or of no value in making predictions of accuracy on another types.

The correlation coefficients between average reaction time for people targets and reaction time for other types of targets were all low and not statistically significant. However, scores on cars, trucks, and heavy construction equipment were positively and significantly related to each other. This means that, except for scores on people, the rankings of observer scores did not change greatly in going from one type to another, i.e., there was some consistency in reaction time across target types.

Average position on the display at detection was interesting: all correlations were statistically significant for both targets and false positives. For targets, 5 of the 6 exceeded .73. It is clear that observers who detect targets of one type high up on the display, corresponding to long detection or acquisition ranges, tend to do so for other types of targets. Similarly, observers who tend not to detect targets of one type until they are relatively close to the aircraft tend to do so for other types of targets.

The average size of target detected by an observer was not consistent (reliable) across target types: 5 of the 6 correlations were too low to attain statistical significance. The one significant r, that between trucks and heavy construction equipment, was only .54. This is too low to be of much value for predictive purposes.

The average contrast of the targets of any one type detected by an observer appeared to be no indication of the average contrast of any other type of target: all r's were too low to be statistically significant.

THE RELATIONSHIPS BETWEEN TARGET CHARACTERISTICS AND THE PERFORMANCE OF OBSERVERS

Appendix II lists for each target the probability that it will be detected, the average time that it was on the display before detection occurred, and the position at detection on the display screen, measured down from the top of the display. Table 15 lists the product moment correlation coefficients for these data when measures for individual targets are used as data pairs.

TABLE 14

CORRELATION COEFFICIENTS BETWEEN OBSERVER SCORES ON DIFFERENT TYPES OF TARGETS FOR VARIOUS PERFORMANCE MEASURES

Targets		Correlation Coefficient (Numbers), r; and Coefficient of Determination (Bars+), r^2						
		Test Score or Observer Performance Measure						
		%D	Accuracy	Detection Time	Mean Target Position	Mean F. P. Position	Mean Target Size	Mean Target Contrast
People	Trucks	.3269	.0904	.3508	.7244**	.7847**	-.1042	
	Cars	.4434	.4945*	.4263	.6986**	.5869*	-.3671	
	HCE	.6481*	.4587*	.2739	.5598*	.7984**	-.0396	
Trucks	People	.3269	.9604	.3508	.7244**	.7847**	-.1042	
	Cars	.2914	.3535	.6949**	.7434**	.7333**	.1722	-.2874
	HCE	.2101	.7496**	.7583**	.6916**	.9418**	.5406*	.3824
Cars	People	.4434	.4945*	.4263	.6986**	.5869*	-.3671	
	Trucks	.2914	.3535	.6949**	.7434**	.7333**	.1722	-.2874
	HCE	.2583	.4378	.7383**	.7288**	.8776**	.2053	.1114
HCE	People	.6481*	.4587*	.2739	.5598*	.7984**	-.0396	
	Trucks	.2101	.7496**	.7583**	.6916**	.9418**	.5406*	.3824
	Cars	.2583	.4378	.7383**	.7288**	.8776*	.2053	.1114

*,** r is statistically significant, by one-tailed or directional test, at the .05 level (one asterisk) or the .01 level (two asterisks)

+ The length of the bars, i.e., the fraction of the distance across the cells, represents r^2, the coefficient of determination. r^2 is the decimal fraction of the variance on one type of target (on a given measure of performance) predictable from the scores on another type of target. Predicition without error is possible when r^2 is unity. Bars are shown only when r is statistically significant, i.e., is large enough to conclude that the correlation is not due entirely to chance.

Explanation: The first entry in the table, .3269, is the correlation coefficient, r, between the percentage of people targets detected by 14 observers and the percentage of trucks detected by these same observers.

TABLE 15

CORRELATION OF OBSERVER PERFORMANCE MEASURES ON INDIVIDUAL TARGETS WITH CHARACTERISTICS OF THE TARGETS

	TARGET CHARACTERISTICS								
	Target Size on Terrain					Displayed Target Image Contrast			
	21 People ✦	15 Trucks	28 Cars	19 HCE	83 All Tgts.	15 Trucks	28 Cars	19 HCE	62 All Tgts. ✦
Performance Measure✦	r-d.f.	r -d.f.	r -d.f.	r -d.f.	r -d.f.	r -d.f.	r -d.f.	r -d.f.	r -d.f.
Detection Probability= % Detections/n observers	.3653-19	.2834-13	-.2584-26	.6078**-17	.4086**-81	.4952*-13	-.4315*-26	-.6328**-17	-.0107(60)
Detection Time = Time on Display Before Detection	-.3330-18	.2322-13	-.5539**-26	-.4935*-17	-.2008*-80	.1546-13	-.3078-26	.1466-17	-.2025-60
Position on Display = Distance Down Display Screen When Detected	.6334**-18	-.1249-13	-.1399-26	-.6008**-17	-.4514**-80	-.1020-13	.0607-26	.1286-17	-.0790-60

*, ** Statistically significant at the .05 level of significance by a directional or one-tailed test is indicated by one asterisk, while two asterisks indicate significance at the .01 level.

✦ Since one person target was not detected by any observer, there are only 20 data pairs for reaction time and display position correlations with size and contrast.

Inspection of the table reveals that:

1. Detection probability significantly increases with increase in target size for heavy construction equipment (HCE), and for all types of targets combined, but not for the other types of targets. The detectability-size correlation, even when significantly different from zero, is not large.

2. Detection probability varies significantly with contrast for trucks, for cars, and for HCE, the target types for which contrast measures were available. However, for trucks detection probability increases with contrast while it decreases with increased contrast for cars and HCE. These correlations are not high.

3. The average time on the display before detection occurs is significantly less for larger targets in the case of cars, of HCE, and of all targets combined.

4. Average time on display before detection was not significantly related to contrast for any target category. Correlations did not even approach statistical significance.

5. Average position on the display (distance down) at detection was positively and significantly related to target size for people but was negatively (and significantly) related for HCE and for all target combined.

6. Average position was not related to image contrast for any type of target.

In summary, while contrast was related to detection probability, it was not related to either rapidity of detection or to position on the display. Also, target size, while positively related to detection probability for some types of targets, to rapidity of detection for some, and to position on the display at detection for some, was not related for some.

A further examination of the influence of target characteristics upon observer detection behavior may be pursued by using as data pairs the means for all observers lumped together for each type of target. This is done in table 16. Note that larger types of targets and more contrasty types of targets were detected sooner and at shorter distanced down the display (at greater acquisition ranges), and larger types of targets were more likely to be detected. Although the correlation coefficients were large and had the expected algebraic signs, only the tendency for shorter reaction times to larger types of targets achieved statistical significance. With the small number of target categories, hence with only 1 or 2 degrees of freedom, only when there is a very high correlation between the variables will the correlation coefficients achieve statistical significance. Table 16 also lists the correlation coefficients between the correlated performance measures of detection probability, screen position and reaction time. Here, all of the correlations were statistically significant. Types of targets that were detected, on the average, at longer acquisition ranges (higher up on the display screen) or more quickly (shorter reaction times) were also more likely to be detected.

DISCUSSION

The present study utilized monochrome, i.e., black-and-white images, so that there were no colors. However, observers had to find and recognize objects with which they were, except for heavy construction equipment, quite familiar. Displayed images look very much like the objects. With some other sensors, such as infrared imagers or high resolution radar, displayed images differ considerably more than do motion pictures from the objects as seen directly with the unaided eye. Many studies have shown that, even with extensive training, detection and recognition systems with displayed images appear to have low detection probabilities and numerous false positives.

TABLE 16

CORRELATIONS+ BETWEEN PERFORMANCE MEASURES
USING MEANS FOR TARGET TYPES AS DATA PAIRS

Score	%D	Accuracy	Time	Position	Size	Contrast
%D = Percentage of Targets Detected		.9676*-2	-.9379*-2	-.9786*-2	.8543-2	.5394-1
Accuracy	.9676*-2		.8287-2	-.8954-2	.7099-2	.2965-1
Mean Detection or Reaction Time	-.9379*-2	-.8287-2		.9776*-2	-.9092*-2	-.6456-1
Mean Position When Detected	-.9786*-2	-.8954-2	.9776*-2		-.9422*-2	-.7042-1
Mean Size of Detected Targets	.8543-2	.7099-2	-.9092*-2	-.9422*-2		.9318-1
Mean Contrast of Detected Targets	.5394-1	.2965-1	-.6456-1	-.7042-1	.9318-1	

*Statistically significant at the .05 level by directional, or one-tailed, test.
+The correlations are product-moment correlation coefficients.

Note 1. The number following each coefficient is the number of degrees of freedom for testing for statistical significance, which is the number of data pairs minus two.

Note 2. The bars below the numerical values are proportional in length to r^2 to indicate how much value the r is in predicting one score from the other. The bars are shown only for statistically significant correlation coefficients.

In discussion earlier in the present report, it was noted that the size and the resolution of the target images were adequate for recognition of even human targets. Aircraft altitude and camera focal length were selected during data collection to be sure that this was true. Also, at a simulated speed of only 60 knots, observers had considerable time to search for targets. Under such conditions, one might expect very commendable observer scores. The scores of the 14 observers on a wide variety of performance measures are summarized in table 17. Other measures than those listed are possible, but those listed in the table are the ones of primary interest. Do they indicate excellent performance on all measures?

Note, from "(D)" in the table, that onl.y 46% of the people and 49% of the trucks were detected and recognized by the average observer. From "(E)" in the table, it may be noted that only 50% of people designations were correct and only 64% of truck designations were correct. On both percent detected and accuracy, performance was noticeably better, but was not near perfect, for cars and trucks. From "(F)" in the table note, from the last column in the table, that the average position on the display screen of targets at the time of detection was 45%, i.e., nearly half way down the display. It was slightly over half way for people and trucks, but only 28% for heavy construction equipment.

From these observations, it is apparent that despite what appears to be adequate imagery, a large fraction of targets are not detected, the detection or acquisition range of those that are found is large, and false positives are frequent. An almost identical conclusion may be drawn from examination of other studies on finding targets of opportunity with more exotic sensors.

Those who plan and design target finding systems sometimes "sell" their systems on the grounds that the detail resolution, dynamic range, signal-to-noise ratio, contrast, modulation transfer function (MTF), etc. of the systems will insure excellent observer performance. Those who evaluate the effectiveness of systems for finding unbriefed targets without regard to data on observer characteristics other than visual resolution and contrast sensitivity, make the same erroneous assumption. It is clear that even narrow fields of view do not solve the target-of-opportunity problem, and may even worsen the situation by being too narrow. Going to ever narrower fields of view for ever better resolution of targets leads to equipment on which too many targets never appear at all on the display.

It is clear that we do not yet have man-equipment systems, even with narrow fields of view, that detect most unbriefed targets, do it quickly, and make almost no mistakes. When observers must search a display, even a slow-moving one, excellent imagery is no guarantee of near perfect performance. There is no doubt that future systems will have better sensors and displays. It is also very probable that the actual performance of future systems against targets will be superior to that of today's systems. From the preceding discussion it appears to be unlikely that the improved image quality of such systems will, or even can, account for the bulk of the improvement that will take place. It may be hypothesized that the significant improvement in performance will come from such areas as operator training, observer aids, and techniques of use. It is clear that much research and development by human factors specialists will be necessary to attain improved systems.

TABLE 17

SUMMARY OF OBSERVER SCORES

Performance Measure	Statistic	Targets: 21 People	15 Trucks	28 Cars	19 HCE	Mean of Means
(A) Number of Targets Correctly Designated	Mean S.D.	9.64 2.27	7.36 1.74	18.86 3.30	15.64 2.28	12.88 1.75
(B) Number of False Positive Responses	Mean S.D.	7.71 4.46	5.50 5.05	5.21 4.25	3.71 4.52	5.54 3.81
(C) Total Number of Responses = A+B	Mean S.D.	17.35 5.05	12.86 5.59	24.07 5.38	19.35 5.69	18.41 4.65
(D) Percentage of Targets Detected	Mean S.D.	45.92% 10.83	49.05% 11.58	67.35% 11.79	82.33% 11.97	61.16% 8.31
(E) Accuracy = % Correct = 100A/(A+B)	Mean S.D.	58.56% 17.46	64.32% 21.39	80.02% 13.70	84.11% 13.96	71.35% 12.49
(F) Target Position at Detection	Mean S.D.	54.73% 12.21	54.68% 15.36	44.30% 11.96	27.52% 8.77	45.29% 10.73
(G) F.P. Position at Detection	Mean S.D.	55.31% 17.52	67.74% 12.13	33.85% 15.24	50.51% 12.00	51.16% 11.91
(H) Reaction Time = Detection Time (In seconds)	Mean S.D.	12.48 2.38	14.09 5.20	10.89 2.78	6.74 2.10	11.05 2.57
(I) Size of Detected Targets (Screen Center)	Mean S.D.	2.87mm .22	6.15mm .44	6.32mm .38	49.83mm 5.98	16.37mm 1.69
(J) Contrast of Detected Targets	Mean S.D.	52.84% 3.24	42.37% 2.28	67.91% 1.60	53.65% 1.63	54.37% 1.44
(K) Acquisition Slant Range	Mean S.D.	2,680' 598	2,660' 747	2,930' 792	3,460' 1,100	2,930'

APPENDIX I

INSTRUCTIONS FOR SUBJECTS

You are about to participate in an experiment designed to study the relative efficiency of television systems and standard optical systems for use in aerial reconnaissance. You will be shown four sections of film, viewing terrain as seen from a plane flying at 340 feet altitude. You will search the display and detect targets — e.g., trucks, cars, people or heavy equipment. However, you will be asked to find only one type of target in each section of the experiment, for instance, in section number one, you might search for only trucks; in section number two, only people; etc. You will be told before each section what target type of detect in that section.

To indicate a target point at the target with your left hand, identify it aloud, and press the appropriate (corresponding) button with your right hand. The position of the button should correspond to the section in which the target is found. The terrain is always moving, so work as quickly as possible.

Targets:

Truck — includes any kind of truck — e.g., a garbage truck, a panel truck, a van, a pickup truck, a tractor-trailer rig, etc.

Car — any kind of automobile — e.g., sedan, station-wagon, sports car, convertible, etc.

Heavy construction equipment — cranes, derricks, bulldozers, dredges, road graders.

People — any man, woman or child.

The targets may be moving or non-moving.

Any questions?

APPENDIX II

TABLE 18

IMAGE CHARACTERISTICS AND PERFORMANCE DATA FOR INDIVIDUAL TARGETS

Target Number	Image Characteristics: Size on Screen+ (Millimeters)	++ Contrast	Performance Measurements: Number of Detections	Detection Probability	Mean Screen Location**	Mean RT (Seconds)*
Cars (28)						
1	4.1	39	14	1.0000	51.1	5.2
2	3.4	16	14	1.0000	29.3	8.4
3	3.8	27	14	1.0000	26.8	12.5
4	2.4	23	11	.7857	42.3	14.2
5	2.4	24	12	.8571	61.2	20.1
6	2.7	14	13	.9286	48.8	22.4
7	2.7	30	8	.5714	57.5	25.3
8	12.0	45	6	.4286	60.8	7.0
9	6.8	52	10	.7143	45.0	5.8
10	14.3	11	14	1.0000	38.6	8.8
11	6.8	40	8	.5714	73.1	4.5
12	14.3	60	6	.4286	15.0	2.0
13	10.9	47	12	.8571	37.5	5.7
14	14.3	78	11	.7857	32.3	7.8
15	6.8	33	7	.5000	30.7	7.4
16	10.2	67	4	.2857	18.8	6.6
17	6.1	16	4	.2857	13.8	3.6
18	5.1	61	11	.7857	12.3	6.1
19	5.8	45	14	1.0000	22.5	5.7
20	5.1	45	9	.6429	51.7	13.6
21	5.1	97	3	.2143	28.3	8.4
22	10.2	83	8	.5714	42.5	7.4
23	4.4	72	12	.8571	62.1	9.6
24	8.5	72	1	.0714	90.0	12.4
25	2.7	50	12	.8571	50.8	15.4
26	9.2	63	11	.7857	80.4	3.4
27	6.5	52	2	.1429	67.5	23.0
28	2.7	35	13	.9286	57.9	23.2

+Size on the display screen is the maximum dimension of the displayed image, which is the diameter of the smallest circle that can contain all of the target image.

++Contrast = (Brightness Difference)/B, where B is brightness of background or of target whichever is larger.

*Reaction times (RT) in seconds was obtained by use of a stopwatch, the projector, and the number of the frame (picture) on which target designation occurred as given on the developed film from the data camera. As explained in the text, reaction time and the target position aren't always equivalent.

**Mean screen location is the percentage of the way down the 133mm screen height when detected.

APPENDIX II (Continued)

Target Number	Physical Measure: Max. Dimension on Screen (mm)	Performance Measures: Number of Detections	Detection Probability	Mean Screen Location	Mean Reaction Time (Sec.)
People (21 Available Targets):					
63	2.1	10	.7143	76.0	11.5
64	3.1	6	.4286	77.5	25.8
65	3.1	6	.4286	78.3	26.0
66	2.4	12	.8571	64.2	19.9
67	3.1	4	.2857	43.8	18.3
68	3.8	13	.9286	28.1	7.3
69	3.4	8	.5714	34.4	9.2
70	3.4	2	.1429	77.5	15.2
71	3.4	2	.1429	52.5	7.8
72	3.1	13	.9286	26.5	4.1
73	3.4	12	.8571	57.5	6.9
74	3.1	5	.3571	71.0	9.2
75	3.4	13	.9286	37.3	10.0
76	3.4	4	.2857	49.8	12.0
77	1.4	0	0	N/A+	N/A+
78	2.4	1	.0714	90.0	32.2
79	1.4	3	.2143	81.7	4.1
80	2.1	6	.4286	85.5	9.2
81	2.1	4	.2857	82.2	8.6
82	.68	4	.2857	80.0	32.6
83	1.7	7	.5000	62.0	17.1

NOTE: The images of people were too small and poorly resolved to permit reliable contrast measurements, hence contrast was not measured for people.

+NA = Not Applicable: There was no meaningful screen travel when detected or mean reaction time either, because the target was not detected: A value of 0 would be wrong.

APPENDIX II (Continued)

Target Number	Image Characteristics		Performance Measurements			
	Size on+ Screen (Millimeters)	Contrast++	Number of Detections	Detection Probability	Mean Screen Location**	Mean RT (Seconds)*
Trucks (15):						
29	3.1	59	7	.5000	82.9	13.8
30	8.2	52	3	.2143	33.3	6.4
31	6.2	48	2	.1429	22.5	4.6
32	6.2	64	12	.8571	43.8	28.2
33	9.9	64	14	1.0000	44.6	17.0
34	5.8	68	13	.9286	40.4	15.2
35	6.8	32	6	.4286	74.2	30.6
36	6.5	43	10	.7143	77.7	6.0
37	3.1	40	3	.2143	58.3	3.8
38	5.1	43	13	.9286	59.5	6.2
39	3.4	33	4	.2857	10.0	5.9
40	5.5	44	3	.2143	88.3	24.8
41	4.1	45	6	.4286	50.8	6.2
42	6.2	65	4	.2857	41.2	2.6
43	6.5	32	3	.2143	46.7	4.0
Heavy Construction Equipment (19):						
44	35.9	84	13	.9286	32.7	4.6
45	44.4	84	13	.9286	30.0	6.3
46	3.8	71	8	.5714	54.4	12.9
47	12.3	81	12	.8571	42.1	7.2
48	50.2	20	13	.9286	21.5	3.9
49	40.0	64	14	1.0000	22.5	7.5
50	100.1	46	14	1.0000	17.9	6.1
51	64.9	80	14	1.0000	20.0	6.1
52	44.4	90	11	.7857	17.3	5.2
53	141.8	75	14	1.0000	15.7	5.3
54	6.2	94	1	.0714	95.0	10.3
55	44.4	92	13	.9286	25.8	8.0
56	8.5	84	8	.5714	37.5	10.3
57	13.7	40	7	.5000	69.3	6.5
58	6.5	79	10	.7143	33.0	7.8
59	93.3	90	14	1.0000	22.5	7.3
60	3.8	55	12	.8571	33.8	9.0
61	42.4	80	14	1.0000	15.7	3.3
62	54.7	11	14	1.0000	21.4	7.7

APPENDIX III

INDIVIDUAL TARGET SUMMARY TABLE AND TABLES OF THE AVERAGE SIZE AND CONTRAST OF DETECTED TARGETS

TABLE 19

SUMMARY OF APPENDIX II DATA FOR INDIVIDUAL TARGETS

Type of Data		Type of Target			
		People	Trucks	Cars	HCE
Number, n		21	15	28	19
Number Presented, 14n		294	210	392	266
Average Size at Display Center (mm.)		2.67	5.77	6.76	42.7
Average Contrast on Display, %		NO DATA	48.8	46.3	69.5
		Performance Measures			
Total Number of Detections, D		135	103	264	219
Mean D = D/14		9.64	7.36	18.64	15.64
Detection Probability* = P		.459	.490	.674	.823
Percent Detected = 100P		45.92%	49.05%	67.35%	82.33%
Average Detected Contrast, %**		NO DATA	52.47	42.46	67.71
Reaction Time in Seconds	Mean	13.7	11.7	10.6	7.13
	S.D.	8.52	9.47	6.70	2.36
Size of Detected Targets (mm. at Center of Display)	Mean	2.86	6.09	6.34	49.0
	S.D.	.75	1.93	3.74	36.6
Location When Detected = % of Display Height	Mean	62.8	51.6	44.6	33.1
	S.D.	20.3	22.3	20.5	20.4
Slant Range+ when Detected in Feet from the Aircraft	Mean	2510	2750	2940	3270
	S.D.	814	1190	1350	2020

*Detection Probability = (Total Number of Detections)/(Number Presented) = 14n/D. Note that, since the number detected includes some targets several times (as they were detected by several observers), the percent detected is not the percent detected at least once.

**Average Detected Contrast = {Σ(Contrast of Every Deteaction)}/(Number of Detections
Some targets are counted, here, as many as 14 times, thus detected contrast is weighted by number of detections. Contrast is the contrast of the target image on the display, not of the actual target object with the surrounding real terrain.

+The slant range is calculated from the average position on the display at the time of detection. The standard deviation of slant range is calculated from the standard deviation in screen position when detected.

APPENDIX III (Continued)

TABLE 20

AVERAGE SIZE* IN MILLIMETERS OF IMAGES OF DETECTED TARGETS

S**	People		Trucks		Cars		HCE		Combined Means	Combined Targets	
	n++	mean	n	mean	n	mean	n	mean	(mean of means)	N	mean+
A	9	2.74	8	5.55	13	6.78	17	46.98	15.51	47	20.34
B	12	2.80	9	5.86	17	5.93	18	44.73	14.83	56	17.72
C	10	2.89	5	5.96	19	5.92	16	49.22	16.00	50	19.17
D	7	2.99	5	6.70	21	6.37	16	49.55	16.40	49	20.02
E	7	2.55	8	6.41	15	6.04	12	57.69	19.17	42	20.29
F	10	2.48	9	6.42	21	6.66	15	47.50	15.76	55	17.00
G	12	3.00	10	5.92	26	6.70	17	46.50	15.53	65	16.31
H	8	3.09	5	6.70	17	5.85	16	49.22	16.22	46	20.55
I	12	2.81	8	5.94	21	6.36	17	46.55	15.42	58	17.35
J	7	3.33	8	5.35	17	5.71	16	46.69	15.27	48	18.96
K	14	2.80	7	6.14	21	6.86	18	44.73	15.13	60	17.13
L	7	2.88	7	6.54	19	6.83	10	66.19	20.61	43	19.95
M	10	3.09	5	6.70	16	6.44	14	55.19	17.86	45	20.89
N	10	2.75	9	5.86	21	6.26	17	46.86	15.43	57	17.69
Sum	135	40.20	103	86.05	264	88.53	219	697.60	229.14	721	263.37
n	14	14	14	14	14	14	14	14	14	14	14
mean	9.64	2.87	736	6.15	18.64	6.32	15.64	49.83	16.37	51.50	18.81
S.D.		.22		.44		.38		5.98	1.69		1.56

* Maximum dimension of target image measured at the center of the display screen, not at the screen location at which detection occurred.

** S=Subject or observer.

\+ (Sum of target sizes)/(total number of targets detected).

++n = number of detections.

APPENDIX III (Continued)

TABLE 21

AVERAGE CONTRAST OF DETECTED TARGETS

	TYPE OF TARGET				
OBSERVER	Trucks	Cars	HCE	Tgt. Sum/n*	Means Sum/3+
A	51.00	43.38	67.47	55.76	53.95
B	48.33	45.12	68 11	55.18	53.85
C	55.00	43.74	69.69	55.52	56.14
D	56.40	44.86	69.94	54.63	57.07
E	53.75	39.00	64.83	51.25	52.53
F	50.67	44.33	65.40	52.16	53.47
G	52.70	45.12	67.94	53.87	55.25
H	56.40	39.18	69.69	54.29	55.09
I	52.25	41.25	66.00	52.43	53.17
J	54.50	39.65	68.38	53.76	54.18
K	45.14	42.33	68.11	52.85	51.86
L	54.14	39.42	68.90	50.47	54.15
M	56.40	42.69	69.14	55.23	56.08
N	53.11	43.05	67.18	53.70	54.45
Sum	739.79	593.12	950.78	751.08	761.24
Mean	52.84	42.37	67.91	53.65	54.37
S.D.	3.24	2.28	1.60	1.63	1.44

* n = total number of all types of targets detected

\+ the means sum/3 is the average or mean of the means

APPENDIX IV

FIELD OF VIEW OF THE CAMERA AND GROUND AND SLANT RANGE COMPUTATIONS

The motion picture camera that took the pictures for the present study had a nominal focal length of six inches. The actual focal length could have been off from the nominal value by as much as 5%. In the computations that follow, the six inch focal length will be converted to 152.4 mm, even though this many digits implies an accuracy of focal length measurement that was not obtained. Similarly, various calculations will be carried out to several digits, and can be rounded off later.

The first calculation to make is that of the horizontal and vertical field of view of the motion picture camera. The geometry is shown in figure 22.

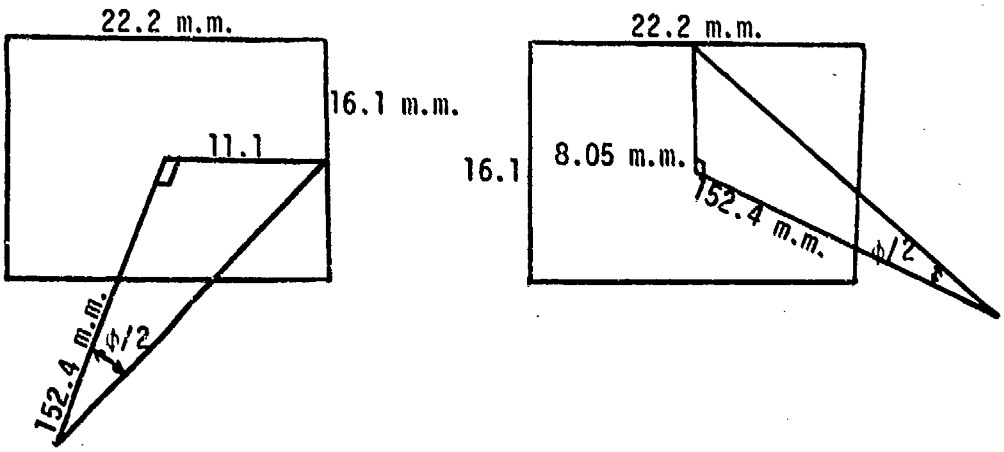


Figure 22. Field of View of the Motion Picture Camera

Horizontal Field of View:

$\tan(\theta/2) = 11.1/152.4$
$\theta = 2 \text{ arc} \tan .07283$
$\theta = 8.3315 = 8^{\circ}\ 20^{\circ}$

Vertical Field of View:

$\tan(\phi/2) = 8.05/152.4$
$\phi = 2 \text{ arc} \tan .05282$
$\phi = 6.047 = 6^{\circ}\ 2.8'$

Figure 22. Field of View of the Motion Picture Camera

Horizontal Field of View:

$\tan(\theta/2) = 11.1/152.4$
$\theta = 2 \text{ arc} \tan .07283$
$\theta = 8.3315 = 8^{\circ}\ 20^{\circ}$

Vertical Field of View:

$\tan(\phi/2) = 8.05/152.4$
$\phi = 2 \text{ arc} \tan .05282$
$\phi = 6.047 = 6^{\circ}\ 2.8'$

The geometry of the ground and slant ranges is illustrated by figure 23 below.

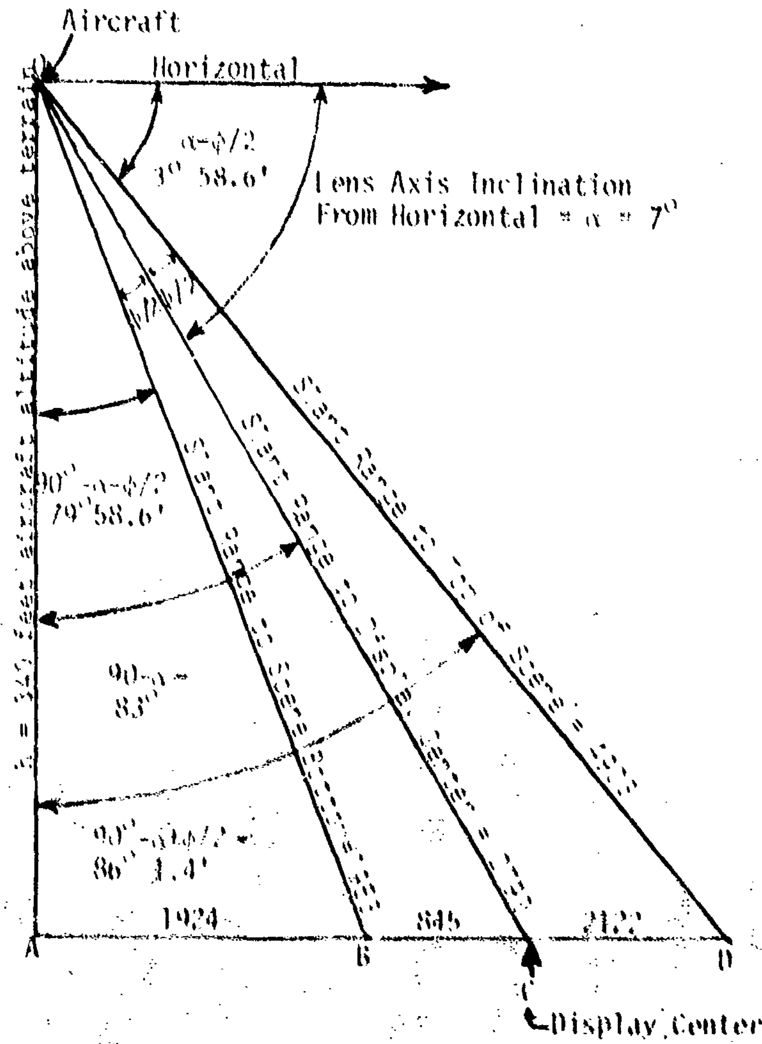


Figure 23. Ground and Slant Ranges in Feet.

Slant Ranges:

OD = h/Cos $(90°-\alpha+\phi/2)$ = 340/Cos (86° 1.4') = 4,903 feet
OC = h/Cos $(90°-\alpha)$ = 340/Cos (83°) = 2,790 feet
OB = h/Cos $(90°-\alpha-\phi/2)$ = 340/Cos (79° 58.6') = 1,953 feet

Ground Ranges:

AD = h Tan $(90°-\alpha+\phi/2)$ = 340 Tan (85° 1.4') = 4,891 feet
AC = h Tan $(90°-\alpha)$ = 340 Tan (83°) = 2,769 feet
AB = h Tan $(90°-\alpha-\phi/2)$ = 340 Tan (79° 58.6') = 1,924 feet
BC = AC - AB = 2,769 - 1,924 = 845 feet
CD = AD - AC = 4,891 - 2,769 = 2,122 feet

APPENDIX V

TABLE 24

TARGET AVAILABILITY BY TENTHS OF DISPLAY HEIGHT

Vertical Tenths* of the Display Screen	Number of Targets Available this often
10	41
9	7
8	7
7	6
6	8
5	5
4	1
3	4
2	4
1	0
—	Sum 83

*Tenths without regard to which vertical tenth, i.e., without regard to the order of the tenths on the display. Targets are credited with every vertical tenth upon which they appeared, even briefly. Not all targets appeared first at the top of the display: Some came on from the side, sometimes part way down the screen, and exited at the bottom or side. Vehicles in rapid motion, even if they entered into the top of the display, sometimes exited at the side.

*U.S.Government Printing Office: 1979 -- 657-002/160